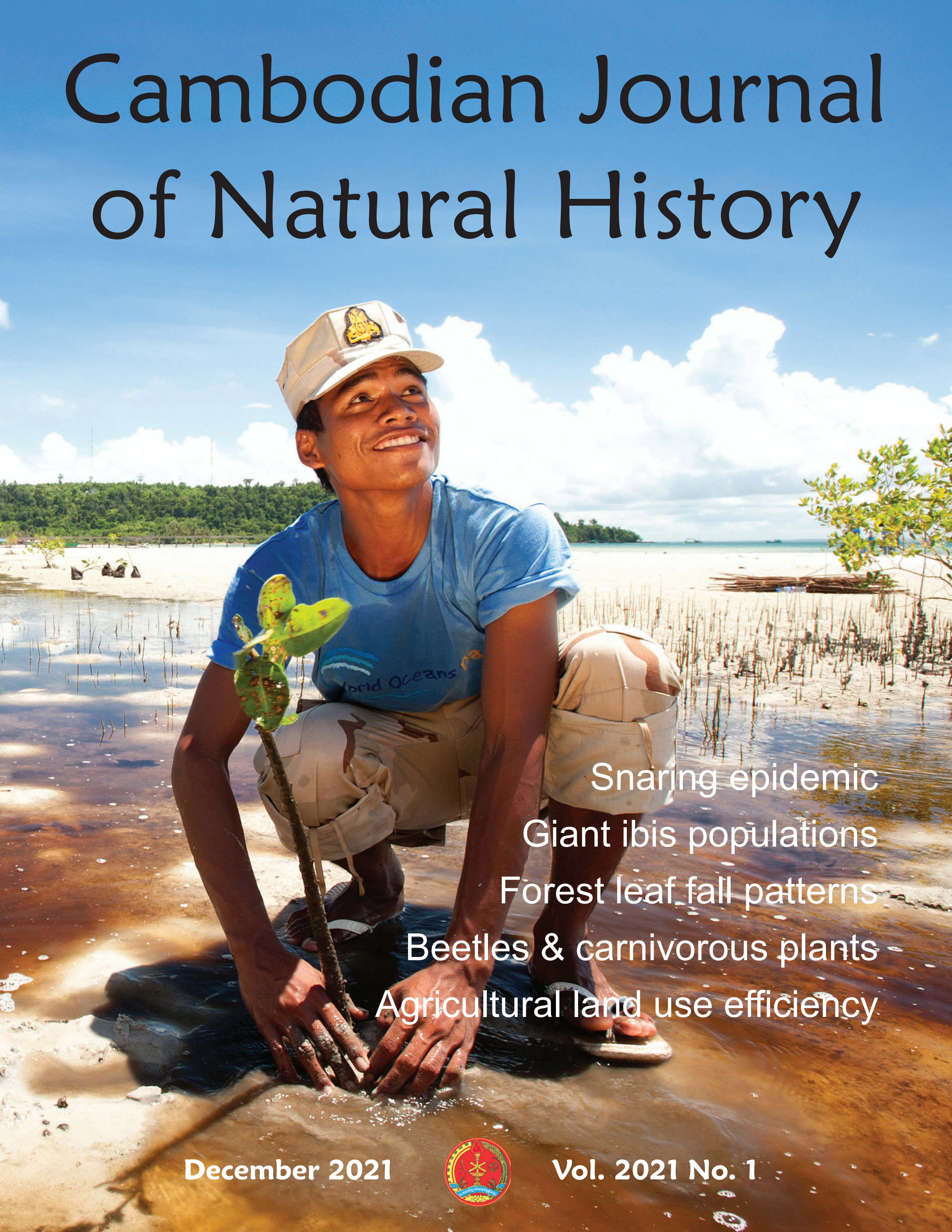
Cambodian Journal of Natural History



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Cover image: Mangrove reafforestation efforts on World Oceans Day, Koh Kong Island, southwest Cambodia (© Jeremy Holden).

Short Communication

Report of carnivorous plants (Droseraceae, Lentibulariaceae and Nepenthaceae) from seasonally dry savannahs in Ratanakiri Province, Cambodia

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Cambodia is home to several species of carnivorous plants that attract, capture, kill and digest prey using modified leaves that act as traps (Mey *et al*., 2010). This group of plants currently consists of about 860 known species belonging to 11 families and 18 genera (Cross *et al*., 2020). In Cambodia, three genera from three families have been recorded: the sundews *Drosera* L. (Droseraceae), the pitcher plants *Nepenthes* L. (Nepenthaceae) and the bladderworts *Utricularia* L. (Lentibulariaceae) (McPherson, 2010). Until the beginning of the 21th century, carnivorous plants in the Indochinese Peninsula (Cambodia, Laos, Thailand and Vietnam, i.e. Indochina, as circumscribed in floristic treatments such as Lecompte (1965)) received little attention from scientists (McPherson, 2010).

Due to their spectacular appearance, species within the genus *Nepenthes* (commonly known as 'tropical pitcher plants', or 'ampuong sramoch' and 'ampuong kralôm' in Khmer) in the Indochinese Peninsula have been subjected to intense research since the late 2000's. This has resulted in the description of 13 new species, one emended species and one variety (Mey, 2009, 2010; Cheek & Jebb, 2009; Catalano, 2010, 2014, 2015, 2017, 2018; Mey *et al*., 2011), two of which are endemic to Cambodia: *N. bokorensis* Mey and *N. holdenii* Mey (Mey *et al*., 2011). At present, five pitcher plant species are known in Cambodia and 18 from the four countries of the Indochinese Peninsula (Cross *et al*., 2020). Most *Nepenthes* plants in Cambodia occur in association with other carnivorous plants such as *Drosera*, represented by four species in Cambodia (Lecompte, 1965; Mey, 2015), and *Utricularia*, represented by at least ten species in Cambodia (Taylor, 1989).

This article documents the first record of populations of *D. burmannii* Vahl (Droseraceae) (Fig. 1), *U. delphinioides* Thorel. ex. Pellegr. (Lentibulariaceae) (Fig. 2) and *N. smilesii* Hemsl. (Nepenthaceae) (Fig. 2) in Veun Sai—Siem Pang National Park, northeast Cambodia. These populations were located in a seasonally dry and sandy savannah (Fig. 3, referred to as 'veal' in Khmer) near Virachey National Park in Ratanakiri Province (exact location withheld for conservation purposes) at an elevation of 110 metres. Based on our observations and according to local rangers in January 2021, this may be the only location where these species occur in the park. The surface area covered by the plants was about 70 m² and a sample of each species was collected, dried and conserved in the herbarium collection of the Royal University of Phnom Penh under accession numbers 0001 (for *D. burmannii*), 0002 (*N. smilesii*) and 0003 (*U. delphinoides*).

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Fig. 1 *Drosera burmannii* Vahl (© Heng Kimly).

Fig. 2 Pitchers of *Nepenthes smilesii* Hemsl. and distinctive violet flower of *Utricularia delphinioides* Thorel. ex. Pellegr. (upper right) (© Pierre-Olivier Maquart).

Fig. 3 Seasonally dry savannah in Veun Sai—Siem Pang National Park.

Drosera burmannii is an acaulescent sundew which forms a rosette of characteristic suborbicular leaves covered with long peripheral tentacles. In Cambodia, it can only be vaguely confused with the juvenile rosettes of young *D. lunata* Buch.-Ham. ex DC before these enter their caulescent phase. The basal rosette of *D. lunata* produces petiolate, transversely elliptic or flabellate leaves which are very different from those of *D. burmannii* (Lowrie *et al*., 2017a). *Drosera burmannii* is a widespread sundew species which can be locally abundant in Cambodia (Mey, unpublished data) and occurs in India, China, Japan, throughout Southeast Asia and across the islands of the Malay Archipelago through to New Guinea and Australia (Lowrie *et al*., 2017b).

Our identification of the bladderwort *U. delphinioides* was similarly straightforward as the species produces a dense inflorescence of very distinctive dark violet flowers (Taylor, 1989) which are the largest for the genus in Cambodia and cannot be confused with any other *Utricularia* species in the Indochinese Peninsula. Populations of the species with pink flowers have been recorded in neighbouring Thailand (Catalano, 2010) but have yet to be observed in Cambodia. *Utricularia delphinioides* also occurs in Laos and Vietnam, where it grows in swamps, near paddy fields, in open wet places in grasslands and in open pine forests in acid soils (Taylor, 1989). Its distribution in Cambodia appears to be much patchier than that of *D. burmannii*, although this may be due to the fact that it is virtually undetectable outside of flowering periods.

Besides *N. mirabilis*, *N. smilesii* is the most widespread pitcher plant species in the Indochinese Peninsula (Mey, 2010). The low elevation at which it is found in Ratanakiri is unusual since the species mainly occurs between 500 and 1,000 m above sea level in the rest of the peninsula (Mey, 2010). *Nepenthes smilesii is* a member of an informal group referred to as the '*Nepenthes thorelii* aggregate' (Mey, 2010) or the '*Nepenthes smilesii* group' (Cheek & Jebb, 2013). Both species groups include very closely related species (including *N. kampotiana*, *N. bokorensis* and *N. holdenii* in Cambodia) that occur across the Indochinese Peninsula and are now included in the *Nepenthes* section Pyrophytae (Cheek & Jebb, 2016). Species in this section are pyrophytes that almost exclusively occur in nutrient-poor soil types in open to semi-open habitats which are seasonally wet. *Nepenthes* plants survive severe droughts and dry season fires in these habitats due to their fleshy underground tuberous rootstocks. In the Indochinese Peninsula, *Nepenthes* spp. usually grow in acidic sandy soils and frequently occur in sympatry with sundews such as *D. indica* L., *D. burmannii* L. (more rarely *D. serpens* Planch. and *D. lunata* Buch.-Ham. ex DC) and various bladderworts such as *U. bifida* L., *U. odorata* Pellegr., *U. minutissima* Vahl, *U. geoffrayi* Pellegr., *U. subuluta* L. and *U. caerulea* L. (Mey, unpublished data).

Due to its close relationship with other taxa in the '*Nepenthes thorelii* aggregate' in Cambodia, Laos, Vietnam and Thailand, identification of *N. smilesii* is more complicated than *D. burmanii* and *U. delphinioides*. However, *N. smilesii* can be confidently distinguished by the following characters: the taxon generally develops lower pitchers that are cylindrical with a bulbous base and produced at the end of relatively short tendrils, whereas the leaves are conspicuously covered with short hairs. Because *N. holdenii* and *N. bokorensis* are restricted to the Cardamom Mountains and Phnom Bokor in Cambodia respectively, *N. smilesii* can only be confused with *N. kampotiana* as both taxa share the same habitat and develop similar cylindrical to narrowly infundibular yellow upper pitchers. However, *N. kampotiana* generally produces pyriform to subglobose lower pitchers at the end of long tendrils and its vegetative parts are glabrous.

We observed the contents of *N. smilesii* pitchers and found several digested arthropods including scorpions (Arachnida: Scorpiones: *Lychas* spp.), ants (Hymenoptera: Formicidae: *Oecophylla* spp.), assassin bugs (Hemiptera: Reduviidae), but also some live larvae of *Toxorhynchites* spp. (Diptera: Culicidae). While some Culicidae larvae, like the Bornean endemics *Culex rajah* Tsukamoto, 1989, *Tx. rajah* Tsukamoto, 1989 and *Topomyia nepenthicola* Miyagi & Toma, 2007 are well-known nepenthebionts (Tsukamoto, 1989; Miyagi & Toma, 2007), there are only a few studies of the prey spectrum of the Indochinese *Nepenthes* (Hosoishi *et al*., 2012). Scorpions have been observed in the pitchers of the natural hybrid *N. mirabilis* x *thorelii* in southern Vietnam (Mey, 2010), but what attracts these predators to *Nepenthes* pitchers remains to be studied and understood.

The last 15 years of research indicate that the natural habitats of carnivorous plants in Cambodia have been severely reduced in private lands, for agricultural expansion, and in protected areas such as the Preah Monivong Bokor National Park, for the tourism industry (Mey, 2010). Carnivorous plants are threatened in the country and two endemic taxa (*N. bokorensis* and *N. holdenii*) can be regarded as Critically Endangered according to IUCN Red List criteria (Cross *et al*., 2020). As the apparently small populations of the three species in Veun Sai—Siem Pang National Park demonstrate, carnivorous plants are sometimes restricted to very small areas. We recommend strict protection of these taxa and their habitats in the national park. Monitoring is also required to develop understanding of the diversity and distribution of carnivorous plants in Cambodia, so that they can be protected in future. This particularly applies to the relatively inconspicuous species in the carnivorous plant genera *Drosera* and *Utricularia*, and to a lesser extent, *Nepenthes*.

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References

Catalano, M. (2010) *Nepenthes della Thailandia: Diario di viaggio*. WOW s.r.o., Prague, Czech Republic.

Catalano, M. (2014) *Nepenthes rosea*, una nuova specie dalla Thailandia peninsulare. *Associazione Italiana Piante Carnivore Magazine*, **36**, 24–31.

Catalano, M. (2015) *Nepenthes kongkandana*, da ufficiosa ad ufficiale. *Associazione Italiana Piante Carnivore Magazine*, **37**, 4–11.

Catalano, M. (2017) Una nueva specie di *Nepenthes* dal Vietnam. *Associazione Italiana Piante Carnivore Magazine*, **46**, 16–23.

Catalano, M. (2018) *Nepenthes orbiculata*, una nueva specie da Phang Nga (Thailandia). *Associazione Italiana Piante Carnivore Magazine*, **50**, 32–43.

Cheek, M.R. & Jebb, M.H.P. (2009) *Nepenthes* group Montanae (Nepenthaceae) in Indo-China, with *N. thai* and *N. bokor* described as new. *Kew Bulletin*, **64**, 319–325.

Cheek, M. & Jebb, M. (2013) Identification and typification of *Nepenthes blancoi*, with *N. abalata* sp. nov. from the western Visayas, Philippines. *Nordic Journal of Botany*, **30**, 1–6.

Cheek, M. & Jebb, M. (2016) *Nepenthes* section Pyrophytae. *Planta Carnivora*, **38**, 44–45.

Cross, A., Krueger, T., Gonella, P.M., Robinson, A.S. & Fleischmann, A.S. (2020) Conservation of carnivorous plants in the age of extinction. *Global Ecology and Conservation*, **24**, e01272.

Hosoishi, S., Park, S.-H., Yamane, S. & Ogata, K. (2012) Species composition of ant prey of the pitcher plant *Nepenthes bokorensis* Mey (Nepenthaceae) in Phnom Bokor National Park, Cambodia. *Cambodian Journal of Natural History*, **2012**, 3–7.

Lecompte, O. (1965) Droseraceae. In *Flore du Cambodge, du Laos et du Vietnam,* vol. 4 (eds A. Aubréville & M.L. Tardieu-Blot), pp. 63–74. Muséum National d'Histoire Naturelle, Paris, France.

Lowrie, A., Nunn, R., Robinson, A., Bourke, G., McPherson, S. & Fleischmann, A. (2017a) *Drosera of the World, Vol. 1 (Oceania)*. Redfern Natural History Productions, Poole, UK.

Lowrie, A., Robinson, A., Nunn, R., Rice, B., Bourke, G., Gibson, R., McPherson, S., Fleischmann, A. (2017b) *Drosera of the World, Vol. 2 (Oceania, Asia, Europe, North America)*. Redfern Natural History Productions, Poole, UK.

