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Clues to Aquatic Beetle Research in Southeast Asia: A Multitude of Ecological Niches, Microhabitats and Deduced Field Sampling Techniques

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Abstract

The basic ecological classification of Southeast Asian beetle families that are associated with aquatic habitats is reviewed. The microhabitat preferences of the taxa are examined on family level with generic examples. Suitable collection methods for quantitative and qualitative sampling are suggested which take into account the different ecological adaptation patterns and microhabitat preferences.

Keywords: Coleoptera; Water beetle; Riparian beetle; Southeast Asia; Biodiversity survey; Ecological classification; Microhabitat preference; Collection method

Introduction

Coleoptera represent the world's largest taxonomic order in terms of the number of species. Currently 360,000 – 400,000 described species are known while more than 1.1 million species can be expected [1]. Less than 2% of them possess a distinct adaption to aquatic habitats, based on estimates of total species numbers of the respective ecological groups by Jäch and Balke [2], plus a presumably similar magnitude of paraquatic/riparian species that are dependent on aquatic habitats in a lesser extent. Both, aquatic and riparian taxa are in particular focus of this paper.

Southeast Asia is usually referred to the countries of Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. However, this paper refers only to the part that belongs to the Oriental Realm. Nevertheless, most information given will apply to adjacent areas too. The entire region is dominated by islands and characterized by a complex biogeographic history [3]. This has led to an overwhelming rate of endemism and thus to a species diversity for which several areas of the region are recognized as biodiversity hotspots [4].

The United Nations has proclaimed an International Decade for Action-'Water for Life' 2005-2015 with conservation priority for freshwater biodiversity. Nevertheless, threats to the freshwater biodiversity have not diminished and freshwater biodiversity has further declined during the last decade. Dudgeon et al. [5] have identified five categories of major threats for aquatic inland systems: overexploitation, pollution, flow modification, destruction or degradation of habitat, and invasion by exotic species. These multiple stressors to the biodiversity are all relevant in a special extent to freshwater habitats of Southeast Asia and its aquatic/riparian beetle fauna. The distributional ranges of many taxa are small due to the high degree of natural fragmentation on the one hand. The anthropogenic impact on inland waters in most countries of the region is high and further increasing, on the other hand.

Since taxonomic and ecological interest in aquatic/riparian beetles has risen in the last decades in Southeast Asia, this paper is aimed to foster further research by providing an overview of the ecological classification and the respective microhabitats colonized by aquatic and riparian beetles.

Ecological Classification of Aquatic and Riparian Coleoptera

In most aquatic insect orders (Odonata, Ephemeroptera, Plecoptera, Trichoptera), all immature life stages live in water and emerge to the terrestrial habitats as adults. In contrast, various patterns of water association in different stages of ontogenesis can be recognized in aquatic and riparian beetles.

Except for maybe some stygobiontic Coleoptera species, probably all aquatic beetles leave the water temporarily at least for a short period of time during their life (e.g., for pupation or, dispersal flight) [2].

Nine ecological groups of water -associated beetles were defined by Jäch [6] based on their life history and behaviour.

Facultative water beetles get actively submerged or live neustic in aquatic habitats for a limited period of time for certain activities (e.g., foraging) during True Water Beetles are submerged in water, or dwell at the water surface for the major part of their adult life. Except for a few families the larvae are strictly aquatic. In Southeast Asia, True water beetles occur in the following families: Hydroscaphidae, Gyrinidae, Dytiscidae, Noteridae, Haliplidae, Epimetopidae, Hydraenidae, Hydrochidae, Spercheidae, Hydrophilidae, Elmidae, and Dryopidae. Except for Hydrophilidae and Dryopidae, terrestrial taxa are exceptional or absent in these families. One Oriental family of True Water Beetles, Torridincolidae (Myxophaga) has never been recorded from Southeast Asia, but their presence cannot be ruled out.

False water beetles possess larvae that live submerged in water, while adults are predominantly terrestrial. These include Scirtidae, Psephenidae, Eulichadidae, Lampyridae (some Luciolinae), and Ptilodactylidae (Cladotominae).

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The larval and/or adult stage. Southeast Asian representatives are surely known in the family Nitidulidae (one or few Amphicrossinae), and Lampyridae (some Luciolinae). However, other species can be expected in Carabidae (some Chlaeniinae), Staphylinidae (some Omaliinae, Staphylininae and Steninae), Scarabaeidae (few Dynastinae), and Monotomidae (some Rhizophaginae).

