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# Arthropods as predators of herpetofauna in Chu Mom Ray National Park, Vietnam

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## ABSTRACT

**A biodiversity survey was conducted in spring 2012 in eastern Chu Mom Ray National Park, Kon Tum Province, central Vietnam, to identify and record predaceous arthropod taxa that are known to include reptile and amphibian prey in their diet as well as those of large body size (>= 60 mm). Five drift fence arrays with pitfalls and double-ended funnel traps were installed in lowland evergreen forest and monitored over 40 nights. Additionally, 22 nocturnal searches were conducted along an adjacent forest stream. Recorded large arthropod predators comprise of one Asian forest scorpion species (*Heterometrus petersii*), at least three different tarantula species in the subfamily Selenocosmiinae, one scolopendromorph centipede species (*Scolopendra dehaani*), one scutigeromorph centipede (*Thereuopoda longicornis*), one giant water bug species (*Lethocerus* cf. *indicus*), one creeping water bug species in the family Naucoridae, two water scorpion species (*Cercotmetus* sp. and *Laccotrephes* sp.), one species of army ant (*Aenictus* sp.), four species of praying mantises (*Hierodula fruhstorferi*, *Hierodula patellifera*, *Tenodera aridifolia* and *Theopropus elegans*) and one species of freshwater crab (*Balssipotamon fruhstorferi*). In two cases, the predation of *Aenictus* sp. on the caecilian *Ichthyophis* cf. *nguyenorum* was observed. Conservation measures for giant water bugs, tarantulas and Asian forest scorpions are discussed.**

**Key words:** Arthropods, predators, herpetofauna, biodiversity survey, conservation.

## INTRODUCTION

Large predacious arthropods have adapted to prey not only on other invertebrates, but also on small vertebrates, including reptiles and amphibians. Possessing significant physical strength and often a potent venom, they are able to kill and devour prey of equal and larger body size, including anurans, lizards and snakes (Menin, Rodrigues & Azevedo, 2005; Kwet & Schlüter, 2002). In Vietnam and other parts of the world, reptiles and amphibians are increasingly endangered due to habitat loss, commercial hunting and collection, diseases and global warming (Blaustein *et al.*, 2010; Stuart, 2004; Suazo-Ortuno, Alvarado-Diaz & Martinez-Ramos, 2008; Swei *et al.*, 2011); hence investigating the trophic relationships between these vertebrate classes and invertebrate taxa will shed light on neglected ecological interactions. Therefore, we herewith present a list of selected arthropod predators native to a Vietnamese national park, which have been observed to prey on herpetofauna, including large taxa (body length >= 60 mm).

## FIELD SITES

Chu Mom Ray National Park (NP) is situated in the Central Highlands of Vietnam (Tây Nguyên), a southern part of the Annamite mountain range (Dãy Trường Sơn), which extends about 1,200 km north-south along Vietnam's central provinces. This ASEAN heritage site lies in Western Kon Tum province and borders Laos and Cambodia. It is located in the districts of Sa Thay, where it covers six communes, and Ngoc Hoi (Ngo *et al.*, 2006; Nguyen *et al.*, 2006). Chu Mom Ray NP stretches from 14°18'00" N to 14°38'45" N, and from 107°29'45" E to 107°47'08" E and received the status of a national park in July 2002 (Do, Ho & Vuong, 2006). The core zone covers 56,771 ha (Do *et al.*, 2006). Annual mean temperature is 23.4°C, and the annual precipitation averages to 1,783 mm (Nguyen *et al.*, 2006). The main vegetation forms are tropical lowland evergreen forest (below 1,000 m) and agricultural plantations (e.g. rice, cassava, pineapple, sugarcane and rubber trees). Major forest types are secondary forests, reforested areas, secondary bamboo forests and old-growth forest (Nguyen *et al*., 2006) (Figure 1 & 2).

## MATERIALS AND METHODS

Terrestrial and aquatic arthropods were recorded in different biotopes in eastern Chu Mom Ray NP from 29 March to 11 June 2012. Terrestrial habitats included paved and unpaved road sections, a sewage drain, bare soil, grassland, forest trails, dense bamboo and shrub vegetation, secondary forest and old-growth forest. Among the aquatic habitats were streams, muddy rivulets, pasture ponds and dammed pools at forest stream barrages.

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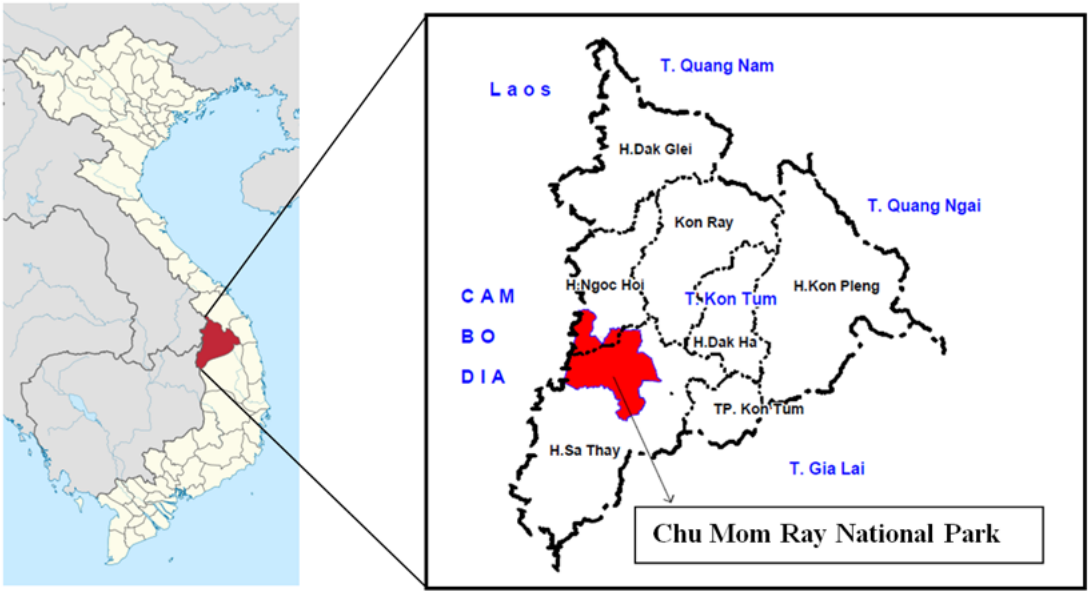