McPherson, S.R. (2010) *Carnivorous Plants and Their Habitats*. Redfern Natural History Productions, Poole, UK.

Mey, F.S. (2009) *Nepenthes bokorensis*, a new species of Nepenthaceae from Cambodia. *Carnivora Australis - Journal of the Australasian Carnivorous Plants Society*, **7**, 6–15.

Mey, F.S. (2010) Introduction to the pitcher plants (*Nepenthes*) of Cambodia. *Cambodian Journal of Natural History*, **2**, 106–117.

Mey, F.S., Catalano, M., Clarke, C., Robinson, A., Fleischmann, A. & McPherson, S. (2010) *Nepenthes holdenii* (Nepenthaceae), a new species of pyrophytic pitcher plant from the Cardamom Mountains of Cambodia. In *Carnivorous Plants and Their Habitats* (ed. S.R. McPherson), pp. 1,306–1,331. Redfern Natural History Productions, Poole, UK.

Mey, F.S., Truong L.H., Dai D.V. & Robinson, A.S. (2011) *Nepenthes thorelii*, an emended description and novel ecological data resulting from its rediscovery in Tay Ninh, Vietnam. In *New Nepenthes - Volume 1* (ed. S.R. McPherson), pp. 104–131. Redfern Natural History Productions, Poole, UK.

Mey, F.S. (2015) *Drosera finlaysoniana? Drosera serpens or Something Else?* Http://carnivorousockhom.blogspot.com/2015/09/drosera-finlaysoniana-drosera-serpens.html [Accessed 4 June 2021].

Miyagi, I. & Toma, T. (2007) A new mosquito of the genus *Topomyia* (Diptera, Culicidae) from a Nepenthes pitcher plant in a Bario highland of Sarawak, Malaysia. *Medical Entomology and Zoology*, **58**, 167–174.

Taylor, P. (1989) T*he Genus Utricularia: A Taxonomic Monograph*. Kew Bulletin Additional Series, XIV, HMSO, London, UK.

Tsukamoto, M. (1989) Two new mosquito species from a pitcher plant of Mt Kinabalu, Sabah, Malaysia: *Culex rajah* and *Toxorhynchites rajah* (Diptera: Culicidae). *Journal of Tropical Medicine and Hygiene*, **17**, 215–228.

Short Communication

Expansion of the range of *Eupatorus siamensis* (Castelnau, 1867) (Coleoptera: Scarabaeidae: Dynastinae) in Cambodia

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The Dynastinae Macleay, 1819 is one of the largest subfamilies in the Scarabaeidae (Coleoptera). The subfamily includes about 1,500 species in 225 genera (Beutel & Leschen, 2016) and over 200 species have been described from Southeast Asia (Pathomwattananurak *et al*., 2019). Within the region, the Dynastinae fauna of Thailand is the most studied with 32 species recorded (Pathomwattananurak *et al*., 2019), whereas aside from collection records gathered at the end of the 19th century and scattered taxonomic revisions (Jameson & Drumont, 2013), in-depth work has yet to be conducted in Cambodia.

Due to their large size and extravagant male ornamentation, species within the genus *Eupatorus* Burmeister, 1847 are among the most remarkable rhinoceros beetles in Southeast Asia. The genus is widely distributed in Asia and Oceania and represented by eight species, namely: *Eupatorus becarii* (Gestro, 1876), *E. birmanicus* Arrow, 1908, *E. endoi* Nagai, 1999, *E. gracilicornis* Arrow, 1908, *E. hardwickei* (Hope, 1831), *E. pyros* Prandi & Grossi, 2021, *E. siamensis* (Castelnau, 1867) and *E. sukkiti* Miyashita & Arnaud, 1996. These beetles are generally found in bamboo forests (Moskalenko, 2017), where the larvae develop in the soil and feed on decaying wood for about a year. Adults are usually active at the end of the rainy season from August to November, feed on nectar, plant sap and rotten fruits and live for about six months (Moskalenko, 2017).

Historically, only *E. gracillicornis*, the most common species in the genus and widely distributed from India to China and throughout Southeast Asia, was recorded in Cambodia (Moskalenko, 2017). More recently however, *E. siamensis* has been reported along the eastern region of the Mekong River in Cambodia, although information on its precise locations was not provided (Prandi & Grossi, 2021). *Eupatorus siamensis* is a large beetle (male size ca. 43–75 mm) and was originally described from Siam (present day Thailand). The type specimen (accession no. MNHN-EC4171) is deposited in the Oberthür Collection in the Museum d'Histoire Naturelle de Paris. The species is known from the Khao Yai, Kalasin, Chaiyaphum, Loei, Mae Hong Son and Phetchabun provinces in Thailand (Ek-Amnuay, 2008; Thinh & Tru, 2008; Pathomwattananurak *et al*., 2019) and is also reported from Vietnam (Gia Lai province) and Laos (no province specified) (Thinh & Tru, 2008). While the presence of *E. siamensis* seems credible in Vietnam and Laos, we are not aware of any specimens deposited in museum collections and so these records may need further confirmation.

We present herein a range expansion for *E. siamensis* in Cambodia. Two large male specimens (60 and 65 mm) were collected in the Chambok Community-Based Eco-

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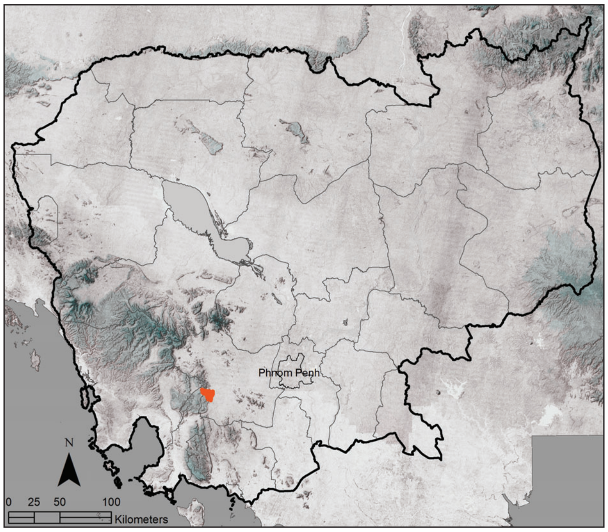

Fig. 1 Location of Chambok Community-Based Eco-Tourism Site (red polygon) in Kampong Speu Province, Cambodia.

Fig. 2 Dorsal (above) and lateral habitus of *Eupatorus siamensis* (Castelnau, 1867) from Chambok Community-Based Eco-Tourism Site.

Fig. 3 Live male of *Eupatorus siamensis* (Castelnau, 1867) observed 4 km west of Kampot (© Greg Allen).

Tourism Site (CBET) in Kampong Speu Province (Fig. 1). These were collected using a UV-light trap in semi-evergreen forest during entomological training sessions focusing on Coleoptera as part of a collaboration between the Cambodian Entomology Initiatives (CEI) and the Illinois Natural History Survey in 2018. Our specimens of the species are distinguished from other members of the genus by their glabrous dorsa, their two divergent and non-spatulate thoracic horns, dark chestnut habitus, and the shape of their aedeagus (Prandi & Grossi, 2021) (Fig. 2).

The observation of *E. siamensis* was made in the community protected area of the CBET, which forms part of the Cardamom Mountains. The CBET occupies a total area of 8,257 ha and borders Kirirom National Park (Lonn, 2013). Vegetation at the site includes bamboo forests, semi-evergreen forests and grasslands with deciduous forests (Chhorn *et al*., 2020; Sin *et al*., 2020). Given their similar vegetation patterns, it is possible that the species occurs throughout the Cardamom and Damrei mountain ranges. Furthermore, observations of *E. siamensis* have been made by nature enthusiasts in Phnom Kulen National Park, Phnom Bok and around Kampot (Allen, 2019) (Fig. 3). As such, the distribution of this insect may be greater than expected and it could potentially occur in most Cambodian dipterocarp forests that include areas of bamboo.

This new record highlights the need for entomological studies and conservation of rare or endangered invertebrates in Cambodia, as even the largest and more noticeable insects such as *E. siamensis* are poorly documented. Fortunately, studies initiated by the CEI in 2015 are beginning to reduce this knowledge gap.

The specimens have been deposited in the collection of the CEI and include the following information: two males (accession no. CEI-004124, CEI-004125) "Cambodia, Kampong Speu Province, Chambok Ecotourism, 11°22.31.1 N, 104°06.47.3 E, 111 m above sea level, 04.X.2018, Phauk, McElrath, CEI team & BIOs stu., CA0106, Light trap, S.N., Forest, rain forest, Eco-tour".

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References

Allen, G. (2019) [*Live Image of Eupatorus siamensis]*. Https://www.facebook.com/photo/?fbid=2107271872902211&set=pcb.10157095789443393 [Accessed 6 June 2021].

Beutel, R.G. & Leschen, R.A.B. (2016) *Handbook of Zoology. Anthropoda: Insecta. Coleoptera, Beetles. Morphology and Systematics (Archostemata, Adephaga, Myxophaga, Polyphaga Partim)*. Volume 1. Walter de Gruyter, Berlin, Germany.

Chhorn S., Chan B., Sin S., Doeurk B., Chhy T., Phauk S. & Sor R. (2020) Diversity, abundance and habitat characteristics of mayflies (Insecta: Ephemeroptera) in Chambok, Kampong Speu Province, southwest Cambodia. *Cambodian Journal of Natural History*, **2020**, 61–68.

Ek-Amnuay, P. (2008) *Beetles of Thailand*. Siam Insect Zoo, Bangkok, Thailand.

Jameson, M.L. & Drumont, A. (2013) Aroid scarabs in the genus *Peltonotus* Burmeister (Coleoptera, Scarabaeidae, Dynastinae): key to species and new distributional data. *Zookeys*, **320**, 63–95.

Lonn P. (2013) Can community-based ecotourism improve local livelihoods? A case study of Chambok community-based ecotourism, southwest Cambodia. *Cambodia Development Review*, **17**, 1–7.

Moskalenko, S. (2017) A new subspecies of *Eupatorus gracillicornis* Arrow, 1908 from Southern Vietnam (Coleoptera, Scarabaeidae, Dynastinae). *Insecta Mundi*, **0580**, 1–10.

Pathomwattananurak, W.N., Jeenthong, T. & Tasen, W. (2019) To the knowledge of the subfamily Dynastinae (Coleoptera: Scarabaeidae) from Thailand. *Far Eastern Entomologist*, **393**, 1–10.

Prandi, M. & Grossi, P.C. (2021) A new species of *Eupatorus* Burmeister, 1847 related to *Eupatorus birmanicus* Arrow, 1908 from southwestern China (Coleoptera: Scarabaeidae: Dynastinae). *Zootaxa*, **4966**, 029–040.

Sin S., Chhorn S., Doeurk B., Hak K., Ith S., Phauk S. & Sor R. (2020) Diet preferences of insectivorous bats (Mammalia: Chiroptera) in Chambok, Kampong Speu Province, Cambodia. *Cambodian Journal of Natural History*, **2020**, 69–77.

Thinh T.H. & Tru H.V. (2008) Phân bò càc loài côn trùng cò già tri bào tòn ò trung bô và tây nguyen [Insects of conservation concern from Central Vietnam]. Hôi nghi côn trùng hoc toàn quòc làn thu 6- Hanoi, 2008 [In Vietnamese].

Short Communication

First record of the carrion beetle *Diamesus osculans* (Vigors, 1825) (Coleoptera: Silphidae) in Cambodia

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Members of the Silphidae are commonly known as carrion beetles (Sikes, 2008). These provide essential services by feeding on decaying organic matter such as dead animals and recycling this in terrestrial ecosystems (Shubeck & Blank, 1982; Wolf & Gibbs, 2004; Oliva & Di-Iorio, 2008; Kalinova *et al*., 2009; Midgley *et al*., 2010; Dekeirsschieter *et al*., 2011), though not all species feed on carrion (Anderson *et al*., 1984; Sikes, 2008). For example, adults of *Silpha* spp. and *Dendroxena* spp. consume the eggs and larvae of flies, snails, caterpillars and slugs, whereas *Aclypea* spp. feed on plants (Sikes, 2008). Some silphid species are attracted to fungi and dung (Hastir & Gaspar, 2001; Sikes, 2005), whereas the remaining species are necrophagous (Hastir & Gaspar, 2001; Sikes, 2005, 2008) and prefer vertebrate carcasses including pigs, rodents and birds (Shubeck & Blank, 1982; Kalinova *et al*., 2009). These are located using sensitive chemoreceptors on the antennal club (Boeckh, 1962; Ernst, 1972; Shubeck & Blank, 1982; Smith & Heese, 1995; Kalinova *et al*., 2009) up to distances of several kilometres (Petruška, 1975).

Carrion beetles are relatively easily recognized by their flattened bodies, large size (10–35 mm in length), lack of ocelli and elytra always punctate, with 6–7 differentiated ventrites (Hansen, 1997). The family includes two subfamilies which comprise approximately 187 valid species in 23 genera (Dobler & Muller, 2000; Sikes, 2008; Majka, 2011; Newton, 2021). The first, the Silphinae, includes 14 genera, four subgenera and about 113 species (Newton, 2021), whereas the second, the Nicrophorinae, comprises 74 species and includes the well-known burying beetles *Nicrophorus* spp. (Sikes, 2008).

Only two species of carrion beetles have been previously documented in Cambodia: *N. nepalensis* Hope, 1831 and *Necrophila (Calosilpha) cyaniventris* (Motschulsky, 1870). These were reported from Phumi Kalai Thum in Ratanakiri Province (Fig. 1) (Nishikawa & Sikes, 2008; Růžička *et al*., 2015) and both species are widely distributed, occuring from India to Southeast Asia. We present the first country record of an additional species, *Diamesus osculans* (Vigors, 1825), based on a single specimen and photographs of additional individuals which were identified following Hope (1840), Williams (1981) and Peck (2001). We also provide an identification key for the three species of Silphidae now known in Cambodia.

Subfamily Silphinae, Genus *Diamesus* Hope, 1840, *Diamesus osculans* (Vigors, 1825). Synonyms: *D. reductus* Pic, 1917, *Necrodes bifasciatus* Dejean, 1833.

Material examined: one female (accession no. CEI-004123, Fig. 2), Phnom Khnang Phsa, R'leak Korng Cherng village, Ta Sal commune, Aural district, Kampong Speu Province, 11°46.731' N, 103°46.592' E (Fig. 1), 869 m above sea level (a.s.l.), 13.VIII.2020, collected by Phauk S. and CEI team using a light trap (LT02) situated in pine forest near a stream.

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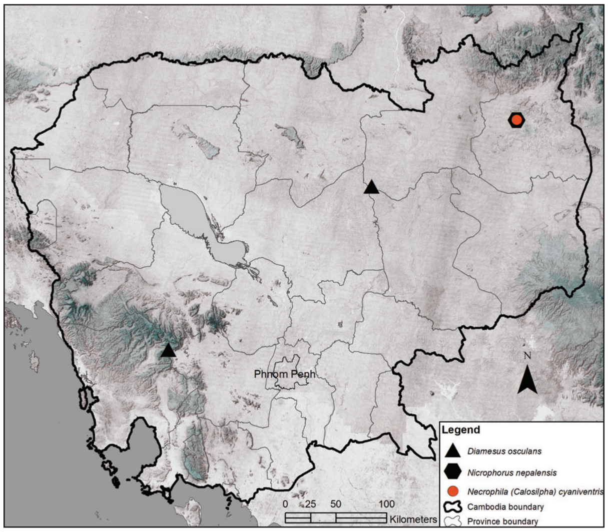

Fig. 1 Existing records of silphid taxa in Cambodia.