Shore Beetles, also commonly called riparian beetles, live in the limnic littoral zone during all developmental stages, but do usually not enter the water voluntarily. Heteroceridae and Georissidae are typical Shore Beetles. However, numerous other families are known to have riparian representatives: e.g., Sphaeriusidae, Carabidae, Helophoridae, Hydrophilidae, Histeridae, Hydraenidae, Ptiliidae, Leiodidae, Staphylinidae, Scarabaeidae, Dryopidae, Limnichidae, Elateridae, Lampyridae, Phycosecidae, Monotomidae, Tenebrionidae, Salpingidae, Anthicidae.

Phytophilous water beetles live on or in submerged plants during at least one developmental stage. Donacia Fabricius (Chrysomelidae) and Bagous Germar (Curculionidae) occur in Southeast Asia.

Parasitic Water Beetles are associated with animal hosts in aquatic habitats during at least one developmental stage. There are no records yet from the Southeast Asia.

True marine beetles do not exist [2]. The following three classifications are used for beetles associated with maritime saltwater habitats:

Epilittoral beetles always inhabit the littoral zone above the high water mark and the spray zone.

Supralittoral beetles occupy the littoral spray zone just above the water line and may get submerged temporarily. Representatives can be expected in the families' Hydraenidae, Dytiscidae, Hydrophilidae.

Eulittoral beetles live in the intertidal zone and get submerged regularly. Published records refer to Laius Guérin-Méneville (Malachiidae). Some additional taxa in the families' Carabidae, Hydraenidae, Limnichidae, and Staphylinidae might also be associated with marine habitats.

True Water Beetles and False Water Beetles are most strongly associated with freshwater habitats. Therefore, further statements herein refer to these groups in more detail. The remaining groups are less distinctly aquatic, the extent of water dependence varies greatly from taxon to taxon, and there is often a rather gradual transition from aquatic, over "paraquatic" to terrestrial life history.

Microhabitat preferences

All kinds of freshwater habitats, such as rivers, creeks, springs, lakes, ditches, puddles, lithotelmata, phytotelmata, seepages and ground water are inhabited by aquatic beetles. The particular species are generally found either in lotic or in lentic habitats, only few are known to occur in both [7,8]. Furthermore, they usually prefer, or are even restricted to one or a few microhabitats.

Habitats in lotic water require a higher degree of evolutionary adaptation since the inhabiting organisms have to resist the hydraulic stress. They have ecological characteristics of 'super specialists' [9]. Some morphological adaptations are: strong claws for benthic forms or well developed natatorial legs for swimming forms; flattening or streamlining of the body; gills (larvae) and plastron (imagines) for respiration, especially in benthic taxa which lack swimming abilities.

The examples of families and genera given herein are mainly based on personal observation of the author and refer only to somewhat common taxa of Southeast Asia. For a more detailed systematic and ecological review, the respective chapters of the Handbook of Zoology [10] (second edition forthcoming) provide most helpful information and primary references, same as the cataogues which are available for the following families: Dytiscidae [11]; Elmidae [12]; Epimetopidae [13]; Georissidae [13]; Haliplidae [14]; Hydraenidae [15]; Hydrochidae [13]; Hydrophilidae [13]; Lamypridae [16]; Limnichidae [17]; Noteridae [18]; Spercheidae [13].

Natural running waters, even torrential mountain streams, are never entirely lotic systems. They are rather a repeated consecution of turbulent water flow (riffle), laminar, non-turbulent flow (run), and calm zones (pool); which might be additionally interrupted by falls.

Waterfalls are only colonized by a few species (larvae of Psephenidae, imagines and larvae of Elmidae) due to the extreme hydraulic stress. Such taxa can be found in crevices of the rock surfaces. Waterfall associated microhabitats such as sprayzones and hygropetric rocks (Figure 1) accommodate some Hydraenidae (Hydraena Kugelann, Limnebius Leach), Hydrophilidae (some Hydrophilinae, Sphaeridiinae), Hydroscapha LeConte (Hydroscaphidae), and Limnichidae.