**Figure 1.** Vietnam and Kon Tum province (left), and Kon Tum province with Chu Mom Ray National Park (right). Source of Vietnam Map: http://en.wikipedia.org/w/index.php?title=File:Kon_Tum_in_Vietnam.svg &page=1 (Last accessed 5 March 2016). Source of Kon Tum Map: Chu Mom Ray National Park 2012.


**Figure 2.** Chu Mom Ray National Park: map showing borders and roads (left) and satellite map (right). Yellow central line: Road 14C. Source: http://maps.google.de/ (Last accessed 9 December 2013).

Pitfall traps are a standard inventory method for determining terrestrial and fossorial arthropod diversity (Weeks & McIntyre, 1997; Sabu & Shiju, 2009; Kaltsas & Simaiakis, 2012), and are sometimes applied in combination with drift fences, which has shown to increase the abundance of individuals and richness of families (Brennan, Majer & Moir, 2005). In Chu Mom Ray NP, five drift fences totaling 35 pitfall traps and 30 self-made funnel traps were erected for a survey on amphibian and reptile diversity in old-growth forest within a distance of 1.92 km to the next field station, between 777 and 846 m above sea level (a.s.l.). Each array was composed of three 10 m long arms (drift fences) which intersected in the center, forming three idealized angles of 120° (Y-shape). The funnel traps were 100 cm long cylinders constructed of fine meshed window screen, with a diameter of about 15 cm and one detachable funnel at each end. The pitfall traps were plastic buckets of 35 liter volume, of which two were dug into the soil at the very end of each array arm, and one in the array center. Leaf litter was placed on the bottom to prevent dehydration of captured animals. All traps were controlled once per day, during 40 days. Predaceous arthropods considered to be capable of preying on herpetofauna were recorded together with amphibians and reptiles, and assigned to the traps in which they were found. The installation and monitoring of light traps is a key method for the sampling of various insect taxa, including aquatic Hemiptera such as Belostomatidae (Hungerford, Walker & Spangler, 1955; Grozeva *et al.*, 2013). Hence, electric lights on the porch of the aforementioned field station building were monitored after sunset during 63 days.

Additionally, a stream section was sampled on 22 evenings with flashlights (transect survey). The distance between the starting and ending point was 500 m. Nocturnal visits were also made to dammed pools, small ponds and other aquatic habitats (see Ohba, 2007). A key method during diurnal searches was the turning of decaying logs, bark and wooden boards (Taylor, 1990).

Target arthropods were photographed and captured. Basic data taken included measurement of the body length and an individual record of the GPS coordinates, altitude, weather conditions and habitat. Additionally, data on minimum and maximum temperature and humidity was collected, as well as the number of rainfall hours per day and the pH values of the surveyed forest stream. A vegetation survey was conducted in the same forest, and deadwood sampled along the 500 m long stream section. Based on the photo vouchers, species were identified by František Kovařík, Fabio Cianferoni, Günther Schmidt, Konrad Fiedler, Reinhard Ehrmann, Gregory Edgecombe, Do Van Tu and Karin Voigtländer.

## RESULTS

### Overview

Species from ten arthropod families recorded in Chu Mom Ray National Park were identified as large (body length >= 60 mm) or as predators of herpetofauna: Scorpionidae (burrowing scorpions), Theraphosidae (tarantulas), Scolopendridae (giant centipedes), Scutigeridae (house centipedes), Belostomatidae (giant water bugs), Naucoridae (creeping water bugs), Nepidae (water scorpions), Formicidae (ants), Mantidae (praying mantises) and Potamidae (freshwater crabs). All arthropods were recorded between 370 and 846 m a.s.l.

### Systematics

***Heterometrus petersii* (THORELL, 1876) (Scorpiones, Scorpionidae)** (Fig. 3.1 & 3.2)

**Identification:** The species was identified by František Kovařík.

Three specimens of *Heterometrus petersii* were found underneath wooden boards at illegal logging sites in secondary forest in the core zone of Chu Mom Ray NP (elevation from 370 m to 380 m a.s.l.). Discoveries were made during the day (18 April 2012, 12:00 AM) and at night (19 April 2012, 7:22 PM). Two females had lengths of 90 and 103 mm respectively, the shorter individual weighing 12 g.

**Selenocosmiinae SIMON, 1889 (Araneae, Theraphosidae)** (Fig. 3.3 - 3.6)

**Identification:** The subfamily Selenocosmiinae was identified by Günther Schmidt.

Four tarantulas belonging to at least three different species in the subfamily Selenocosmiinae were observed at the edge of an unpaved, interprovincial road and at the steep bank of a slow-flowing, muddy rivulet (387 m a.s.l.). Road observations were made at 9:40 and 12:10 AM (11 May 2012), while encounters at the stream took place at night (17 April 2012, 9:59 PM, and 19 April 2012, 9:56 PM). A small individual (33 mm body length) was hiding inside a silk-lined funnel underneath a piece of rotting bamboo next to a road. Three larger specimens were found inside funnel-shaped underground burrows (Fig. 7.2).