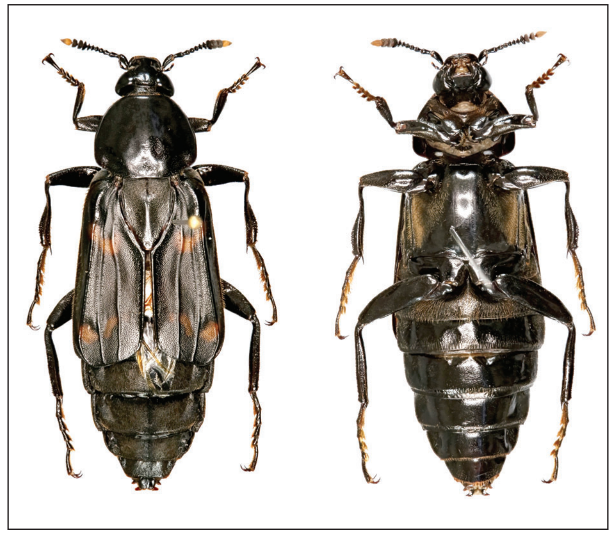

Fig. 2 Dorsal (left) and ventral (right) view of adult female *Diamesus osculans* (Vigors, 1825) collected at Phnom Khnang Phsa, Kampong Speu Province.

Fig. 3 Live *Diamesus osculans* scavenging on a wild pig carcass in Prey Lang Wildlife Sanctuary, Stung Treng Province (© Hun Seiha).

Additional records: Observed by Mr. Hun Seiha on 15.XII.2020 (https://www.inaturalist.org/observations/93230483; Fig. 3), Prey Lang Wildlife Sanctuary, Stung Treng Province, 13°14.705′ N, 105°37.278′ E (Fig. 1), 129 m a.s.l.

Description: Body black and dorsoventrally flattened with yellow setae, elytra shortened and not covering the four terminal segments of the abdomen. These characters match the specimen of *D. osculans* described from India (Peck, 2001). Pronotum finely punctate, two irregular, orange maculae on each elytron. Antenna with 11 antennomeres, basal segment of club black, further two segments of club greyish, segment XI orange at base with red spot on apex. Setae on mesotarsus longer than on other surfaces, metafemora weakly expanded. Body large, length 42 mm (Fig. 2).

Ecology: Phnom Khnang Phsa is situated on the border of the Koh Kong and Kampong Speu provinces in the Central Cardamom Mountains National Park (Fig. 1). Habitats in the area include grasslands surrounded by patches of evergreen and pine forests and elevations reach up to 1,030 m a.s.l. Our specimen was captured using a light trap and numerous individuals were photographed scavenging on a carcass of a wild pig *Sus scrofa* Linnaeus, 1758 in the Stung Treng portion of Prey Lang Wildlife Sanctuary (Fig. 3). Prey Lang represents one of the largest areas of lowland evergreen forest remaining in the Indo-Burma region (Hayes *et al*., 2015).

Distribution: Diamesus osculans is a widespread species, occurring in Sri Lanka to southern India, China, Philippines, Vietnam, Laos, Thailand, Malaysia, Indonesia (Sumatra, Java, Borneo, Papua), Papua New Guinea, New Britain, and Australia (Růžička *et al*., 2000, 2002; Peck, 2001). Our records represent the first for Cambodia.

Carrion beetles have received very little attention in Cambodia compared to other countries in Asia such as India with ≈29 known species, China with ≈74 known species, Japan with ≈27 known species, North Korea with

≈24 known species, South Korea with ≈26 known species and Nepal with ≈20 known species (Růžička *et al*., 2011, 2015; Růžička, 2021). The genus *Diamesus* comprises just two taxa, namely *D. bimaculatus* Portevin, 1914 which is endemic to Taiwan (Peck, 2001) and *D. osculans* which is widely distributed. *Diamesus osculans* has been recorded at 235 m in Myanmar and up to 1,200 m in Laos (Růžička *et al*., 2000), whereas we observed the species at 869 m a.s.l. (Phnom Khnang Phsa) and 129 m a.s.l. (Prey Lang) in Cambodia.

Our study contributes to understanding of carrion beetles in Cambodia. These provide important services in decomposing and recycling organic materials in natural ecosystems and further inventory studies should be undertaken to improve knowledge of their diversity and occurrence in the country.

Key to the three species of Silphidae known in Cambodia

1. Elytra completely without posterior macula, blue metallic glossy. Pronotum orange in dorsal view……………………*Necrophila (Calosilpha) cyaniventris*

1′. Elytra with posterior macula, black metallic. Pronotum black in dorsal view..2

2. Usually with orange spot medially on frons. Apical 3 segments of antennal club orange. Elytra with posterior macula reaching dorsal margin.......*Nicrophorus nepalensis*

2′. Without any orange spot on frons. Apical 2 segments of antennal club grayish, ultimate segment orange at base and apex with a red spot. Elytra with posterior macula not reaching dorsal margin....................*Diamesus osculans*

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We are grateful to the rangers of the Central Cardamom Mountains National Park and local porters from R'leak Korng Cherng village for their help during our survey and thank Hun Seiha for allowing us to include his record of *D. osculans*. We also thank the Swedish International Development Cooperation Agency (under the Cambodia Bilateral Programme Contribution grant, no. 5410004501) and the Centre for Biodiversity Conservation for financial and other support.

References

Anderson, R.S. & Peck, S.B. (1984) Binomics of neartic species of *Aclypea* Reitter: phytophagous "carrion" beetles (Coleoptera: Silphidae). *Pan-Pacific Entomologist*, **60**, 248–255.

Boeckh, J. (1962) Elektrophysiologische Untersuchungen an einzelnen Geruchsrezeptoren auf den Antennen des Totengräbers (*Necrophorus*, Coleoptera). *Zeitschrift für vergleichende Physiologie*, **46**, 212–248.

Dekeirsschieter, J., Verhaggen, F., Lognay, G. & Haubruge, E. (2011) Large carrion beetles (Coleoptera, Silphidae) in western Europe: a review. *Biotechnologie, Agronomie, Société et Environnement*, 15, 435–447.

Dobler, S. & Müller, J.K. (2000) Resolving phylogeny at the family level by mitochondrial cytochrome oxidase sequences: phylogeny of carrion beetles (Coleoptera, Silphidae). *Molecular Phylogenetics and Evolution*, **15**, 390–402.

Ernst, K.D. (1972) Sensillum coelosphaericum, die Feinstruktur eines neuen olfaktorischen Sensillentyps. *Zeitschrift für Zellforschung und Mikroskopische Anatomie*, **132**, 95–106.

Hansen, M. (1997) Phylogeny and classification of the staphyliniform beetle families (Coleoptera). *Biologiske Skrifter*, **48**, 1–399.

Hastir, P. & Gaspar, C. (2001) Diagnose d'une famille de fossoyeurs: les Silphidae. *Notes fauniques de Gembloux*, **44**, 13–25.

Hayes, B., Khou E.H., Neang T., Furey, N., Chhin S., Holden, J., Hun S., Phen S., La P. & Simpson, V. (2015) *Biodiversity Assessment of Prey Lang: Kratie, Kampong Thom, Stung Treng and Preah Vihear Provinces*. Conservation International, Winrock International, USAID, Phnom Penh, Cambodia.

Hope, F.W. (1840) *The Coleopterist's Manual: Part the Third, Containing Various Families, Genera and Species of Beetles Recorded by Linneus and Fabricius, Also Descriptions of Newly Discovered and Unpublished Insects*. J.C. Bridgewater, Bowdery and Kerby, London, UK.

Kalinova, B., Podskalská, H., Růžička, J. & Hoskovec, M. (2009) Irresistible bouquet of death—how are burying beetles (Coleoptera: Silphidae: *Nicrophorus*) attracted by carcasses. *Naturwissenschaften*, **96**, 889–899.

Majka, C.G. (2011) The Silphidae (Coleoptera) of the maritime provinces of Canada. *Journal of the Acadian Entomological Society*, **7**, 83–101.

Midgley, J.M., Richards, C.S. & Villet, M.H. (2010) The utility of Coleoptera in forensic investigations. In *Current Concepts in Forensic Entomology* (eds J. Amendt, M.L. Goff, C.P. Campobasso & M. Grassberge), pp. 57–68. Springer, Dordrecht, Netherlands.

Newton, A.F. (2021) StaphBase: Staphyliniformia world catalog database (version November 2018). In *Species 2000 & ITIS Catalogue of Life, 2020-06-04 Beta* (eds Y. Roskov, G. Ower, T. Orrell, D. Nicolson, N. Bailly, P.M. Kirk, T. Bourgoin, R.E. Dewalt, W. Decock, E. van Nieukerken & L. Penev). Https://www.catalogueoflife.org/data/browse?taxon¬Key=626Y9 [accessed 30 August 2021].

Nishikawa, M. & Sikes, D.S. (2008) New records and range extensions of the Asian Silphidae (Coleoptera). *Special Publication of the Japan Coleopterological Society (Osaka)*, **2**, 127–143.

Oliva, A. & Di-Iorio, O.R. (2008) Silphidae. In *Biodiversidad de Artropodos Argentinos, Volume 2* (eds L.E. Claps, G. Debandi & S. Roig-Junent), pp. 461–470. Sociedad Entomologica Argentina, Buenos Aires, Argentina.

Peck, S.B. (2001) Review of the carrion beetles of Australia and New Guinea (Coleoptera: Silphidae). *Australian Journal of Entomology*, **40**, 93–101.

Petruska, F. (1975) The effect of predominating winds on the flight of some species of beetles from the group of Silphidae into pitfall traps (Col. Silphidae). *Acta Universitatis Palackianae Olomucensis, Facultas Rerum Naturalist*, **51**, 55–175.

Růžička, J. (2021) New records of carrion beetles (Coleoptera: Silphidae) from Bangladesh, India and Nepal. *Klapalekiana*, **57**, 137–145.

Růžička, J., Háva, J. & Schneider, J. (2000) Taxonomical and distributional notes on Oriental Silphidae, with description of *Nicrophorus sausai* sp. n. (Insecta: Coleoptera). *Reichenbachia*, **33**, 377–384.

Růžička, J., Qubaiova, J., Nishikawa, M. & Schneider, J. (2015) Revision of Palearctic and Oriental *Necrophila* Kirby et Spence, part 3: subgenus *Calosilpha* Portevin (Coleoptera: Silphidae: Silphinae). *Zootaxa*, **4013**, 451–502.

Růžička, J., Schneider, J., Sikes, D.S. & Háva, J. (2002) Distributional records of carrion beetles (Coleoptera: Silphidae) from China, Part II. *Reichenbachia*, **38**, 227–252.

Růžička, J., Šípková, H. & Schneider, J. (2011) Notes on carrion beetles (Coleoptera: Silphidae) from India. *Klapalekiana*, **47**, 239–245.

Shubeck, P.P. & Blank, D.L. (1982) Carrion beetle attraction to buried fetal pig carrion (Coleoptera: Silphidae). *The Coleopterists' Bulletin*, **36**, 240–245.

Sikes, D.S. (2005) Silphidae Latreille, 1807. In *Handbook of Zoology, Vol. 4: Arthropoda: Insecta* (eds N.P. Kristensen & R.G. Beutel), pp. 288–296. Walter de Gruyter, Berlin, Germany.

Sikes, D.S. (2008) Carrion beetles (Coleoptera: Silphidae). In *Encyclopedia of Entomology* (ed. J.L. Capinera), pp. 749–758. Springer, London, UK.

Smith, R.J. & Heese, B. (1995) Carcass selection in a high altitude population of the burying beetle, *Nicrophorus investigator* (Silphidae). *The Southwestern Naturalist*, **40**, 50–55.

Williams, G. (1981) Records of the carrion beetle '*Diamesus osculans*' Vigor (Silphidae: Coleoptera) from New South Wales. *The Australian Entomologist*, **8**, 47.

Wolf, J.M. & Gibbs, J.P. (2004) Silphids in urban forests: diversity and function. *Urban Ecosystems*, **7**, 371–384.

A second population assessment of the Critically Endangered giant ibis *Thaumatibis gigantea* in Siem Pang Wildlife Sanctuary, Cambodia

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មូលន័យសង្ខេប

ត្រយ៉ងយក្ស *Thaumatibis gigantea* ជាបក្សីដ៏កម្រជិតផុតពូជបំផុត ដែលចំនួនសត្វពេញវ័យនៅសេសសល់មានតិចជាង ២០០ក្បាល ក្នុងនោះវត្តមានរបស់វាភាគច្រើនមាននៅកម្ពុជា។ ការយល់ដឹងពីទំហំ និងបម្រែបម្រួលនៃចំនួនរបស់បក្សីប្រភេទនេះ គឺពិតជាសំខាន់ណាស់ក្នុងការគ្រប់គ្រង និងអភិរក្សប្រកបដោយភាពជោគជ័យ។ យោងតាមការស្រាវជ្រាវនៅតាមត្រពាំងពីខែកុម្ភៈ ដល់ខែមេសា ឆ្នាំ ២០២០ និងការស្វែងរកនិងពិនិត្យតាមដានសំបុកប្រចាំឆ្នាំពីខែមិថុនា ដល់ខែ កញ្ញា ក្នុងអំឡុងពីឆ្នាំ ២០១៣ ដល់ ២០២០ ធ្វើឱ្យយើងអាចផ្តល់ទិន្នន័យប៉ាន់ប្រមាណចំនួនត្រយ៉ងយក្សជាលើកទី២ នៅក្នុងដែនជម្រកសត្វព្រៃសៀមប៉ាង។ ជាមធ្យមមានត្រយ៉ងយក្សចំនួន ៥០.៦ក្បាល ត្រូវបានរកឃើញក្នុងខែនីមួយៗពីការស្រាវជ្រាវនៅតាមត្រពាំង ហើយចំនួនដែលរាប់ឃើញច្រើនជាងគេ (៥៨ក្បាល) គឺស្ថិតក្នុងខែមីនា។ សំបុកសរុបចំនួន ៧៨សំបុក ត្រូវបានរកឃើញក្នុងអំឡុងរដូវបង្កាត់ពូជសរុបទាំង ០៨រដូវចាប់ពីឆ្នាំ២០១៣ ដល់ ២០២០។ ចំនួនសំបុកដែលត្រូវបានរកឃើញជារៀងរាល់ឆ្នាំមានការកើនឡើង ហើយ ៧៤%នៃសំបុកទាំងនោះទទួលបានជោគជ័យ។ កូនត្រយ៉ងយក្សចំនួន ៨៣ក្បាលបានហើរចេញពីសំបុកក្នុងអំឡុងពេលនៃការសិក្សានេះ ដោយគិតជាមធ្យមមានកូនចំនួន ១.០៦ក្បាល បានហើរចេញពីក្នុងមួយសំបុក (សម្រាប់សំបុកទាំងអស់) និងចំនួន ១.៤៣ក្បាល បានហើរចេញពីក្នុងមួយសំបុក (ចំពោះសំបុកដែលជោគជ័យ)។ លទ្ធផលរកឃើញនេះបង្ហាញថា មានត្រយ៉ងយក្សពេញវ័យយ៉ាងតិចចំនួន ៥៣ក្បាល (២៦គូ) មានវត្តមានក្នុងដែនជម្រកសត្វព្រៃសៀមប៉ាង តែយ៉ាងណាក្តី ចំនួនជាក់ស្តែងរបស់វាអាចមានចំនួនច្រើនជាងនេះ ព្រោះការសិក្សានេះធ្វើឡើងបានតែ២៥%នៃទីជម្រកសមស្របទាំងអស់របស់វាតែប៉ុណ្ណោះ។ ការរកឃើញនេះប្រហែលគ្នាទៅនឹងការប៉ាន់ប្រមាណទិន្នន័យត្រយ៉ងយក្សដែលត្រូវបានស្រាវជ្រាវកាលពីឆ្នាំ២០១៤ ហើយទិន្នន័យនេះចង្អុលបង្ហាញថាចំនួនត្រយ៉ងយក្សអាចនឹងមានវត្តមានថេរ ក្នុងដែនជម្រកសត្វព្រៃសៀមប៉ាង។ មូលហេតុដែលធ្វើឱ្យសំបុកត្រយ៉ងយក្សបរាជ័យនៅមិនទាន់ត្រូវបានគេដឹងនៅឡើយ។ អត្រារស់រានមានជីវិតរបស់កូនត្រយ៉ងយក្សក្រោយពីហើរចេញពីសំបុក និងសមាមាត្រប្រចាំឆ្នាំនៃសត្វត្រយ៉ងយក្សជំទង់ដែលអាចបង្កាត់ពូជនៅក្នុងចំនួនរបស់វានៅក្នុងតំបន់នេះក៏នៅមិនទាន់ត្រូវបានគេដឹងនៅឡើយទេ។ ការសិក្សាស្រាវជ្រាវបន្ថែមតាមរយៈការបំពាក់ឧបករណ៍តាមដានទៅលើសត្វត្រយ៉ងយក្សជំទង់ អាចជួយបំពេញចន្លោះខ្វះខាតនៃចំណេះដឹងទាំងនេះបាន។