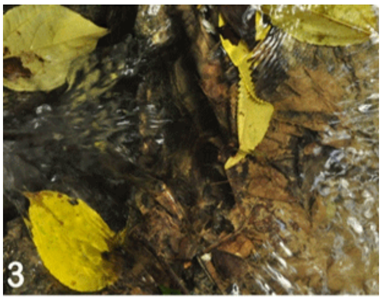
Riffle and run sections of creeks and rivers are typically occupied by Elmidae, Dyropidae, Psephenidae (larvae), as well as some Gyrinidae, Dytiscidae, Limnichidae, Scirtidae and a few specialized species of Hydraenidae, Hydrophilidae and Lampyridae (larvae). Most genera are typically found only in particular microhabitats of the lotic zones, such as bottom gravel and sand (Figure 2 lower picture area): Zaitzeviaria Nomura, Grouvellinus Champion, some Stenelmis Dufour (Elmidae), Psepheninae; in shallow waters additionally Graphosolus Jäch & Kodada (Elmidae); submerged wood (Figure 2 middle): Eubrianacinae, Eubriinae (Psephenidae), Graphelmis Delève, some Ancyronyx

Figures 1: Hygropetric rocks and attached roots and mosses at the sprayzone of a waterfall

Figures 2: Bottom gravel (lower part of the picture), submerged wood (middle), and herbaceous vegetation (upper part of the picture), three different microhabitats with varying beetle fauna.

Erichson and Stenelmis (Elmidae); leaf packs (Figure 3): some Hydraena spp. (Hydraenidae), some Pelthydrus Orchymont (Hydrophilidae); many Scirtidae and Limnichidae, Elmomorphus Sharp, Pachyparnus Fairmaire, Stenomystax Kodada, Jäch & Čiampor (Dryopidae), Eubrianacinae, Eubriinae (Psephenidae); rock surfaces (Figure 4): some Ancyronyx and Leptelmis Sharp (Elmidae); submerged root packs and herbaceous plants (Figure 2 upper picture area; Figure 11): some Ancyronyx and Potamophilinus Grouvelle (Elmidae), Dryopidae, Neptosternus Sharp (Dytiscidae); the water surface (neustic): Patrus Aubé and Porrhorhynchus Laporte, (Gyrinidae).

Well-shaded, shallow helocrenes (Figure 5) covered with Coarse Particulate Organic Matter (CPOM) and gravel substrates, are often colonized by Psephenidae, Lacconectus Motschulsky and Microdytes Balfour-Browne (Dytiscidae), Graphosolus (Elmidae), some Hydraena and Limnebius (Hydraenidae); Hydroscapha (Hydroscaphidae), Georissus Latreille (Georissidae), Anacaena Thomson, Agraphydrus Régimbart, Enochrus Thomson, Helochares Mulsant (Hydrophilidae), Limnichus Latreille and other Limnichidae as well as Scirtidae.



Figures 3: Trapped leaf packs in a riffle of a creek.

Figures 4: Littoral rocks.

Figures 5: A shaded helecrene in a forest.

The lentic habitats associated with running waters are calm pool sections of the stream and side pools (Figure 6) or residual pools that are not directly connected to the stream. The littoral mud, sand, gravel as well as leaf litter and other CPOM deposits of such lentic microhabitats are usually occupied by similar beetle assemblages, but not necessarily the same species of Patrus (Gyrinidae), Laccophilus Leach, Hydroglyphus Motschulsky, Hydaticus Leach, Lacconectus, Copelatus Erichson and Platynectes Régimbart (Dytiscidae), Sphaeriusidae, Hydraena and Limnebius (Hydraenidae), Anacaena, Paracymus Thomson, Agraphydrus, Chaetarthria Stephens, Enochrus, Helochares, Sternolophus Solier (Hydrophilidae), Hydrochus Leach (Hydrochidae), Scirtidae, Limnichidae, Georissidae.

The fauna of sun-exposed pools (Figure 7), which are commonly found in larger river beds during dry season resembles the fauna of the littoral zone and side puddles of lakes and accomodates genera such as Eretes Laporte, Hydaticus, Hydroglyphus, Hydrovatus Motschulsky, Laccophilus, Leiodytes Guignot (Dytiscidae), Limnebius (Hydraenidae), Anacaena, Paracymus, Agraphydrus, Chaetarthria, Enochrus, Helochares, Sternolophus, Laccobius Erichson; Coelostoma, Berosus Leach, Armostus Sharp (Hydrophilidae), Byrrhinus Motschulsky, Pelochares Mulsant & Rey (Limnichidae). Most of these live benthic, or partly fossoric in the upper layer of the substrate, others are active swimmers or neustic (e.g., Dineutus).

Vegetated zones of stagnant waters (Figure 8) are the only microhabitats where Noteridae and Haliplidae might be found, together with some Dytiscidae, Hydraenidae, Hydrochidae, Hydrophilidae, Scirtidae and Spercheus Kugelann (Spercheidae).

Rain puddles at higher altitude, which are usually well-vegetated, are the habitats of some specialized Dytiscidae (e.g., Rhantus Dejean); neustic Gyrinidae (Gyrinus Müller), and Hydrophilidae (e.g., Enochrus, Anacaena).