***Scolopendra dehaani* BRANDT, 1840**

**(Scolopendromorpha, Scolopendridae)** (Fig. 4.1 - 4.3)

**Identification:** Both species were identified by Gregory Edgecombe.

17 giant centipedes (Scolopendridae, *Scolopendra dehaani*) were recorded inside evergreen and bamboo forest, often foraging along stream banks at night, where they could be observed on leaf litter, inside underground burrows and on trees (755 m a.s.l.). During the day, centipedes were only found inside pitfalls and funnel traps, or underneath larger pieces of deadwood (707 m a.s.l.). A large specimen was captured moving along on a stream bank around 10:25 PM (28 May 2012), a smaller one was found underneath a rotten log at 1:30 PM (2 May 2012).

Nine trapped centipedes (Scolopendridae) did not exceed 6 cm body length (from the beginning of the cephalic plate to the end of the terminal sternite), whereas six individuals found foraging at night measured around 10 cm body length, and a single one reaching 22 cm. The latter and another larger specimen (15 cm body length) were discovered on the ground, while most smaller individuals were found on trees and a liana. One individual resting on a tree stem in about 4 m height was feeding on a snail.

***Thereuopoda longicornis* (FABRICIUS, 1793)**

**(Scutigeromorpha, Scutigeridae)** (Fig. 4.4 & 4.5)

Eleven house centipedes (Scutigeridae, *Thereuopoda longicornis*) were observed in various habitats, including evergreen forest (775 m a.s.l.) and a field station building. Apart from individuals captured at the drift fence, all observations were made after dark (e.g., on 21 May 2014, 8:01 PM). Body sizes of house centipedes did not appear to differ significantly between trapped specimens (seven) and individuals found foraging at night (four), although the largest two recorded specimens were discovered outside of traps, measuring 58 and 62 mm from the epistome to the end of the telsom. One individual was found devouring a cricket.

***Lethocerus* cf. *indicus* (LEPELETIER & SERVILLE, 1825) (Hemiptera, Belostomatidae)** (Fig. 5.1 & 5.2)

**Identification:** All water bugs were determined by Fabio Cianferoni.

A single specimen of *Lethocerus* cf. *indicus* was encountered at the illuminated porch of a field station building , lying upside down on the concrete floor (7 April 2012, 8:40 PM, 695 m a.s.l.).


**Figure 3.** 1) *Heterometrus petersii*, 103 mm body length (dorsolateral view), 2) *Heterometrus petersii* (same specimen, dorsal view), 3) and 4) Tarantula (Selenocosmiinae), inside its silk-lined burrow at the edge of an interprovincial road; photo taken at day, 5) Tarantula (Selenocosmiinae) inside silk-lined burrow at the edge of a muddy rivulet; photo taken at night, 6) The same individual showing its chelicerae when threatened (photographs by D. Jestrzemski).

m a.s.l.). The individual measured 82 mm body length. On the same day, rain had fallen from 4:50 to 7:15 PM. When released inside a young forest stand, the insect moved a few meters on the leaf litter before climbing up a smaller tree to a height of 4-5 m.

**Naucoridae LEACH, 1815 (Hemiptera)** (Fig. 5.3 & 5.4)

A single, dead specimen of Naucoridae was recorded on a paved road surrounded by secondary forest (695 m a.s.l.). The insect (18 mm body length) was found on 10 April 2012 (12:15 PM), on a dry and sunny day.

***Cercotmetus* sp. AMYOT & SERVILLE, 1843 (Hemiptera, Nepidae)** (Fig. 5.5)

Several specimens of *Cercotmetus* sp. were recorded in a


**Fig. 4.** 1) *Scolopendra dehaani*, specimen with 220 mm body length, 2) *Scolopendra dehaani*, resting on tree trunk, 3) *Scolopendra dehaani*, resting on liana, 4) *Thereuopoda longicornis*, 50 mm specimen captured in a funnel trap, 5) Close-up view of *Thereuopoda longicornis* resting on a rotting tree stump (62 mm body length); the 5th right leg is missing (photographs by D. Jestrzemski).

shallow, muddy rivulet surrounded by secondary bamboo forest in Chu Mom Ray NP core zone (384 m a.s.l.). A water stick insect nymph was observed on 19 April 2013 (7:30 PM).

***Laccotrephes* sp. STÅL, 1865 (Hemiptera, Nepidae)** (Fig. 5.6)

Three water scorpions (*Laccotrephes* sp.) were recorded at and around a field station. Two specimens were observed inside a shallow pasture pond about 220 m from the station, situated at the edge of agricultural farmland and degraded, forest, in the national park buffer zone (11 April 2012, 11:23 PM) (674 m a.s.l.). The pond had a diameter of about 2.5 m with a depth of ca. 15 cm, and was inhabited by tadpoles. A water scorpion of 35 mm body length (without siphon) preyed and fed upon a tadpole, before being grabbed by an equally large conspecific. Both insects engaged in copulation. When visited again on 4 May and 8 June 2012, the pond was dried out (Fig. 8.4 – 8.6). A larger water scorpion was found in a muddy puddle next to an illuminated building (694 m a.s.l.), on 8 June 2012 (11:10 PM). The insect had a body length of 47 mm (without siphon).