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Abstract

The Critically Endangered giant ibis *Thaumatibis gigantea* numbers fewer than 200 mature individuals that mainly occur in Cambodia. Understanding the size and trends of remaining populations of the species are crucial to its successful conservation management. Based on waterhole surveys in February–April 2020 and annual nest searches and monitoring in June–September of 2013–2020, we provide a second estimate for giant ibis populations in Siem Pang Wildlife Sanctuary. On average, 50.6 giant ibises were detected each month in our waterhole surveys and most birds (58) were detected in March. A total of 78 nests were located over the eight breeding seasons in 2013–2020. Numbers of nests found each year increased and 74% of all nests proved successful. This led to 83 chicks fledging during the study period, giving a mean figure of 1.06 chicks fledged per nest for all nests and 1.43 for successful nests alone. Our results indicate a minimum of 53 mature giant ibises (26 pairs) occur in Siem Pang Wildlife Sanctuary, although the actual population could be larger as only 25% of suitable habitats at the site were sampled. This is similar to a comparable estimate made in 2014 and suggests giant ibis populations may be stable in Siem Pang Wildlife Sanctuary. While encouraging, the reasons for failures of giant ibis nests remain incompletely known. The post-fledging survival rate of juvenile giant ibises also remains unknown, as does the proportion of juveniles annually recruited into the local breeding population. Studies that deploy tracking devices on juvenile birds could help to reduce these knowledge gaps.

Keywords Auditory detections, giant ibis, visual detections, waterholes.

Introduction

The giant ibis *Thaumatibis gigantea* is the largest species in the worldwide ibis family Threskiornithidae and is listed as Critically Endangered by the IUCN (BirdLife International, 2018). Its taxonomic position in a monotypic genus further increases its conservation importance. The giant ibis has an extremely small population estimated at 194 individuals which has undergone an extremely rapid decline as a result of hunting, disturbance and lowland deforestation. It is likely to continue to decline rapidly owing to on-going deforestation and human disturbance (BirdLife International, 2018). The range of the species has also contracted resulting in its extinction in Thailand and near extinction in Laos and Vietnam, such that recent records from the latter countries probably refer only to spill-over from Cambodia (Eames *et al*., 2003). As a result, the species may be considered as confined to Cambodia for conservation purposes. The latter population is currently confined to protected areas in northern and eastern Cambodia including the Chhep, Kulen Promtep, Siem Pang, Lomphat, Phnom Prich, Seima and Srepok wildlife sanctuaries (Loveridge & Ty, 2015).

A ten-year action plan for the giant ibis has been published for the period 2015–2025 (Loveridge & Ty, 2015). The third objective of this plan specifies the need to "develop a unified census method", "conduct census of priority sites" and "identify and map priority sites within protected areas to inform site management plans" (Loveridge & Ty, 2015). The first systematic population assessment for giant ibises comprised a survey (rather than a census) undertaken in Siem Pang Wildlife Sanctuary (SPWS) (Ty *et al*., 2016). The authors estimated 49.5 ± 10 mature birds occurred at the site, but did not qualify the basis for their error margin. The same methods were later employed at Lomphat Wildlife Sanctuary where 40 giant ibises were estimated to occur (Pin *et al*., 2020). No error margin was provided for the latter. We report here on a waterhole (trapeang) survey undertaken at SPWS in 2020 and evaluate the breeding success of giant ibises at the site between 2013–2020 to determine if any changes have occurred in its populations.

Methods

Our study was conducted in SPWS which encompasses 1,337 km^2 in Stung Treng Province, northeast Cambodia (140°10'N, 106°13'E; Fig 1). The sanctuary combines the former Siem Pang and Prey Siem Pang Khang Lech wildlife sanctuaries and was designated on 6 November 2019. The site is contiguous with the Xe Pian National Protected Area (Laos) and the Virachey and Veun Sai-Siem Pang national parks in Cambodia and forms part of a 11,217 km^2 network of protected areas in Laos, Cambodia and Vietnam, one of the largest nominally protected landscapes in the Mekong basin (Loveridge *et al*., 2018). The conservation importance of SPWS is well documented and the site supports populations of seven Critically Endangered taxa comprising five bird species, one mammal species and one reptile species (BirdLife International, 2012; Ty *et al*., 2016; Loveridge *et al*., 2017, 2018). Approximately half of the site consists of deciduous dipterocarp forests which include over 200 waterholes and stretches of riverine forest that provide

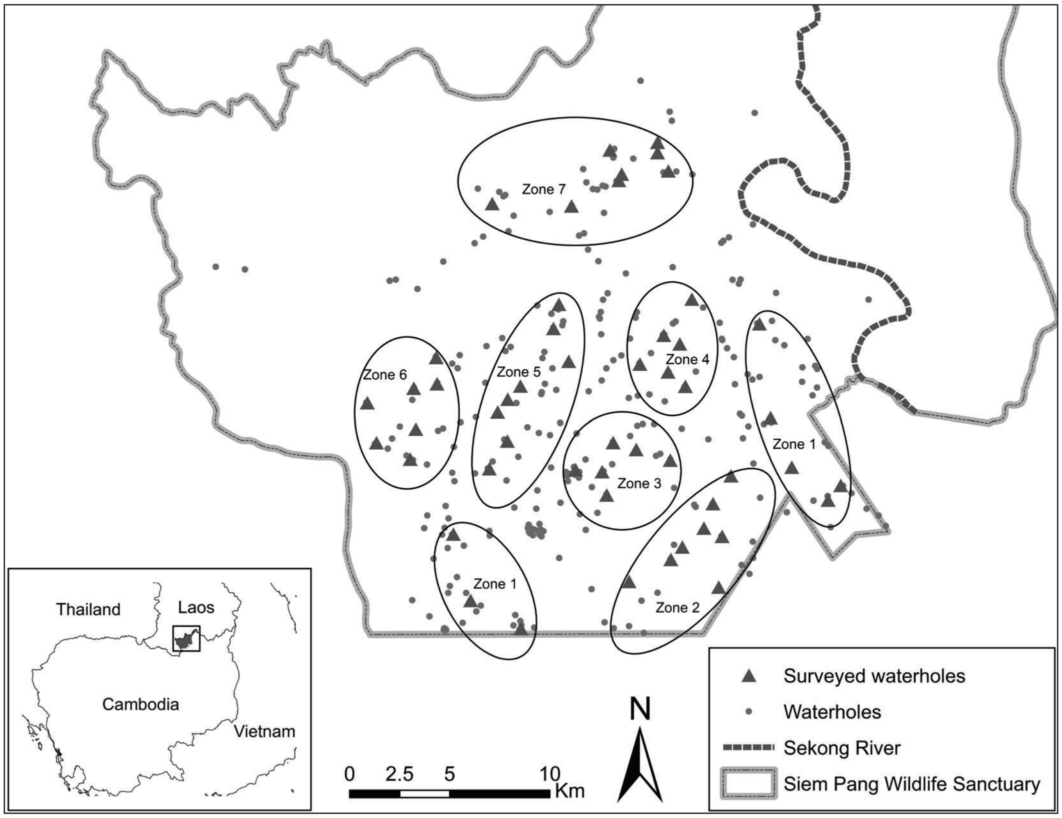

Fig. 1 Location of Siem Pang Wildlife Sanctuary and waterhole zones selected for giant ibis surveys in 2020.

suitable habitat for giant ibises. The local climate is monsoonal with a pronounced wet and dry season, which occur from May to October and from November to April, respectively. Detailed accounts of the biodiversity, vegetation and climate of SPWS are provided by BirdLife International (2012) and Ty *et al*. (2016).

Waterhole surveys

Our survey was based on observations at waterholes (Fig. 1) and adopted the methods developed by Ty *et al*. (2016). Waterholes provide important foraging habitats for giant ibises, especially during the dry season (Keo, 2008). The survey was conducted from the 17th to the 23rd day of each month in February–April 2020. A team of ten surveyors familiar with giant ibis were trained in the survey protocol and GPS and compass use. Training was not provided in distance estimation and surveyors estimated their distance to calling birds based on their personal experience.

To maximize detections, we focused on surveying waterholes that were visited by giant ibises between 2015 and 2019. Following Ty *et al*. (2016), we did not attempt to survey all known waterholes at SPWS since these number over 200. Rather, we identified 76 waterholes where at least one detection of giant ibis occurred during the dry seasons (January–April) of 2015–2019. Fifty-one of these waterholes were randomly selected for survey, similar to the sample size of 49 waterholes selected by Ty *et al*. (2016). To facilitate the field survey, each waterhole was assigned to one of seven zones. Each zone was located at least 3 km from its nearest neighbour and included six to eight waterholes (Fig. 1).

A single zone was surveyed over the course of one day by the field team and overall, each waterhole was visited once each month by observers in pairs or individually. Giant ibis frequently call from their roosts at SPWS from 0500 to 0600 hrs, then cease calling and travel to foraging sites around 0600 hrs (Ty *et al*., 2016). Because disturbance caused by human activity generally begins around 0700 hrs (Ty *et al*., 2016), our counts were confined to 0530–0700 hrs to coincide with calling activity during the least disturbed period of the day. To avoid disturbance, our observers approached waterholes slowly and chose concealed vantage points affording a clear view of the entire waterhole before 0530 hrs. Data recorded on visual detections of giant ibises comprised: number of

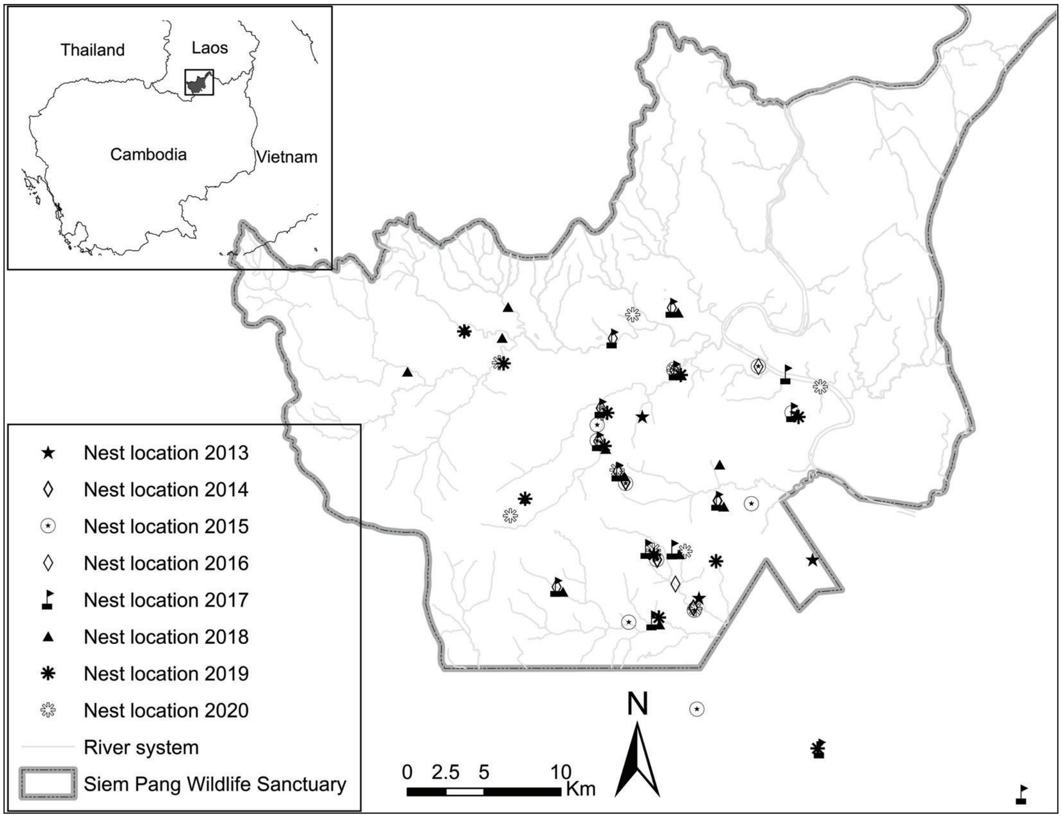

Fig. 2 Locations of giant ibis nests monitored during the 2013–2020 breeding seasons in Siem Pang Wildlife Sanctuary.

individuals observed; time of observation; duration of stay at waterhole; and entrance and exit direction, time and flight height. The identity of any birds flushed on approach to a waterhole was also noted. Data recorded on auditory detections comprised the time, direction and bearing of call and estimated distance from the observer.

Nest monitoring

The third objective of the action plan for giant ibis advocates research efforts including nest monitoring to inform conservation actions (Loveridge & Ty, 2015). Nest monitoring for giant ibises in SPWS predates this guidance, having begun in 2013. More specifically, we undertook searches for giant ibis nests from June to September each year in 2013–2020.

Giant ibises begin mating in May and June and build nests from late June until early August (Keo, 2008). Our surveys were divided into two phases. Because giant ibises show high fidelity to their nest sites (BirdLife International, unpublished data), the first phase involved checking nest locations found in the previous season, whereas the second phase comprised searches for new nests in new areas. During the first phase, we first checked the locations of nests from the previous season every two weeks to minimize disturbance. This was undertaken from June to July each year and once confirmed, the nests were observed for at least 30 minutes once a fortnight from incubation onwards. This monitoring increased to one visit per week from the beginning of the hatching period until fledging in an attempt to determine the dates of both. Information on human disturbance and predation events were also recorded. Nests were considered successful if their chicks fledged and failures if they did not.