Lithothelmata are colonized by Scirtidae larvae, Hydraenidae,

Figures 6: A small side pool of a creek.

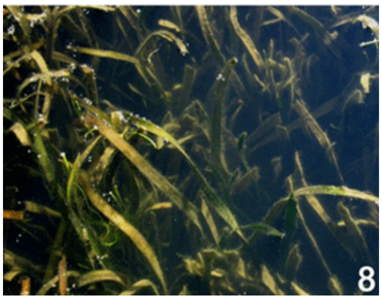
Figures 7: A sun-exposed side pool of a river.

Hydrophilidae and Dytiscidae. Several of these taxa can become surprisingly abundant when the water remains for longer periods in these usually temporary microhabitats.

Phytothelmata are known to be colonized by Exochomoscirtes Pic, Scirtes Illiger, and Prionocyphon Redtenbacher (Scirtidae) [19] and water-filled bamboo trunks are known to accommodate Amphicrossus Huys (Nitidulidae) [20], Hesperomimus Cameron and Hesperus Fauvel (Staphylinidae) [21].

The particular microhabitat of the marine genus Laius (Malachiidae) is littoral coral limestone which is exposed at least during low tide [22]. The beetles usually hide in crevices of the rough surface.

Coleoptera that dwell in subterranean aquatic habitats are known from other biogeographic regions, most of them from Australia [23]. Some of the genera to which they belong occur in Southeast Asia too, e.g., Copelatus, Limbodessus (Dytiscidae), but subterranean or stygobiontic representatives are not yet discovered from Southeast Asia.



Figures 8: A vegetated shallow zone of a lake.

Figures 9: Manual checking of bottom substrates by handnets.

Figures 10: A piece of wood taken off from a run section of a river (with crawling Ancyronyx schillhammeri).

Figures 11: Disturbing river substrates (roots) by hand from where the specimens are washed into the net by the current.

Field Collection of Aquatic Beetles

Due to these various types of ecological adaptations and the numerous microhabitats where water associated beetles occur, appropriate field sampling techniques are required to yield optimal results. Unfortunately, there is no single method that would allow catching all ecological and taxonomic groups. Major considerations for the selection of the collection methods are: (1) is the sampling intended for qualitative occurrence data (usually faunistic and systematic studies); or (2) quantitative abundance data (usually ecological studies); and (A) are the adult beetles (usually the only identifiable stage) found in or close to water; or (B) do they emerge from the water after the larval development (False Water Beetles).

The probably most convenient and commonly practiced method to obtain occurrence data is direct access of the beetles' microhabitats (see chapter 'Microhabitat Preferences') by manual checking of the substrates and scooping of their habitats by fine-meshed handnets (Figure 9). Nets with bendable frame are most practical as their opening can be adjusted for various substrate surfaces and broadened for sampling of the water surface.

Leaf litter, submerged woods, root packs, stones and alike are taken off from the sampling site to be searched carefully for the respective taxa (Figure 10). Placement on a light-colored plastic tarpaulin and sufficient lighting conditions to allow better detection of the specimens will ease the procedure. Some taxa will just crawl-off interstices after their substrate has been exposed to air for some minutes.

Sand and gravel substrates as well as rock surfaces and other hardly movable substrates are best sampled on-site by disturbing their surfaces by hand and simultaneously catching the beetles by the help of a net (Figure 11). For lentic species it might be required to produce a strong turbulent current by hand to wash them off from their substrates (Figure 12). The net should be placed directly below or behind the hand-disturbed substrates to allow the current to wash the specimens into the net. Species in lotic habitats that have been disturbed by hand are commonly floating at the water surface for the moment and can be caught by use of the handnet.

Hygropetric habitats, sprayzones of waterfalls and helocrenes are best manually sampled (Figure 13) in team-work as it might be necessary to rinse water (e.g., by help of a small container) over the collection site while simultaneously disturbing the substrate surfaces by hand and collecting the run-off into a net. Nets with flexible frame are best suitable for such microhabitats.

Baited traps (such as plastic bottles with their upper portion cut off and tightly re-attached in opposite direction to create a funnel trap) are useful for carnivorous taxa, such as Dytiscidae. The traps are baited

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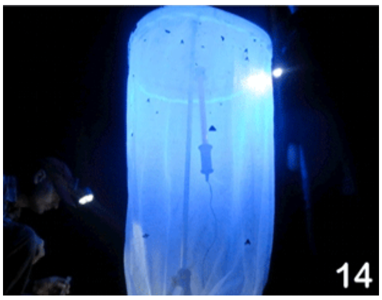
by small pieces of meat. They should be secured by a string and placed bottom-up in calm or slow-flowing waters for a few nights (and days). An air bubble inside the trap will keep specimens longer alive.