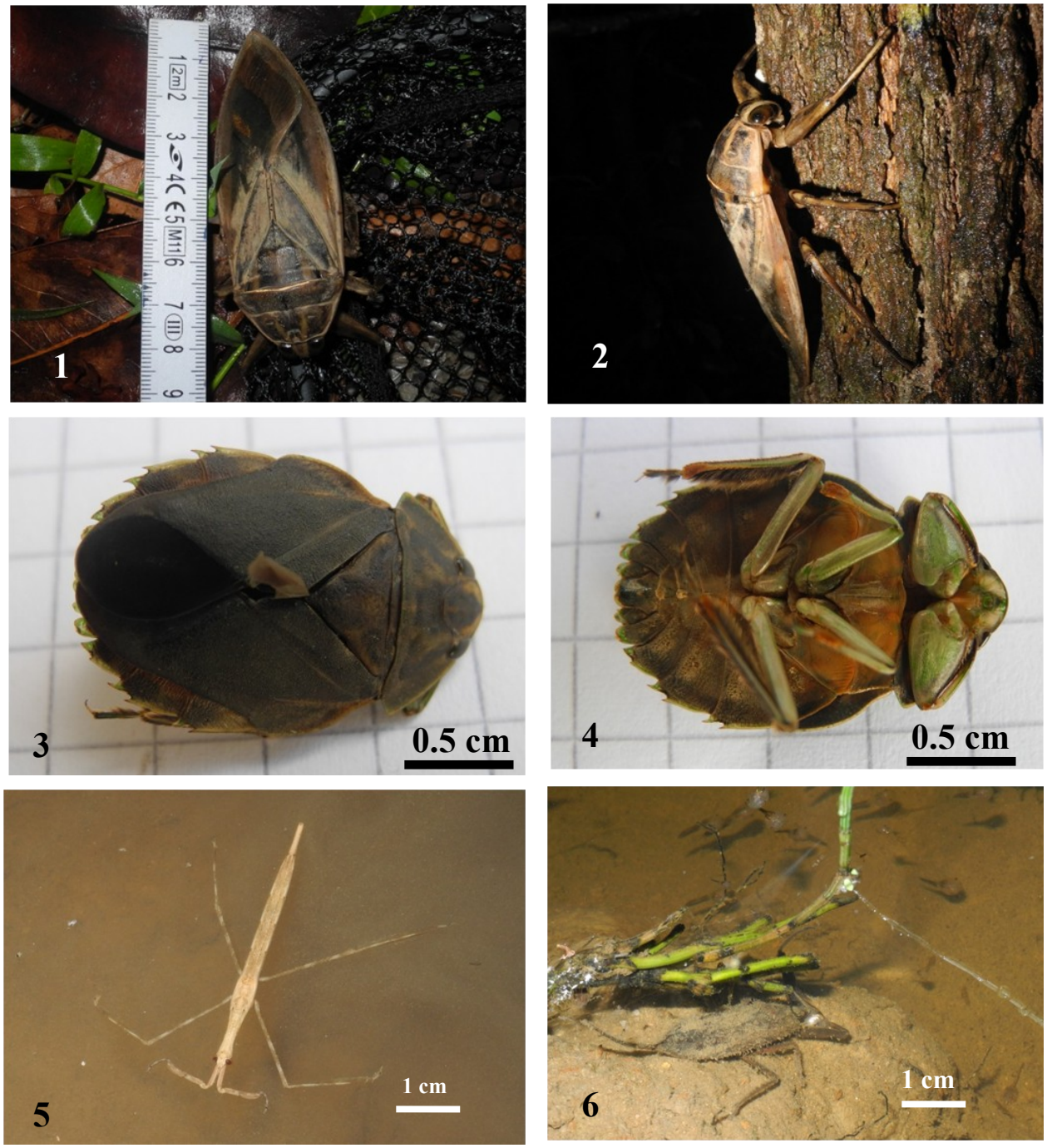


**Fig. 5.** 1) *Lethocerus* cf. *indicus*, 82 mm specimen, 2) The same specimen, climbing up a tree, 3 and 4) Naucoridae specimen (dorsal and ventral view), found dead on road; scale bar unit = 5 mm, 5) Nymph of *Cercotmetus* sp. in a muddy rivulet , 6) *Laccotrephes* sp. with a captured tadpole in a shallow, temporary pond at the edge of a cattle pasture (photograph by D. Jestrzemski).

***Aenictus* sp. SHUCKARD, 1840 (Hymenoptera, Formicidae)** (Fig. 6.1)

**Identification:** Army ants were determined to genus level by Konrad Fiedler.

In Chu Mom Ray NP, army ants in the genus *Aenictus* were recorded in various habitats (including forest and open land), under humid or dry conditions during day and night, but more commonly after sunset. The body length of *Aenictus* sp. was around 8 mm.

In two cases, *Aenictus* sp. was observed to devour the caecilian *Ichthyophis* cf. *nguyenorum* which had fallen into a sewage drain passing along a paved road surrounded by secondary forest (11 May 2012, 8:50 PM, 709 m a.s.l.). On two other occasions it was observed that single army ants were attacking a specimen of *Ichthyophis* cf. *nguyenorum* in the same drain without being able to overpower it (29 May 2012, 8:22 PM, 681 m a.s.l.).