Searches for new nests were undertaken from July to September each year. Adult giant ibises are more conspicuous during this period as they are active and frequently call. Following Ty *et al.* (2016), listening posts were employed to search areas of suitable habitat for nests which comprised habitats in the vicinity of waterholes, rivers and streams (Fig. 2) (Keo, 2008; Wright *et al.*, 2012). Searches were conducted over five- to seven-day periods by a team of seven or more trained observers. These were split into groups of two or three observers and each group surveyed separate locations with a ≥ 2km radius from 0500 hrs every day to ensure detection of giant ibis calls made from their roosts. The direction and distance of each calling bout was noted by the observers, who then progressively navigated towards the calling bird. In each instance, observers took care not to disturb either member of the pair and remained alert to alarm calls. Upon finding a nest, the observers recorded its location and estimated the height and identity of the nest tree. Once confirmed, all new nests were monitored as previously outlined.

Data analysis

Waterhole surveys: Following Ty *et al*. (2016) and Pin *et al*. (2020), we screened our data to remove potential double-counts of the same individual in vocal and sight detections as follows: 1) when birds were observed flying from the same direction as previously detected calling birds, one of the detections was excluded; 2) vocal detections of individual birds by the same observers within a 45° radius were considered the same individual unless they occurred at the same time. Potential double counts of individual birds moving between waterholes on the same morning (as suggested by their timing) were also excluded. More specifically, we first considered the time a bird was sighted at a given location, the time it departed for another location and the bearing on which it departed. If a bird was then observed flying from the direction in which one had already been recorded, this record was excluded from the count for the new location.

Following these adjustments, a maximum monthly count was calculated for each zone following Ty *et al*. (2016) by summing the number of unique individuals recorded by visual and auditory detections. A minimum monthly count was also calculated for each zone which was based on auditory detections alone (as these provided higher counts). The actual estimate of monthly detection for each zone was taken as the mid-point between these two figures in providing a conservative estimate combining both types of detections (Ty *et al*., 2016).

Nest monitoring: Following Pin *et al.* (2020), we summed the number of nests found each year, distinguishing the number of successful nests, the number of fledged chicks recorded at each nest, and the total number of giant ibis recorded (including adults and young seen at nests). We estimated the total number of giant ibis recorded by summing the number of fledged chicks and adults seen at nests during the monitoring period. The average number of chicks per nest was estimated by dividing the total number of fledged chicks by the total number of successful nests (Pin *et al*., 2020).

Results

Waterhole surveys

Following removal of 36 potential double-counts from our data for February, 41 from March and 43 from April, our minimum and maximum counts for giant ibises were 41 and 51 in February, 48 and 58 in March and 30 and 43 in April, respectively (Table 1). Our monthly population estimates were consequently of 46 giant ibises in February, 53 in March and 36.5 in April. Total numbers of visual detections were similar between months, whereas figures for auditory detections were similar in February and March but lower in April. The mean monthly total for detections (auditory and visual) was 50.6 birds. The greatest number of giant ibises were recorded at waterholes in zone seven (Fig. 1).

Nest monitoring

A total of 78 giant ibis nests were found and monitored during the study period (Table 2, Fig. 3). The number of nests found each year increased from two in 2013 to a maximum of 16 in 2018 and decreased in 2019 and 2020. Fifty-eight (74%) of the 78 nests were successful and a total of 83 chicks fledged over the study period. An average of 1.06 fledged chicks per nest was recorded for all nests monitored, whereas the equivalent figure for successful nests only was 1.43. On average, 7.25 of the 9.75 nests found each year were successful, with 10.5 chicks fledging per study year.

Twenty-six percent of nests were not successful, mostly for unknown reasons. One chick was found dead in a nest, whereas another was found dead under the nest tree. Broken eggs were found under a nest tree on six occasions, whereas bad weather (wind and rain) caused nest failure on one occasion and disturbance from nearby logging on two occasions. Predation was not observed but claw marks made by the Southeast Asian monitor lizard *Varanus nebulosus* were observed on a nest tree on two occasions (Mem Mai pers. obs.). A party of long-tailed macaques *Macaca fascicularis* were also observed 70 m from a failed nest on another occasion. The best documented case of nest destruction by another species involved a juvenile slender-billed vulture *Gyps tenuirostris* which nested in the same tree as a giant ibis nest at Jong Brolay Kondal (14°10′35″N, 106°16′5″E) in August 2020. The fledged juvenile returned to the nest tree to roost on 3 August, but did so in the giant ibis nest, resulting in its destruction (Fig. 4).

Table 1 Corrected figures for visual and auditory detections of giant ibises in Siem Pang Wildlife Sanctuary in February–April 2020.

Zone	No. of waterholes	February		March		April	
		Visual Detections	Auditory Detections	Visual Detections	Auditory Detections	Visual Detections	Auditory Detections
1	8	2	0	0	4	2	4
2	7	2	10	0	6	1	4
3	7	0	2	3	2	0	4
4	6	0	5	3	7	2	5
5	8	0	9	4	8	3	7
6	7	1	3	0	5	3	0
7	8	5	12	0	16	2	6
subtotal	**51**	**10**	**41**	**10**	**48**	**13**	**30**
Total		**51**		**58**		**43**	

Table 2 Summary of nest monitoring results for giant ibises in Siem Pang Wildlife Sanctuary, 2013–2020.

Breeding season	Nests found	Successful nests	No. of adults	No. of chicks fledged	Total individuals
2013	2	1	4	1	5
2014	4	3	8	4	12
2015	11	6	22	6	28
2016	9	9	18	16	34
2017	15	13	30	19	49
2018	16	12	32	16	48
2019	11	7	22	11	33
2020	10	7	20	10	30
Total	**78**	**58**	**156**	**83**	**239**

Discussion

Our study is the second attempt to determine the population size of giant ibises in SPWS. The first attempt was undertaken in 2014 and provided a minimum population estimate of 49.5 ± 10 adults (Ty *et al.*, 2016). Unlike a similar study in Lomphat Wildlife Sanctuary (Pin *et al.*, 2020), total numbers of adult giant ibis derived from our waterhole surveys and nest monitoring differed markedly. For example, the results of our waterhole survey suggest a minimum of 53 ± 5 mature giant ibises (26 pairs) occurred at SPWS in 2020. This figure is similar to the 2014 estimate of 49.5 birds (Ty *et al*., 2016). In contrast, our nest monitoring data for the same year suggested a minimum population of 20 adults and 10 fledglings, giving a total of 30 individuals. This is based on ten nests being found and assumes the species is monogamous.

During our study design, we selected waterholes known to be frequented by giant ibises due to time and resource constraints. This would bias any attempt to extrapolate our results to larger areas. Notwithstanding this, since we only sampled 51 of the 200 waterholes

Fig. 3 Giant ibises nesting in Siem Pang Wildlife Sanctuary, 29 July 2014 (© Jonathan Eames).

Fig. 4 Juvenile slender-billed vulture in giant ibis nest, Siem Pang Wildlife Sanctuary (© BirdLife International/Mem Mai).

currently known in SPWS, our population estimate would likely have been higher had all of the waterholes were sampled. This also seems probable considering over 3,023 incidental sightings of giant ibises were made in SPWS between 2013 and 2019, an average of 36 sightings per month (BirdLife International, unpublished data).

The timing of our waterhole survey differed slightly from Ty *et al*. (2016) who undertook their field work in January–March and obtained the highest count in February. Our field work was conducted in February–April and obtained the highest combined count in March. Notwithstanding this, our visual detections were highest in April 2020 when the rains began. These precipitated the first yearly emergence of large numbers of frogs which may have stimulated giant ibis activity. This raises the possibility that the February–April might be a more appropriate survey period. Increases in the number of observers and waterholes sampled would likely also lead to a greater proportion of the population being detected. One difficulty experienced with the survey method was distance estimation. As this becomes increasingly subjective beyond 100 m, it would be worth including training and ground-truthing for distance estimation in preparations for future surveys.

The number of nests we found each year differed greatly, ranging from a low of two nests in 2013 to a high of 16 nests in 2018 (Table 2). As the survey team remained largely unchanged during the study period, our team members became more familiar with nest searches and the ecology and breeding behaviour of giant ibises. Similar to the findings of Pin *et al*. (2020) in Lomphat Wildlife Sanctuary, we believe this likely contributed to improved levels of nest detection over time.

During the course of our study, we detected breeding of giant ibises outside of the typical nesting season. In 2016 and 2017 for instance, a giant ibis nest along the Sekong River fledged young in early December. Additionally, a pair of giant ibises were observed building a nest next to the O'Lao'k Stream in early October 2020. If successful, this nest would have fledged in January 2021. As such, continuation of nest searches through October each year might increase the number of nests found in future surveys.

We recorded a nest success rate of 74% (58 of 78 nests) which is lower than the 90% rate (28 of 31 nests) documented at Lomphat Wildlife Sanctuary by Pin *et al*. (2020). The reasons for this difference are not clear. Pin *et al*. (2020) recorded an average figure of 1.53 chicks fledging per nest whereas our average figures were 1.06 for all nests and 1.43 for successful nests alone. These differences cannot be explained by differences in conservation effort between the sites because nest protection efforts were not undertaken at Lomphat Wildlife Sanctuary (Pin *et al*., 2020) whereas the use of nest guardians ceased at SPWS in 2016.

Although 83 giant ibises successfully fledged during our study at SPWS, the causes of nest failures remain incompletely known. Nest predation by common palm civets *Paradoxurus hermaphroditus* and/or yellow-throated martens *Martes flavigula* was reported on two occasions in 2004 (Keo, 2008). However, no supporting evidence was provided and Southeast Asian monitor lizards were not considered. The latter species is widespread in the deciduous dipterocarp forests at SPWS, an accomplished tree-climber and its close relative, the water monitor lizard *Varanus salvator,* is known to feed on birds and their eggs (Das, 2010). Southeast Asian monitor lizards are targeted by human hunters at SPWS and it is possible that this hunting pressure may have contributed to successful fledging of giant ibis chicks by reducing local populations of the lizard. While less than ideal, this possibility might be preferable on balance, considering Southeast Asian monitor lizards are widely distributed in the region and regarded as Least Concern, whereas giant ibises are largely confined to Cambodia and Critically Endangered.

The post-fledging survival rate of juvenile giant ibises remains unknown at SPWS, as does the proportion of juveniles annually recruited into the local breeding population. This is unlikely to be optimal however. For example, a juvenile giant ibis was found in a weakened state near Trapeang Daikla (14°11′44′′N, 106°14′2′′E) on 16 November 2020. This was easily captured by hand and taken into care and was later reported to be underweight, dehydrated and suffering from a feather louse infestation and possibly avian malaria (BirdLife International, unpublished data). The bird has since recovered (Christel Griffoen, pers. comm.).

Two large groups of giant ibises were observed during the study period which were unprecedented. A flock of 15 giant ibises was recorded at Veel Kreel (14°10′34′′N, 106°13′22′′E) on 4 July 2018. As this date appears too early for flocks of post-breeding adults and young, they could potentially have been non-breeding birds. Additionally, a flock of 14 giant ibises was recorded at O'Sangke (14°16′19′′N, 106° 3′25′′E) on 21 September 2018. This date is late enough to include post-breeding adults and juveniles, although the age of first breeding and whether giant ibises breed annually remains unknown. The deployment of tracking devices on juvenile birds would help to fill this knowledge gap and is recommended in the action plan for giant ibises (Loveridge & Ty, 2015). It would also help to determine whether giant ibises are truly monogamous (currently assumed to be the case), their degree of fidelity to nest sites and provide an indication of territory sizes, none of which are currently known.

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References

BirdLife International (2012) *The Biodiversity of the Proposed Western Siem Pang Protected Forest, Stung Treng Province, Cambodia*. BirdLife International Cambodia Programme, Phnom Penh, Cambodia.

BirdLife International (2018) *Giant Ibis Thaumatibis gigantea. The IUCN Red List of Threatened Species 2018: e.T22697536A134200680*. Https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22697536A134200680.en [Accessed 12 November 2020].

Das, I. (2010) *A Field Guide to the Reptiles of Thailand and South-East Asia*. Asia Books, Bangkok, Thailand.

Eames, J.C., Le T.T. & Nguyen D.T. (2003) *The Final Biodiversity Report for Yok Don National Park, Vietnam*. Unpublished report to the PARC Project, Yok Don Component, Hanoi, Vietnam.

Keo O. (2008) *Ecology and conservation of giant ibis in Cambodia*. PhD thesis, University of East Anglia, Norwich, UK.

Loveridge, R., Kidney, D., Ty S., Eang S., Eames, J.C. & Borchers, D. (2017) First systematic survey of green peafowl *Pavo muticus* in northeastern Cambodia reveals a population stronghold and preference for disappearing riverine habitat. *Cambodian Journal of Natural History*, **2017**, 157–167.

Loveridge, R. & Ty S. (2015) *Ten-Year Species Action Plan for the Giant Ibis Thaumatibis gigantea in Cambodia. 2015–2025*. BirdLife International—Cambodia Programme, Phnom Penh, Cambodia.

Loveridge, R., Cusack, J.J., Eames, J.C., Eang S. & Willcox, D. (2018) Mammal records and conservation threats in Siem Pang Wildlife Sanctuary and Siem Pang Khang Lech Wildlife Sanctuary, Cambodia. *Cambodian Journal of Natural History*, **2018**, 76–89.

Pin C., Bou V., Eames, J.C., Samorn V. & Thol S. (2020) The first population assessment of the Critically Endangered Giant Ibis *Thaumatibis gigantea* in Lomphat Wildlife Sanctuary, Cambodia. *Cambodian Journal of Natural History*, **2020**, 7–14.

Ty S., Yav N., Eames, J.C., Sum P., Hong L., Thi S., Bou V. & Loveridge, R. (2016) The first population census of the Critically Endangered giant ibis in Western Siem Pang, northeastern Cambodia. *Cambodian Journal of Natural History*, **2016**, 51–59.

Wright, H.L., Collar, N.J., Lake, I.R., Bou V. & Dolman, P.M. (2012) Foraging ecology of sympatric white-shouldered ibis *Pseudibis davisoni* and giant ibis *Thaumatibis gigantea* in northern Cambodia. *Forktail*, **28**, 93–100.