Light traps (Figure 14) might be helpful in collecting False Water Beetles and True Water Beetles during dispersal flights, but yields are very much biased and comprise of only a small and not representative collection of taxa. Studies from the Malay Peninsula and Singapore suggest that one fifth to one third of the aquatic beetle species are attracted to light [24,25] most of them were Dytiscidae and Hydrophilidae. The various light trapping methods are described in entomological textbooks and encyclopedia [e.g., 26]. However, this method does not allow tracing the specific aquatic habitat of the larvae or an aquatic origin of the collected specimens at all. The latter applies to the next method too.

Commonly practiced methods to collect adults of False Water Beetles are sweeping riparian vegetation with a large handnet or beating branches and leaves with a stick over a clap net ("Japanese umbrella"). False Water Beetles and Riparian Beetles might be collected

Figures 12: Disturbing littoral bottom substrates (sand) by hand in lenthic habitats.

Figures 13: Beetle collection from hygropetric rock.



Figures 14: Light trapping with a "black light" lamp and screen.

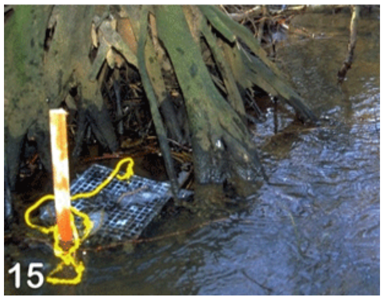
by hand or by the use of an aspirator from the littoral zone above the waterline. Stones and other large objects should be turned or lifted for this procedure as many taxa use to hide under them.

For abundance data, colonization traps, drift nets, and emergence traps are good choices when taking into account their specific features.

Colonization traps (Figure 15) are usually coarse-meshed baskets filled with the typical substrates of the sampling site which are exposed at the microhabitat for at least one week before taken-off for examination. The separation of the organisms from the substrate is laborious. The samples comprise of a good number of microhabitat-specific benthic taxa, but yield usually more immature stages than imagines. More detailed descriptions of this sampling method are provided by Mason or Peckarsky, for instance [27,28].

The function of drift traps is based on the phenomenon of accidental or random drift of almost all aquatic organisms, including benthic forms. Therefore, it is only applicable to lotic habitats. The yield is quantifiable by estimation of the flow through the net in time. Surprisingly, this method has yielded new species in the Philippines that have not been caught yet by any other method despite intense sampling of the same habitats [29]. High loads of organic particles in the water can complicate the sampling and subsequent extraction of the organisms. A practical instruction is provided by English [30].

Emergence traps (Figure 16) yield mainly False Water Beetles (e.g., Psephenidae), Facultative Water Beetles, and Shore Beetles. The effort to construct even a simple tent-like emergence trap might be quite high considering the rather limited spectrum of taxa trapped, but the method might still be the only efficient approach for certain scientific questions. The detailed description of a trap model suitable for tropical rivers and implications for the usefulness of the method are given by Freitag [31]. Some comments on the beetle taxa yields from Philippine streams are provided by Freitag and Zettel [32] and Freitag [33].



Figures 15: A colonizartion basket filled with natural substrates and exposed in a river.

Figures 16: An emergence trap spanned over a small water fall.

Conclusions and Recommendations

Water dwelling beetles are quite heterogenic in their adaptations to aquatic habitats. Manifold strategies have evolved in terms of which time during their live history they dwell in water and which particular niche they utilize. This requires special consideration in field research and collection. Several methods are usually needed to assess the entire assemblage of these interesting insects in a particular habitat or ecosystem. Especially those groups that are commonly overlooked require special attention to enhance first of all the taxonomic and distributional knowledge.

It is further recommended to collect and analyze aquatic and riparian beetle samples at microhabitat level. Simultaneous recording of the following data is suggested: locality properties (coordinates, elevation, surrounding land-use/vegetation type); specific microhabitat characteristics (type of water body, current, substrate type and size), preferably supplemented by limnological parameters (water temperature, dissolved oxygen, pH, biochemical and chemical oxygen demand, nutrient load). This would substantially improve the still insufficient ecological knowledge about many species and make them useful for applied approaches, for instance as bio indicators in water quality assessments or bio monitoring organisms in conservation biology.

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