***Hierodula fruhstorferi* WERNER, 1916 (Mantodea, Mantidae)** (Fig. 6.3)

***Hierodula patellifera* (SERVILLE, 1839) (Mantodea, Mantidae)**

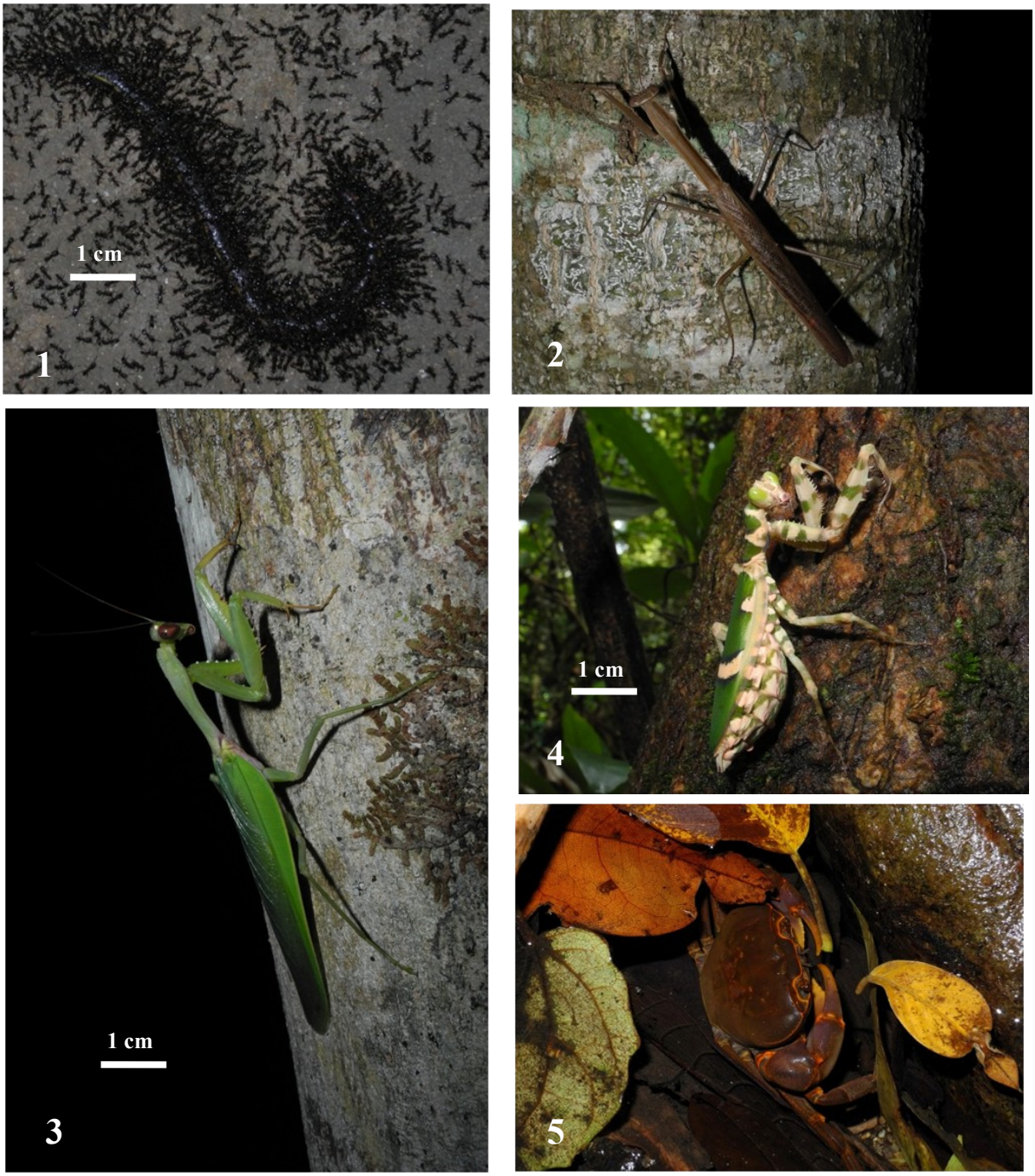


**Fig. 6.** 1) *Aenictus sp.* devouring a yellow-striped caecilian (*Ichthyophis* cf. *nguyenorum*) inside a sewage drain from which caecilians and small snakes were unable to escape , 2) *Tenodera aridifolia*, found in a field station building , 3) *Hierodula fruhstorferi*, found in a field station building, 4) *Theopropus elegans*, found in a patch of shrubland at day, 5) *Balssipotamon fruhstorferi* foraging in a forest stream at night (photograph by D. Jestrzemski).

***Tenodera aridifolia* (STOLL, 1813) (Mantodea, Mantidae)** (Fig. 6.2)

***Theopropus elegans* (WESTWOOD, 1832) (Mantodea, Mantidae)** (Fig. 6.4)

**Identification:** All praying mantises were determined to species level by Reinhard Ehrmann.

Adults of three different mantis species could be observed around the buildings of a field station (695 m a.s.l.): *Tenodera aridifolia* (male), *Hierodula fruhstorferi* (male) and *Hierodula patellifera* (female). The mantids were lurking for prey after sunset, with *T. aridifolia* and *H. fruhstorferi* gathering around electric lights at the ceiling of the buildings (10 May 2012, 7:30 PM), and *H. patellifera* foraging on a small ornamental tree at the entrance of a field station building (27 May 2012, 7:50 PM). In contrast, *Theopropus elegans* was observed inside evergreen forest next to a drift fence array (843 m a.s.l.). The adult female was found on a tree during daytime (2 June 2012, 11:10 AM). The specimen of *H. fruhstorferi* was the largest mantid recorded in Chu Mom Ray NP (87 mm body length).