Bimodal leaf fall in a lowland dry evergreen forest in Cambodia

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វដ្តជីវិតស្លឹកគឺជាសមាសភាគដ៏សារៈសំខាន់មួយនៃស្ថានប្រព័ន្ធព្រៃឈើ ដោយវាជាអ្នកកំណត់នូវបរិមាណ និងសកម្មភាពសរីរៈនៃស្លឹក(សរីរាង្គធ្វើរស្មីសំយោគ)។ យើងបានធ្វើការវាយតម្លៃលើវដ្តជ្រុះ និងលាស់ថ្មីនៃស្លឹកតាមព្រៃស្រោងតំបន់ទំនាបស្ងួតខេត្តកំពង់ធំនៃប្រទេសកម្ពុជា។ ការសិក្សាលើស្លឹកឈើដែលជ្រុះបានបង្ហាញថា រុក្ខជាតិជម្រុះស្លឹកច្រើនបំផុតនៅអំឡុងដើមរដូវប្រាំងចំពោះពពួកអំបូរឈើទាល(*Dipterocarpus costatus* និង *Anisoptera costata*) ប៉ុន្តែនៅក្នុងអំឡុងចុងរដូវប្រាំងវិញសម្រាប់ប្រភេទដើមឈើដែលដុះតាមគម្របព្រៃកម្ពស់មធ្យម និងទាប។ តាមការសង្កេតលើវដ្តជ្រុះនៃពន្លក និងគម្របព្រៃបានបង្ហាញថា ការជម្រុះស្លឹកបានកើតឡើងនាដើមរដូវប្រាំងសម្រាប់អំបូរឈើទាលដែលជាគម្របព្រៃខ្ពស់ៗ។ ម៉ាស់ស្លឹក(កំណត់តាមអុបទិកជាសន្ទស្សន៍ផ្ទៃស្លឹក) បានថយចុះតិចតួច ពីរដងគឺ ម្តងនៅដើមរដូវប្រាំង និងម្តទៀតនៅចុងរដូវប្រាំង។ លទ្ធផលនេះបានបង្ហាញថា ការជម្រុះស្លឹកនៃប្រភេទឈើដែលដុះតាមគម្របព្រៃកម្ពស់មធ្យម និងទាបកើតមានឡើងក្នុងដំណាក់កាលចុងក្រោយនៃចុងរដូវប្រាំង។ យើងស្នើឲ្យមានការពន្យល់បែបសម្មតិកម្មពីសារៈប្រយោជន៍អេកូឡូស៊ីនៃលំនាំវដ្តស្លឹកដែលខុសប្លែកនេះ។ ព្រឹត្តការណ៍ជម្រុះស្លឹកមិនធម្មតានេះក៏ប្រទះឃើញផងដែរ នៅពេលដែលរដូវប្រាំងមានរយៈពេលវែង។ ការរិចរិលព្រៃរួមមាន ការដកហូតព្រៃអំបូរឈើទាលខ្ពស់ៗ កំពុងបន្តកើតមានឡើងនៅក្នុងព្រៃស្រោងតំបន់ទំនាបស្ងួត។ ទាំងនេះ ប្រហែលជាអាចធ្វើឲ្យមានការផ្លាស់ប្តូរយ៉ាងសំខាន់ លើស្ថានប្រព័ន្ធព្រៃស្រោងតំបន់ទំនាបស្ងួត តាមរយៈការផ្លាស់ប្តូរវដ្ត និងម៉ាស់ស្លឹករុក្ខជាតិ។

Abstract

Leaf phenology is an important component of forest ecosystems as it determines the quantity and physiological activity of leaves, the organs that carry out photosynthesis. We assessed the phenology of leaf shedding and flushing in a lowland dry evergreen forest in Kampong Thom Province, Cambodia. Leaf litter surveys indicated that the peak of leaf shedding occurred during the early dry season for tall dipterocarps (*Dipterocarpus costatus* and *Anisoptera costata*), but during the late dry season for mid- to low-canopy tree species. Bud scale drop phenology and canopy observations suggested that flushing occurred early in the dry season in upper-canopy dipterocarps. Stand-scale leaf mass, measured

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optically as leaf area index, showed two periods of slight, but significant reduction: one in the early dry season and the other in the late dry season. This indicates that flushing in low- and mid-canopy species occurred in the last phase of the dry season at the latest. We propose hypothetical explanations for the ecological advantages of these discrete phenological patterns. An anomalous leaf shedding event was also found in association with a lengthy monsoon break. Forest degradation, including the removal of tall dipterocarp trees, is ongoing in lowland dry evergreen forests. This may lead to substantial changes in lowland dry evergreen forest ecosystems by altering stand-scale leaf phenology and leaf mass.

Keywords *Anisoptera costata*, *Dipterocarpus costatus*, ENSO, forest degradation, leaf area index, leaf phenology, lowland dry evergreen forest

Introduction

Evergreen forests occupied 15.8 % of the land area in Cambodia as of 2016 (Fig. 1; Ministry of Environment, 2018). Evergreen forests in Cambodia are classified into four subtypes, based on lowland or sub-montane location and moist or dry climate, using the classification system of the *Terrestrial Vegetation and Land-use Patterns* map published by the Ministry of Environment (MoE) in 2007 (cited in Brun, 2013). This subdivision is based on elevation, with 650 m used as the boundary between lowland and sub-montane vegetation types, as well as other bioclimatic criteria that differentiate the humid coastal ranges (moist, annual precipitation ca. >2000 mm), lower-humidity inland forests (dry) and hinterlands (Brun, 2013) (Fig. 2). Lowland dry evergreen forest, one of the four evergreen forest subtypes, is referred to as dry evergreen forest in the classification system of the Cambodian Forestry Administration (FA, 2011). Lowland dry evergreen forests in Cambodia typically develop on sandy alluvial plains, where soils are deep. Despite the seasonal tropical climate in which little rain falls for half the year (Kabeya *et al*., 2007), plants in lowland dry evergreen forests have access to abundant groundwater (Araki *et al*., 2008; Ohnuki *et al*., 2008b; Toriyama *et al*., 2011) via their deep root systems (Tanaka *et al*., 2004; Ohnuki *et al*., 2008a). This facilitates year-round foliage retention, resulting in evergreen forests. Such habitats occur to the north of the Tonlé Sap flood basin and west of the Mekong River (Fig. 3; Rundel, 1999). These areas are referred to as "Semi-Evergreen Forest on Alluvial Plains" in Rundel's (1999) classification and details of the forest classification systems used in Cambodia have been described by Brun (2013).

Lowland dry evergreen forests comprise multi-story forests of trees that maintain their leaves throughout the year, as is typical for evergreen forests (FA, 2011). Despite relatively constant leaf mass (Richardson *et al*., 2013), the physiological activity of the canopy in evergreen forests may not be constant. This is because physiological activity in leaves typically changes during leaf maturation (Pallardy, 2010), as demonstrated by a tall dipterocarp in a lowland dry evergreen forest (Ito *et al*., 2018). In other words, the leaf age structure of the canopy can govern physiological activities in the canopy (Field, 1987; Brodribb & Holbrook, 2005).

Leaf phenology refers to the recurring temporal aspects of natural phenomena associated with leaves, such as leaf flush, maturation, senescence and defoliation. As a result, it may be important for understanding the seasonality of eco-hydrological processes in tropical dry forests (Hutyra *et al*., 2007; Wu *et al*., 2016, 2017). Leaf phenology may vary according to community composition because dynamic changes in leaf age structure within the canopy can arise from the combined phenology of individual tree species at the stand scale. Understanding stand-scale leaf phenology may provide insight into ecosystem structure and function in forest systems (Cleland *et al*., 2007). As a consequence, clarifying stand-scale leaf phenology in the lowland dry evergreen forests of Cambodia may enhance understanding of forest ecosystems nationally and inform conservation planning for these.

Thus far, leaf phenology in Cambodian forests has mainly been studied in the context of remote sensing and land/forest classification. Clear differences in phenology have been observed between evergreen and deciduous forests during the dry season, whereby deciduous forests showed marked and spatially-uniform losses and subsequent gains in new leaf area, whereas evergreen forests exhibited less pronounced changes (e.g., Ito *et al*., 2008). Almost all remote sensing studies of the phenology of evergreen forests have assumed either negligible intra-annual variability (e.g., Langner *et al*., 2014) or unimodal seasonal changes, i.e., that leaf flushing occurs once a year (Venkatappa *et al*., 2019; Scheiter *et al*., 2020). An exception is the study of Ito *et al*. (2008), who used satellite imagery to demonstrate that the leaf phenology of Cambodian evergreen forests is spatially and temporally heterogeneous. Although Ito *et al*. (2008) found that approximately 30% of evergreen forests shed a detectable

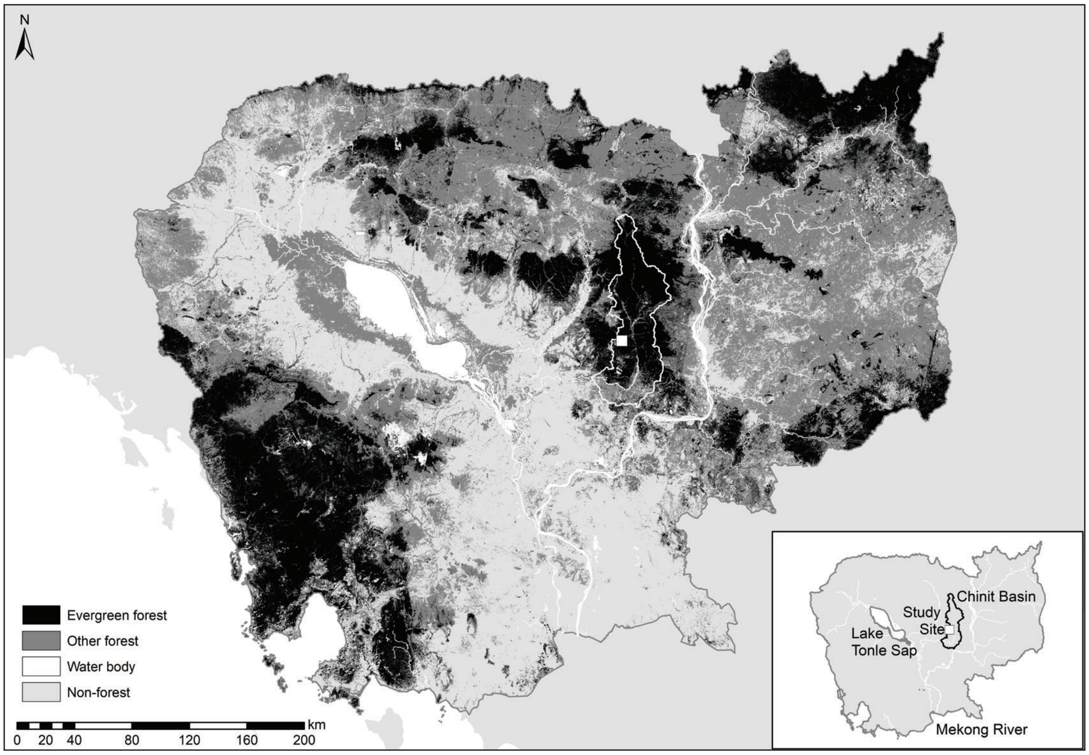

Fig. 1 Distribution of evergreen forests in Cambodia. Classification based on FA (2011). The open square represents the study site and the white line indicates the basin of the Chinit River.

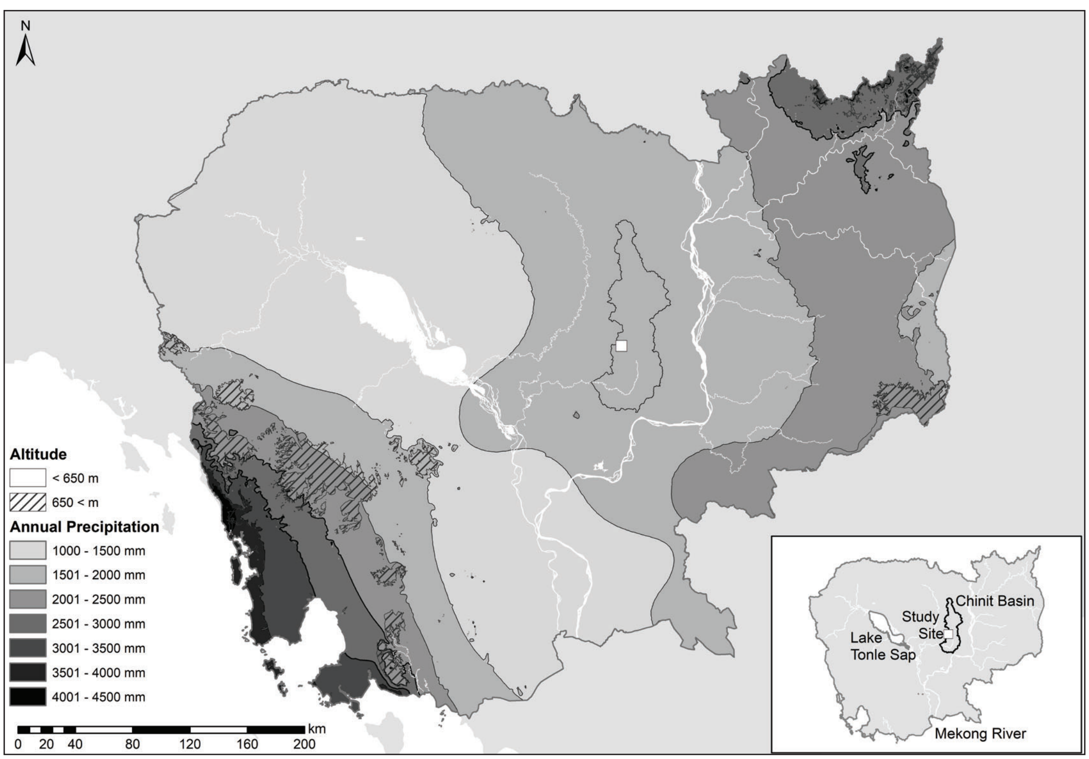

Fig. 2 Annual precipitation and elevation classes in Cambodia. Precipitation data obtained from the WorldClim global climate and weather database (https://www.worldclim.org/data/index.html). The open square represents the study site and the black line indicates the basin of the Chinit River.

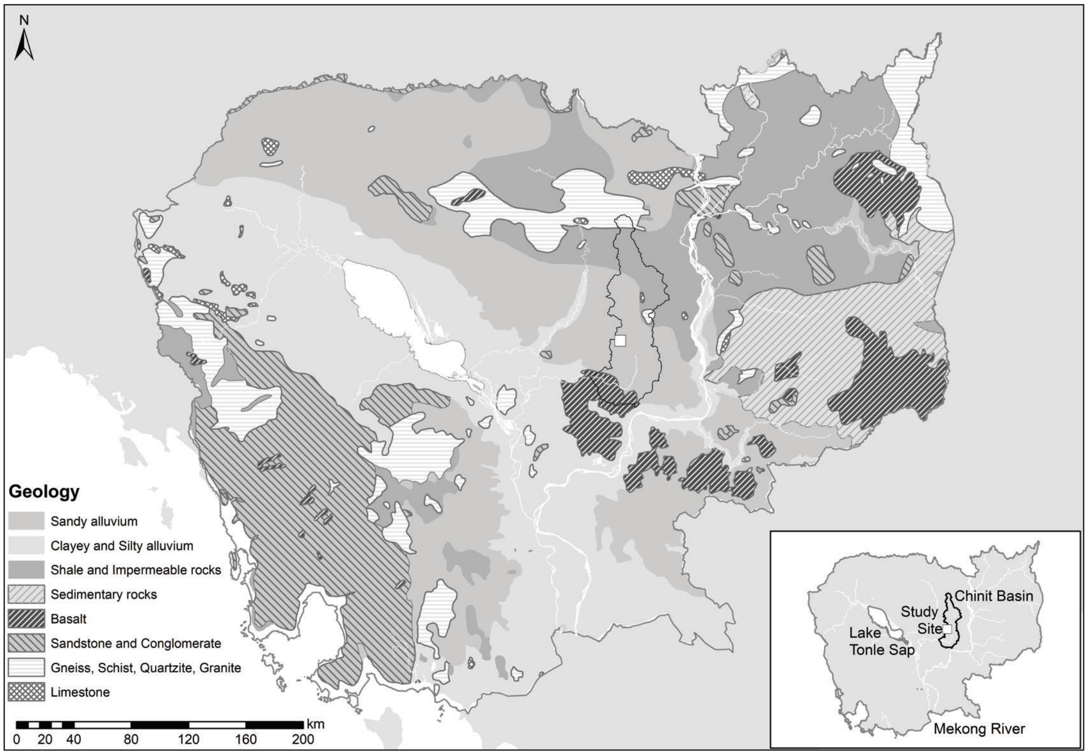

Fig. 3 Geology of Cambodia. Data provided by the Forestry Adminstration (Cambodia). The open square represents the study site and the black line indicates the basin of the Chinit River.

volume of leaves twice during a single dry season (i.e., early and late in the dry season), they did not explicitly link this heterogeneity to the characteristics of the sites or species present in each forest. Species-specific leaf phenological characteristics have been widely reported for species in the Dipterocarpaceae (reviewed by Ghazoul, 2016). This family includes many of the major component species of Cambodian forests (FA & Cambodia Tree Seed Project, 2003), although available reports do not include dipterocarp species that occur in lowland dry evergreen forests. To the best of our knowledge, no reports based on empirical field data exist on the stand-scale leaf phenology of lowland dry evergreen forests in Cambodia.