**Fig. 7.** 1) Illegal logging site as habitat of *Heterometrus petersii*, 2) Tarantula (Selenocosmiinae) underneath a piece of rotting bamboo next to a road; note the silk-lined hiding place, 3) Deadwood as microhabitat of *Scolopendra dehaani*, 4) Liana as microhabitat of *Scolopendra dehaani*, 5) Microhabitat of *Scolopendra dehaani*: a large tree with a high proportion of deadwood, 6) Forest floor next to a large tree with a high deadwood proportion: habitat of a 220 mm *Scolopendra dehaani* specimen (photographs by D. Jestrzemski).

**Other large arthropod predators and omnivores**

Freshwater crabs of the species *Balssipotamon fruhstorferi* (BALSS, 1916) (Decapoda, Potamidae) were regularly observed in a forest stream and frequently trapped and released at the drift fences (on 24 out of 40 days). In three events, crabs were trapped together with anurans between 18 and 97 mm body length. The largest of these, an individual of the toad *Duttaphrynus melanostictus*, was found dead, with a deep, circular-shaped flesh wound of about 1 cm diameter in its lower abdomen. Inside the wound, the body tissue appeared to be carved out, and no blood was visible. Whip scorpions (Thelyphonida) were mainly recorded in secondary and old-growth forest, and rarely on the outside walls of buildings. At the drift fence, they were among the most commonly captured arthropods. On 20 out of 40 control days, a total of 55 whip scorpions were trapped in pitfalls and funnel traps, and consequently released. At least two situations involved a whip scorpion trapped in a pitfall together with a smaller anuran: a 51 mm specimen with a juvenile *Xenophrys major* (SVL 30 mm), and a 48 mm specimen with a very small frog which escaped before being photographed (SVL ~10 mm). Measured whip scorpions did not exceed 51 mm body length (without the flagellum on the end of the pygidium). No predation of whip scorpions or freshwater crabs on vertebrates was observed (Fig. 6.5)

## DISCUSSION

**Aquatic Heteroptera as predators of herpetofauna**

Giant water bugs in the genus *Lethocerus* are the largest Asian Heteroptera (Perez Goodwyn, 2006). As nocturnal aquatic predators, they inhabit rice fields, ponds, lakes, ditches and slow-running rivers and streams (Kopelke, 1982; Yoon *et al*., 2010; Haddad *et al.*, 2010; Choate, 2011; Vũ & Lê, 2012). The observation of *Lethocerus* cf. *indicus* at an illuminated field station after sunset underlines a typical behavior of giant water bugs: they are attracted by artificial lights during nocturnal flights. As a consequence, these insects are commonly found in areas inhabited by humans, lying upside down until they die from dehydration (Ohba & Takagi, 2005).

Due to the proximity of the field station to the paddies of local farmers, it can be assumed that the observed specimen had migrated from a nearby rice field. A Vietnamese study of *L. indicus* (2000-2010) showed that 81% of all specimens inhabited paddies of maximally 50 cm depth, and only 14% were caught in ponds and lakes (above 50 cm depth) (Vũ & Lê, 2012).

Besides consuming a wide range of aquatic invertebrates and small fish, giant water bugs prey on amphibians (Kopelke, 1982; Kwet & Schlüter, 2002; Bernard, 2007; Ohba, 2011b) which they kill and digest with their saliva (Haddad *et al.*, 2010). While mature specimens eat full-grown frogs, nymphs prefer tadpoles (Ohba, 2011a). During all development stages, nymphs and adult belostomids are able to capture and devour animals exceeding their own body mass (Ohba, Tatsuta & Nakasuji, 2008), including juvenile turtles (Ohba, 2011b). In Chu Mom Ray NP, the most frequently encountered amphibian around paddy fields and on open lands (e.g. cattle pastures) was the cricket frog *Fejervarya limnocharis*, followed by *Microhyla fissipes*, *Polypedates* cf. *megacephalus* and *P.* cf. *mutus*. Another common amphibian species in the Chu Mom Ray buffer zone was the caecilian *Ichthyophis* cf. *nguyenorum* which was mainly found in a sewage drain, about 500-1000 m away from paddy fields. It was sharing its habitat with the semi-aquatic snake *Rhabdophis subminiatus*. Since giant


**Fig. 8.** 1 and 2) Dried-out creek bed as habitat of *Thereuopoda longicornis*, 3) Front porch of a field station building; spots of nocturnal arthropod encounters highlighted yellow (*Tenodera aridifolia*, ceiling), green (*Lethocerus* cf. *indicus*, floor) and red arrow (*Hierodula patellifera*, small ornamental tree), 4) Temporary pond at the edge of a cattle pasture as habitat of *Laccotrephes* sp., 5 and 6) The same pond on 10 April 2012 (left), and dried up on 4 May 2012 (right) (photographs by D. Jestrzemski).

water bugs are important predators of anurans and other aquatic herpetofauna as well as fish, their occurrence is an indicator of amphibian populations (Hirai & Hidaka, 2002; Tarr & Babbitt, 2010) and possibly other potential aquatic vertebrate prey (e.g. various fish species). *Lethocerus* spp. also regulate populations of freshwater snails and mosquito larvae, some of which are disease vectors in developing countries (Ohba & Nakasuji, 2006). While the winged adults of *L. indicus* inhabit large water bodies and even rivers, the instars of the nymphs only occur in temporary water bodies (Nesemann & Sharma 2013). Females require waters with oviposition substrata to lay eggs (Mukai, Baba & Ishii, 2005).

In Asia, water scorpions (Nepidae) are commonly found in rice fields, ponds and slow-flowing or stagnant water bodies (Ohba & Perez Goodwyn, 2010; Ghosh & Chandra, 2011), with exception of the water stick insect genus *Cercotmetus*, whose members occur along the margins of flowing streams (Polhemus & Polhemus, 2013). Nepidae (i.e. *Laccotrephes* spp.) are major predators of tadpoles (Ohba & Perez Goodwyn, 2010; Ohba, 2011a), which was also observed in Chu Mom Ray NP. Besides, water scorpions feed on various aquatic insects such as mosquito larvae. Hence, they are regarded as highly beneficial for humans (Ohba & Perez Goodwyn, 2010).

**Centipedes as predators of amphibians and reptiles**

Giant centipedes (Scolopendridae) belong to the few terrestrial arthropods that prey on a wide range of reptiles and amphibians, including small frogs, toads, lizards and snakes (Easterla, 1975; Bush *et al*., 2001; Molinari *et al.*, 2005). Preferring dark and damp environments, Scolopendridae usually seek shelter during the day. They hide in caves (Molinari *et al*., 2005) and underneath rocks, leaves and bark (Voigtländer, 2009). The large individual of *Scolopendra dehaani* (22 cm body length) found at a surveyed forest stream shares its habitat with several species of smaller herpetofauna recorded at and nearby the stream, including the Asian common toad (*Duttaphrynus melanostictus*), lizards (*Acanthosaura*, *Cyrtodactylus*, *Sphenomorphus*) and small snakes (*Lycodon fasciatus*, *Psammodynastes pulverulentus* and *Pareas margaritophorus*).

As venomous nocturnal hunters, Scutigeridae are known to consume various arthropods such as myriapods, crustaceans, arachnids and insects, but predation on vertebrates has not been observed to date (G. Edgecombe, pers. comm., 15 November 2013). *Thereuopoda longicornis*, which was recorded in various habitats of Chu Mom Ray NP, reaches a maximum body length of 8 cm (Würmli, 1979).

**Terrestrial arachnids as predators of herpetofauna in Chu Mom Ray**

Apart from giant centipedes, also tarantulas commonly prey on herpetofauna, including frogs, caecilians, skinks and snakes (Malkmus, 1998; Menin *et al.*, 2005). The large Selenocosmiinae observed at a rivulet inside secondary bamboo forest share their habitat with the frog species *Limnonectes poilani* and *Hylarana* cf. *nigrovittata*. Reaching a body length of 90-125 mm (Kovařík, 2004), the Vietnamese scorpion *Heterometrus petersii* is a large invertebrate predator native to tropical Asian forests (Booncham *et al*., 2007; Jiao & Zhu, 2009). Several scorpion species have been observed preying on lizards in in North America, Africa and Europe (Castilla, Herrel & Gosá, 2009).

Army ants are top predators in tropical forests, raiding the forest floor with many thousands of workers

and killing any prey unable to flee, including lizards and snakes (O'Donnell, Kaspari & Lattke, 2005). As a consequence, every raid party of army ants heavily influences movements, interactions and mortality of forest floor fauna (Kronauer, 2009). Many ants, especially aggressive or large species, include anurans in their prey, but predation also occurs vice versa, with some frogs foraging in ant nests without being attacked, probably due to their skin secretions. Cross-predation occurs when ants prey on juvenile anurans but are eaten by the adults (Kwet & Schlüter, 2002). In Chu Mom Ray, all three predation events of the army ant *Aenictus* sp. on caecilians were recorded in sewage drains, from which the caecilians could hardly escape. In two of the cases it was unclear whether the caecilians had been killed by the ants or had died due to other reasons ( Fig. 7 & 8).

**Freshwater crabs as predators of herpetofauna**

Tropical freshwater crab species are known to attack and kill anurans (Gray, Oellet & Green, 2002; Affonso & Signorelly, 2011; Pyke *et al*., 2013) as well as snakes (Maitland, 2003; Murphy, 2010; Vyas & Upadhayay, 2015). Yet, predation of the Vietnamese freshwater crab species *Balssipotamon fruhstorferi* on herpetofauna has not been confirmed. While *B. fruhstorferi* includes land snails in its diet, local people reported it to be a prey species of snakes, turtles and birds (T.V. Do, pers. comm., 27 February 2016). Despite the frequent presence of *B. fruhstorferi* at the Chu Mom Ray NP study site, no predation events involving freshwater crabs could be observed. However, the possibility remains that the dead *Duttaphrynus melanostictus* individual recorded at the drift fence was injured and killed by the freshwater crab found in the same pitfall trap.