The objective of our study was to investigate leaf phenology in a lowland dry evergreen forest in central Cambodia. We measured leaf and bud-scale fall using litter traps, directly observed leaf flush and optically measured seasonal changes in leaf mass. We also consider hypothetical explanations for the ecological functions of the phenological patterns observed. Finally, we consider how extreme climate events and forest degradation may influence leaf phenology and related ecosystem processes.

Methods

Study site

The study site was located in Kampong Thom Province (12°76′N, 105°48′E; Figs 1–3), within the Stung Chinit River catchment where the Stung Chinit River flows through the central plains of Cambodia into Tonlé Sap Lake. While elevations within the Chinit catchment range from 19 to 653 m, 90% of the drainage area is below 140 m (Kabeya *et al*., 2021). The study site was situated in a flat, gently rolling alluvial plain 80–100 m above sea level (a.s.l.), on sandy alluvium with shale distributed in the upstream area (Fig. 3). The forest at the study site was classified as lowland dry evergreen forest in the *Terrestrial Vegetation and Land-use Patterns* map published by MoE in 2007 (cited in Brun, 2013). The study forest had a basal area of 42.3 m^2 ha^{-1} and a tree density of 1,817 trees ha^{-1} (diameter at breast height [DBH] > 5 cm), based on a census conducted within a 30 × 80 m permanent sample plot in 2011. Two tall dipterocarp species, *Dipterocarpus costatus* C.F. Gaertn and *Anisoptera costata* Korth., dominated the upper canopy layer of the forest (Pooma, 2002; Tani *et al*., 2007) and details of the plant species composition of the study area are provided in Annex 1.

Seasonal and interannual variations in precipitation

Cambodia has a subtropical climate driven by two monsoon seasons: the cool, dry northeastern monsoon from November to March, and the humid southwestern monsoon from May to October (Kabeya *et al*., 2021). The seasonal tropical climate of our study area can generally be divided into three seasons: an early dry season with little rain (ca. 50 mm) and decreasing air temperature (from 25.5 to 24.5 °C), a late dry season with little rain (ca. 100 mm, pre-monsoon rain, Kabeya *et al*., 2007) and increasing air temperature (from 25 to 28 °C), and a rainy season providing >90 % of the annual precipitation, with moderate air temperature (approximately 26°C) (Kabeya *et al*., 2008; Chann *et al*., 2011). We defined the timing of these three seasons as follows: early dry season (late October–late December), late dry season (early January–mid May), and rainy season (late May–mid October).

The monsoon exhibits substantial interannual variability which is closely related to El Niño/Southern Oscillation (ENSO) (Räsänen & Kummu, 2013). In Southeast Asia and Oceania, the El Niño phase tends to result in high temperatures and water shortages, whereas substantial rainfall tends to occur during the La Niña phase. According to Kabeya *et al*. (2021) for 2007–2016 and our data for 2000–2006 and 2017–2019 (classified using the same methods), an El Niño phase occurred in the central lowlands of Cambodia during 2005, 2010 and 2015–2016, whereas a La Niña phase occurred during 2000–2001, 2006, 2008–2009 and 2011–2012 and a neutral phase during 2002–2004, 2007, 2013–2014 and 2017–2019 (El Niño and La Niña phases were distinguished based on Southern Oscillation Index values of −10 and +10, respectively). Based on observations in 2007–2016, the annual rainfall of neutral, La Niña, and El Niño years near the study site was approximately 1,600 mm, >1,800 mm and 1,100–1,200 mm, respectively (Kabeya *et al*., 2021).

Kabeya *et al*. (2021) reported the mean onset and withdrawal dates of the rainy season in 2007–2016 as 26 May (± 18 days) and 25 October (± 13 days), respectively. These were based on Matsumoto (1997) in defining "the onset (withdrawal) of the summer rainy season is that of the first (last) pentad (5-days) when the mean pentad precipitation exceeds annual mean pentad precipitation [Pm = (Annual precipitation) / 73] in at least three consecutive pentads, following (before being) lower than it in more than three consecutive pentads. The middle date of this defined pentad is considered the onset or withdrawal date". Onset and withdrawal dates for 2004–2006 were obtained by Kabeya *et al*. (unpublished data). The summer rainy season is sometimes divided into two rainy seasons based on breaks similar to short dry seasons, known as monsoon breaks (Matsumoto, 1997). Monsoon breaks were defined as periods when pentad precipitation was lower than Pm for more than three consecutive pentads (Kabeya *et al*., 2021). A relationship between monsoon breaks and ENSO phase has been suggested (Kabeya *et al*., 2021). From 2007 to 2016, monsoon breaks were observed in 2008, 2009, 2012 and 2016 at the study site (e.g., four out of 10 years, with three of the four year being in the La Niña phase) (Kabeya *et al*., 2021). Breaks typically began around the end of July or early August and had a mean duration of 36 days (Kabeya *et al*., 2021).

Seasonal variations in groundwater level and solar radiation

Soils at the study site are generally sandy and classified as Haplic Acrisols (Alumic, Profondic) in the *World Reference Base for Soil Resources* (Toriyama *et al*., 2007, 2008). The depth of the groundwater table varies substantially due to the gently undulating nature of the overlying topography. The depth of the groundwater table and corresponding rooting depth are ca. −10 m at the end of the dry season (Araki *et al*., 2008; Ohnuki *et al*., 2008a, 2008b) and the soils dry rapidly in December (Araki *et al*., 2008). Interannual variations in monthly mean groundwater levels are available for 2004–2007 (Fig. 4a, revised from Chann *et al*., 2011).

Meteorological data have been collected at the site using a 60 m tall observation tower since 2004, although data gaps have resulted from mechanical breakdowns caused by lightning and other factors (Nobuhiro *et al*., 2009; Chann *et al*., 2011). Seasonal variations in solar radiation are relatively minor, despite the presence of distinct rainy and dry seasons. This is because rainfall is concentrated in the evening (Nobuhiro *et al*., 2010). Seasonal differences in solar radiation in the study area were typically < 10%, with the exception of the last two months of the rainy season, when the difference was 20% (Fig. 4b, revised from Chann *et al*., 2011).

Leaf phenology

We investigated stand-scale leaf phenology using the following three methods.

1. Litter traps—Litter collection was used to assess leaf shedding phenology from September 2004 to January 2015. This period was divided into three phases in data analyses. During Phase I (September 2004–February 2007), a 1 m² frame was employed for litter collection in the study forest. During Phase II (February 2007–February 2009), a second 1 m² frame was added for litter collection. During Phase III (March 2009–January 2015), four litter net traps with a total area of 2 m² were employed within a 50 x 100 m forest stand.

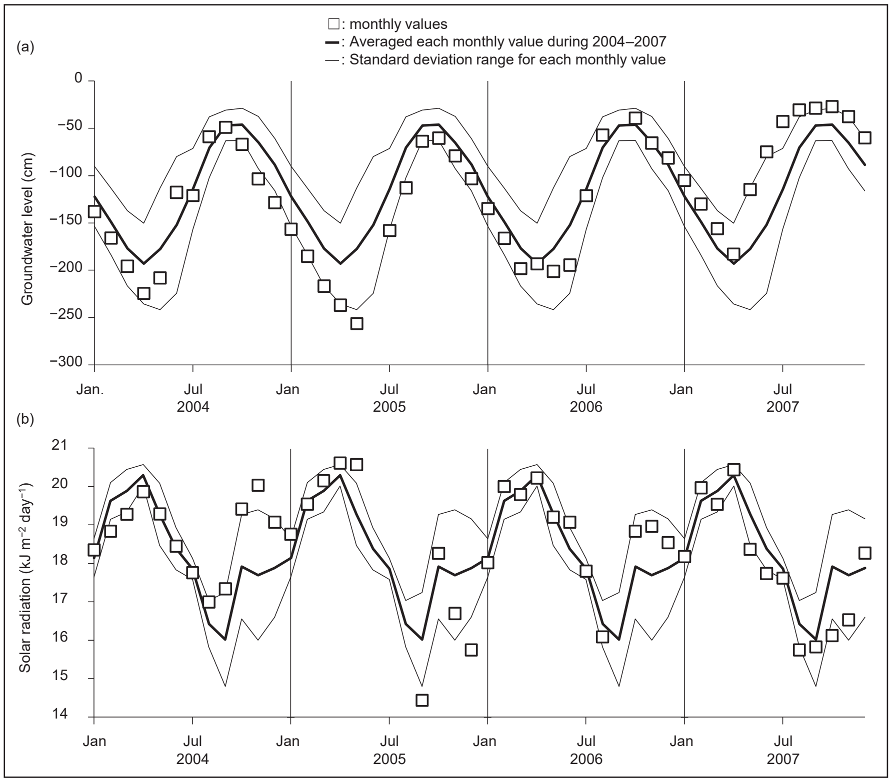

Fig. 4 Variations in monthly mean groundwater level (a) and monthly mean daily solar radiation (b) at the study site in 2004–2007. Data were unavailable for June 2005 and September 2006 for groundwater level and for June–August 2005 and September 2006 for solar radiation.

Litter was generally collected three times per month. However, longer collection intervals occurred on three occasions during the early stages of Phase I (namely a 47-day collection interval from 24 September 2004–10 November 2004, a 20-day collection interval from 30 December 2004–19 January 2005 and a 40-day collection interval from 19 January 2005–28 February 2005) (Fig. 5).

All litter collected was divided according to species and the oven-dried weights for each species were recorded. We report the weights for tall dipterocarps (*D. costatus* ['Chhoeuteal Bankouy' in Khmer] and *A. costata* ['Phdiek']), mid-layer dipterocarps (*Vatica odorata* (Griff.) Symington ['Chromas'] and *Hopea recopei* Pierre ex Laness. ['Chromas Trang']), and other mid- to understory tree species. Litter collected from trees in the middle to understory layers included an abundance of material from *Diospyros* spp. and *Syzygium* spp. These layers also included some mid-sized to tall tree species such as *Lophopetalum duperreanum* Pierre and *Sindora siamensis* Teysm. ex Miq. and further information on these species is given in Annex 1. Some shrub (e.g., *Psydrax pergracilis* (Bourd.) Ridsdale) and vine (e.g., several species of *Uvaria* (Annonaceae), *Willughbeia edulis* Roxb. (Apocynaceae), and *Peltophorum dasyrhachis* (Miq.) Kurz (Fabaceae)) species were also represented in the litter. We also counted the number of tree species producing fallen leaves during each collection interval. The amount of fallen leaves was corrected for trap area (g m^{-2}), but not for collection interval, except for the longer collection intervals previously mentioned.

Because *Dipterocarpus* species produce a distinctive bud scale indicative of leaf flushing, the amount of bud scales collected by litter traps was used to estimate the leaf flushing phenology of *D. costatus*. These data, collected from October 2006 to February 2007 (during Phase I), were used for reference only due to errors made by local collectors whereby uncollected scales were carried over to later collection intervals.

2. Direct crown observations—Crown observations were conducted using binoculars to confirm the leaf flush phenology of *D. costatus* and *A. costata*. Observations were made from 29 September 2004 to 19 September 2005 and from 30 October 2006 to 30 June 2012. Observations were made three times per month, generally on the 10th, 20th and 30th, but sometimes varied by 1–2 days. Three

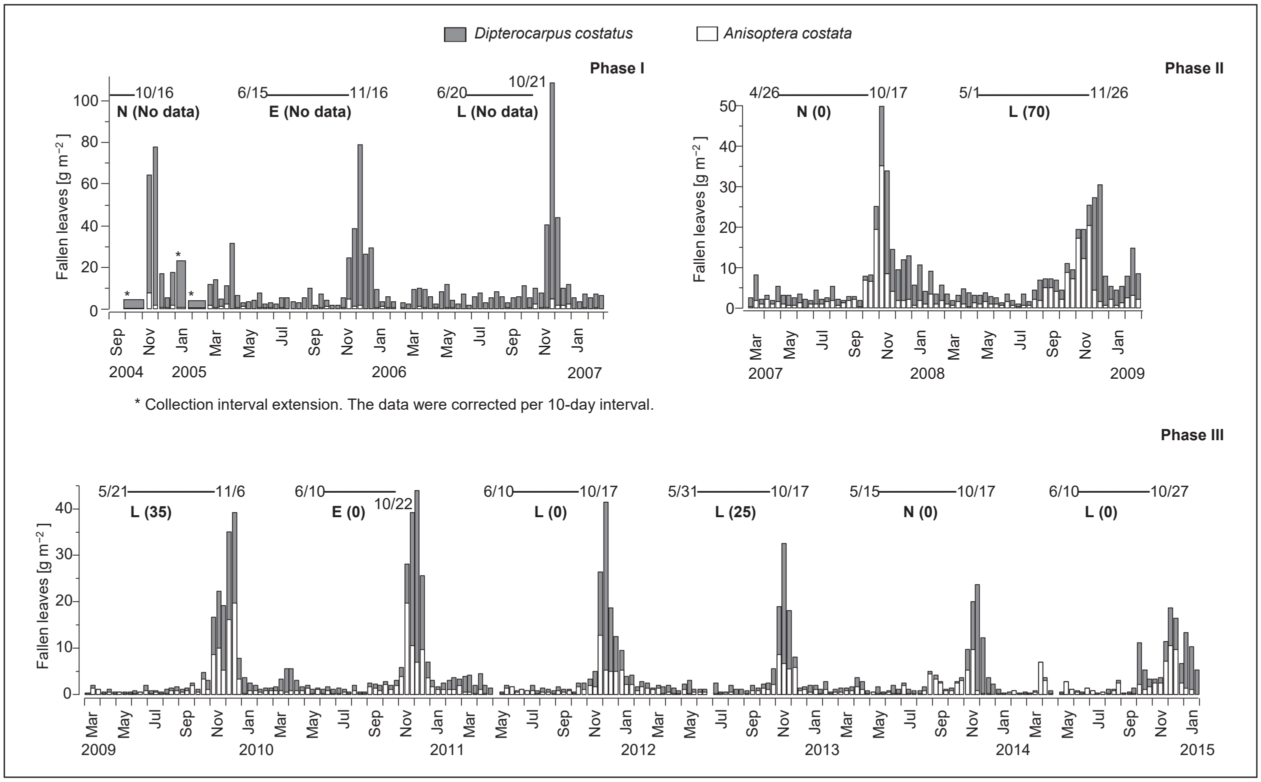

Fig. 5 Leaf shedding phenology of tall dipterocarps in a Cambodian lowland evergreen forest. Horizontal lines indicate the duration of the rainy season, with onset and withdrawal dates. Bold capital letters and numbers in parentheses refer to the El Niño/La Niña phase, and the length (in days) of the monsoon break (0 if it did not occur): E, El Niño; L, La Niña; N, neutral. No data are shown for the 2004–2006 monsoon break. Dates were derived from Kabeya *et al.* (2021) and Kabeya *et al.* (unpublished data). Asterisks (*) in Phase I indicate notes regarding collection interval extension (see text for details). The data for the three phases were corrected for 10-day intervals.

individuals of each tree species were observed and the presence or absence of leaves in the canopy was recorded. We also recorded whether pale green leaves were present in the canopy, which were assumed to be freshly developed. The recording threshold was set at 10% or more of total leaves in the canopy being newly flushed.