**Conservation of aquatic Heteroptera**

Giant water bugs (*Lethocerus deyrolli*) are severely endangered in Japan (Hirai & Hidaka, 2002; Mukai *et al.*, 2005; Ohba & Takagi, 2005; Ohba & Nakasuji, 2006; Ohba, 2007; Yoon *et al.* 2010; Nagaba & Takeda, 2013) and Korea (Ho, Kim & Kim, 2009; Yoon *et al.*, 2010). Major threats to *L. deyrolli* are the loss of aquatic habitats, water pollution and pesticide use (Hirai & Hidaka, 2002; Ohba & Takagi, 2005; Nagaba & Takeda, 2013), and the decrease in available prey (Ohba & Takagi, 2005; Ho *et al*., 2009), particularly the disappearance of frogs (Hirai & Hidaka, 2002). Research in Japan also showed that declining numbers of tadpoles led to increased predation levels of water scorpions on giant water bug nymphs (Ohba, 2011a). Additionally, artificial lights attract water bugs during migration flights, which consequently assemble around the light sources and quickly die from dehydration (Ohba & Takagi, 2005; Yoon *et al.*, 2010). Street lighting is therefore considered to be a key cause of the ongoing extinction of *L. deyrolli* in Japan (Nagaba & Takeda, 2013) and in Korea (Yoon *et al.*, 2010). In Thailand, Laos, Vietnam and Cambodia, *L. indicus* is traditionally used for human consumption, particularly for spicing, since the male scent glands contain sex pheromones that produce a characteristic odor (Kiatbenjakul, Intarapichet & Cadwallader, 2013). Consequently, males are preferred in Thai cuisine (FAO, 2013). Traders in Southeast Asia catch and sell this water bug in large numbers, taking advantage of the insect's attraction to artificial light sources. Prices and demand for *L. indicus* are increasing in Thailand, and large quantities of giant water bugs are imported from Cambodia and Myanmar. Due to pollution and changes in habitat and environment, Thai populations of *L. indicus* are declining (FAO, 2013). Similarly, Polhemus & Polhemus (2013) report that no captures of *L. indicus* could be obtained in Singapore in over two decades, supposing that urban light pollution may have had an adverse impact on *L. indicus*.

For their survival, giant water bugs heavily depend on aquatic anurans and their tadpoles (Hirai & Hidaka, 2002; Ohba, 2011a), as well as on paddies, ponds and other stagnant water bodies (Ho *et al.*, 2009; Nagaba & Takeda, 2013). When paddies are drained for the rice harvest, giant water bugs (*L. deyrolli*) are forced to migrate to other habitats (Mukai *et al*., 2005; Ohba & Takagi, 2005). Therefore, permanent ponds with sufficient vegetation are considered important refuges for *Lethocerus* populations, buffering the temporary loss of paddy habitats and the impact of dry seasons (Saijo, 2001). Reduced migration flight activities also enable giant water bugs to save energy and maintain body weight (Ohba & Takagi, 2005). In order to prevent light attraction and increase the probability of wetland inhabitation by *Lethocerus deyrolli*, habitats should have a buffer area of at least 600-700 m radius free from artificial lights (Ho *et al*., 2009).

**Conservation of terrestrial arachnids**

According to Yen & Ro (2013), wild populations of tarantulas are heavily exploited for trade in Cambodia. Today, Cambodian traders consider tarantula populations to be declining, which they attribute to the widespread deforestation. Collectors now concentrate on remaining forests or catch the tarantulas in cashew nut plantations. Many customers are foreign (e.g. Vietnamese), and believe that tarantulas are of medical value (Yen & Ro, 2013). Scorpions in the genus *Heterometrus* are native to tropical Asian forests (Booncham *et al*., 2007) and frequently collected and traded (see De Vosjoli, 1991; Jiao & Zhu, 2009). *Heterometrus petersii* is both kept as a pet and used in traditional Chinese medicine (Ma *et al*., 2010). In Chu Mom Ray NP, both female specimens of *H. petersii* (as well as an undocumented third individual) were the only scorpions recorded during the survey, and found in sites of illegal timber extraction. Poaching of wildlife and illegal logging are widespread problems in the national park (Jestrzemski *et al*., 2013).

**Conservation of Vietnamese freshwater crabs**

The freshwater crab *B. fruhstorferii* is endemic to Vietnam, where it is known only from three localities (Esser & Cumberlidge, 2008; Do, 2014). It is listed as vulnerable (VU) in the Vietnamese Red Data Book 2007. Vietnam's freshwater crabs show a high degree of endemism (42 out of 49 species) and face several threats such as water pollution, habitat loss, deforestation and overexploitation for human consumption (Do, 2014) (Fig. 9).


**Fig. 9.** Asian forest scorpions (cf. *Heterometrus* sp.) for sale in a wildlife shop in Hochiminh City. Jars with scorpions are highlighted by yellow arrows. Note the monitor lizard, cobra and pangolins (photograph by D. Jestrzemski).

## CONCLUSION AND RECOMMENDATIONS

Among the large arthropod predators recorded in Chu Mom Ray, giant water bugs (*Lethocerus indicus*), Asian forest scorpions (*Heterometrus* spp.) and tarantulas (Theraphosidae) are heavily traded taxa in Southeast Asia, with unknown consequences for the individual populations. These invertebrates are also associated with threatened habitats such as wetlands and forests. *Lethocerus* sp. should be mapped in Chu Mom Ray NP, in order to identify suitable habitats and start a monitoring program for giant water bugs and their prey (i.e. amphibian populations), as a fundament of future conservation planning. It is further recommended to preserve paddies, ponds and their amphibian populations, and to establish new, permanent ponds with sufficient vegetation as refuges for giant water bugs and other aquatic fauna. Pesticide use in paddies should be strictly limited in the buffer zone of Chu Mom Ray NP. Following the recommendations of Ho *et al*. (2009), electric lights should be kept away as far as possible from *Lethocerus* habitats, ideally more than 600 m. Light-attracted giant water bugs found at field stations should be rescued and transferred to suitable wetlands.

The conservation of tarantula and Asian forest scorpion diversity is directly linked to the preservation of their habitats (i.e. forests with sufficient structural richness and streams). Strict measures against illegal loggers, poachers and wildlife traders are necessary to safeguard the biological diversity of Vietnam's protected areas. Environmental education programs for residents and schools in the buffer zone should be extended to include the conservation and sustainable management of endangered invertebrates.

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