3. *Optical measurement of leaf area index*—Seasonal changes in leaf area at the stand scale were estimated using non-destructive optical methods (plant canopy analyser, LAI-2000, Li-Cor, Nebraska, USA) to determine the leaf area index (LAI, m m^{-1}). The LAI was estimated at ten points, which produced different measurements. When using the plant canopy analyser, the sensor's azimuthal field of view was limited to 90°. These measurements were typically made once a month from March 2003 to May 2012, although measurement interval varied. In addition, we also estimated LAI on the basis of hemispherical photographs (Tani *et al.*, 2011). These were taken on the same day and at the same locations as the plant canopy analyser measurements, except in 2008 (due to equipment loss).

Leaf mass per area

The leaf mass per area (LMA) of *D. costatus* was measured from fallen leaves collected in litter traps for intervals with at least ten leaves from August 2005 to July 2006. Five constant-area (30 mm^2) discs were punched out from a collected leaf, oven-dried and individually weighed. Shrinkage of drying fallen leaves relative to fresh leaves was neglected. In total, 585 leaves collected on 14 days were measured.

Statistical analysis

Seasonal changes in leaf litter weights in four categories (*D. costatus*, *A. costata*, mid-layered dipterocarps, and other mid- to understory species) were assessed using a generalized linear model (GLM) framework. The GLM incorporated collection date as a categorical explanatory variable (10 day periods, 36 periods per year). The amounts of litter per category were influenced by trap location and individual trees. Importantly, numerical data could not be directly compared across collection phases. For this reason, we incorporated collection phase (i.e., PHASE I, II, or III) into the GLM as a categorical random effect. We excluded data up to February 2005 (Phase I) from the analysis due to the extended collection intervals. The hypothesis that each parameter had a value of zero was evaluated using *t*-tests. The GLM estimated the least square means (LSMs) of litter weights in four categories for each collection date. LSMs represent the predicted values across the various collection dates when other model factors were held constant at the average coefficient over all levels for each factor. The amount of litter that fell during each of three periods, i.e., the early dry season (late October–late December), the late dry season (early January–mid May), and the rainy season (late May–mid October), was estimated by summing the predicted LSMs from each collection date. The percentage of leaf fall occurring in each period was calculated based on the total annual leaf fall.

LAI data collected between March 2003 and June 2004 (totalling 16 measurement periods) using the plant canopy analyser were assessed to determine seasonal changes. We used a GLM framework incorporating measurement date as a categorical explanatory variable and measurement point (n = 10) as a random effect. Significant differences among measurement dates were evaluated using post-hoc Tukey-Kramer HSD tests.

We observed occasional fluctuations in the plant canopy analyser data collected after July 2004. These may have been caused by the deterioration of the sensors during the measurement period, but this cannot be confirmed. The data for the entire period, as measured using the two methods (plant canopy analyser and hemispherical photographs), were subjected to the following statistical analyses to detect seasonal trends in LAI while mitigating the effects of instrument malfunctions, differences between instruments, uneven measurement dates and inter-annual variations in canopy conditions due to tree growth and mortality. Seasonal changes in LAI were assessed using a GLM framework incorporating measurement date as a categorical explanatory variable (10-day periods, 36 periods per year), and measurement point, measurement method (plant canopy analyser or hemispherical photographs), measurement year, and the interaction of the latter two variables as random effects. Since LAI was not measured on the same day every month, each measurement date was classified into 10-day periods (i.e., 36 periods per year), then converted into categorical data and incorporated into the GLM. No data were available for mid-April. The hypothesis that each parameter had a value of zero was evaluated using *t*-tests. The GLM estimated LSMs for each measurement date. Annual mean (± SD) and range were estimated by averaging and ranging the LSM for each measurement date.

Seasonal variations in LMA were assessed using a GLM framework incorporating collection date as an explanatory variable and individual leaf as a random effect. Significant differences among dates were evaluated using post-hoc Tukey-Kramer HSD tests. The GLM estimated LSMs for each sampling date. All statistical analysis was conducted using JMP statistical software (ver. 10.0, SAS Institute Inc., North Carolina, USA).

Results

Phenology of leaf and bud scale shed

Leaf and bud scale shedding phenology are shown in Figs 5–7. The tall dipterocarps *D. costatus* and *A. costata* shed leaves during the early dry season (Fig. 5). The shedding peak of *A. costata* was 0–20 days earlier than that of *D. costatus*. For *D. costatus*, sporadic leaf shedding was observed in the early rainy season (Fig. 5). The peak of leaf shedding for tall dipterocarp species in the early dry season was generally sharp, excluding blunt peaks observed in 2008–2009 (Fig. 5, Phase II), or from 2014 to 2015 (Fig. 5, Phase III). The dates of onset and termination and the duration of the rainy season or El Niño/La Niña phase, and the occurrence and lengths of monsoon breaks (derived from Kabeya *et al*., 2021; Kabeya *et al*., unpublished data) are also shown in Fig. 5.

Mid- and lower layer components of the forest, including other dipterocarps (*Vatica odorata* and *Hopea recopei*) mainly shed leaves in the late dry season (Fig. 6). The number of species shedding leaves was relatively large in the late dry season, with peaks in January–February for most species (Fig. 6). The peak of leaf shedding for low- and mid-canopy species was relatively blunt, except for a sharp peak in February 2009 (Fig. 6, Phase II).

The fall of *D. costatus* bud scales typically peaked between mid-November and mid-December (Fig. 7). The peak of bud scale fall (i.e., the peak of leaf flushing) coincided with peak leaf fall in *D. costatus* (Fig. 5). Bud scale fall from *D. costatus* was also observed during the late dry season and early in the rainy season (Fig. 7).

Leaf fall patterns were further generalized through GLM analysis (Fig. 8). Significantly elevated levels of leaf shedding continued over 40 days and 60 days in the early

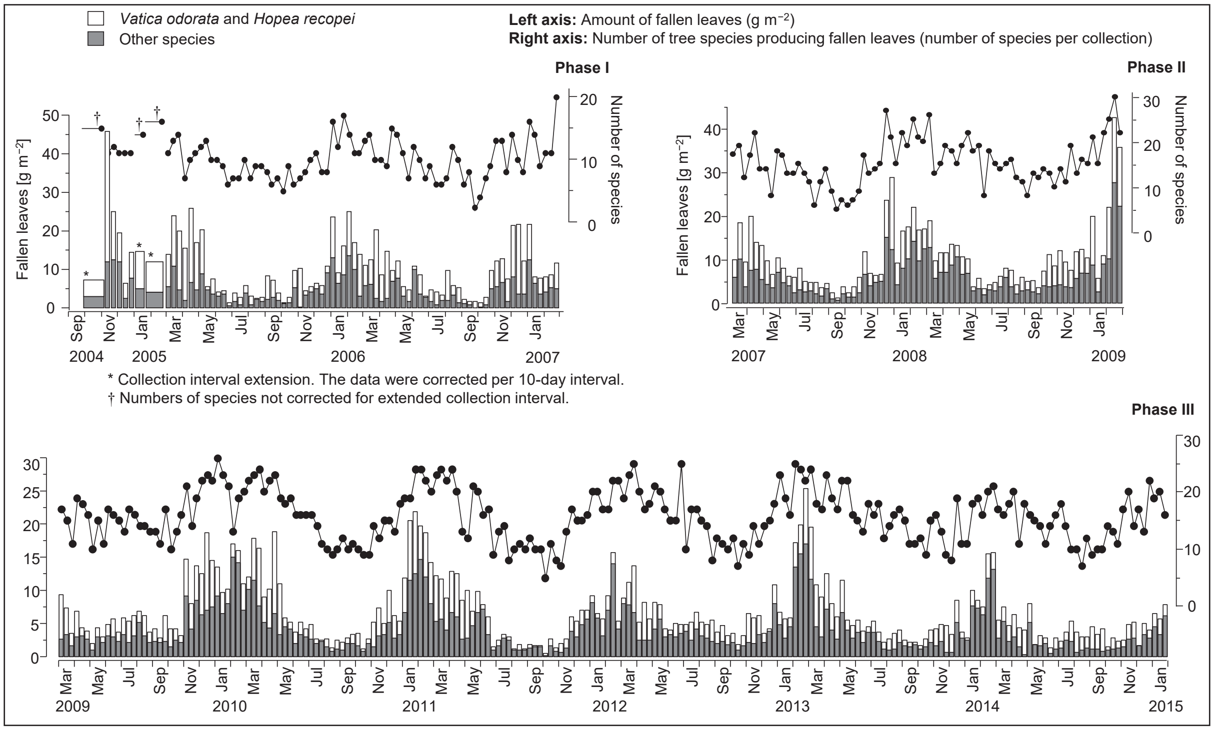

Fig. 6 Leaf shedding phenology of species in the middle and understory layers. Columns indicate the volume of fallen leaves (left axis), whereas lines indicate the number of other litter-producing tree species (i.e., all species aside from *D. costatus*, *A. costata*, *V. odorata* and *H. recopei*; right axis). Asterisks (*) in Phase I indicate extended collection intervals (see text for details). The data for the three phases were corrected for 10-day intervals. Numbers of species were not corrected for trap area or collection interval. '†' in phase I indicates the total number of species collected during extended intervals.

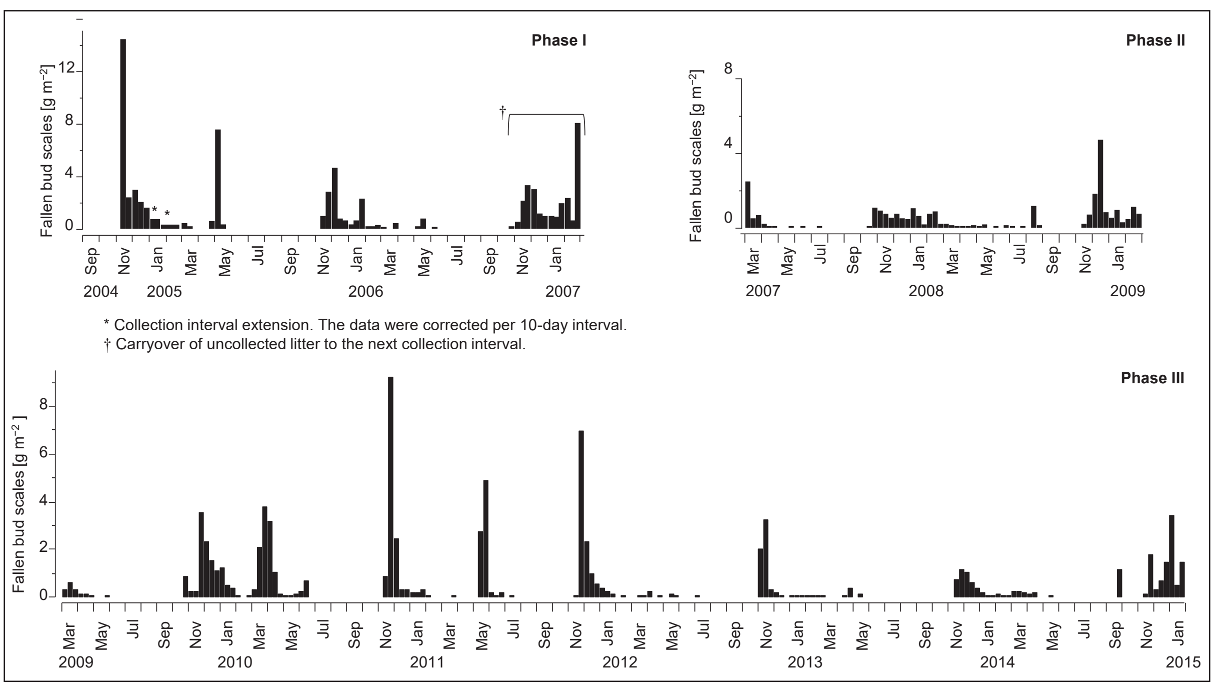

Fig. 7 Bud scale shedding phenology of *D. costatus*. Asterisks (*) in Phase I indicate extended collection intervals (see text for details). The data for the three phases were corrected for 10-day intervals. '†' in Phase I indicates carryover of uncollected litter to the next collection interval.

dry season for *D. costatus* and *A. costata*, respectively (Fig. 8a–b). Peaks in leaf shedding were less clear and lasted longer during late dry season in mid- to low-canopy species (Fig. 8c–d).

According to our GLM, 50.8% and 58.2% of total annual leaf fall occurred during the early dry season for *D. costatus* and *A. costata*, respectively. During the late dry season, 27.9% and 19.9% of total annual leaf fall occurred for *D. costatus* and *A. costata*, respectively. Meanwhile, 21.4% and 18.3% of the annual leaf fall for mid-layer dipterocarps and other mid- and understory species occurred in the early dry season, respectively. During the late dry season, 54.4% and 58.9% of annual leaf fall occurred for the mid-layer dipterocarps and other mid- and understory species, respectively. Some mid- to low-canopy species displayed leaf shedding throughout the dry and rainy seasons. For example, leaf litter from *Peltophorum dasyrhachis* (Miq.) Kurz (Fabaceae) and *Syzygium syzygioides* (Miq.) Merr. & L.M. Perry (Myrtaceae) were found on 87% and 82% (respectively) of all collection dates in Phase III (n = 213). However, the peak of leaf shedding occurred during the late dry season (February) rather than the early dry season.

Direct crown observations

Direct observations confirmed that leafless branches were rarely observed on *D. costatus* and *A. costata* throughout the year. Leaf flushing occurred mainly during November and December in these two tall dipterocarps. The peak of leaf flushing was slightly earlier in *A. costata* (mid–late November) than *D. costatus* (late November–early December) (Table 1).

Leaf area index

Leaf area index measurements collected with the plant canopy analyser during the first study year (March 2003 to June 2004) are shown in Table 2. Maximum and minimum values were observed in mid-July (4.66 m m^{-1}) and late April (3.85 m m^{-1}), respectively. The annual difference (0.81 m m^{-1}) corresponded to 17% of the largest observed LAI value. We consistently observed relatively large values during the rainy season, which did not differ significantly from the maximum observed values. Values decreased in mid-November (4.15 m m^{-1}) as the rainy season shifted towards the onset of the dry season, and then gradually increased in late December and mid-January. LAI decreased rapidly between mid-January (4.26 m m^{-1}) and late April (3.85 m m^{-1}), but began to increase again (3.88 m m^{-1}) in mid-May, before the rainy season started. The increase in mid-May was observed in both 2003 and 2004.

The GLM based on the full dataset estimated that annual mean (± SD) LAI was 3.93 ± 0.23 m m^{-1} and ranged from 3.53 to 4.39 m m^{-1} (Fig. 9). The annual difference (0.86 m m^{-1}) was equivalent to 20% of the largest observed LAI value. The largest and second largest LAI occurred in early August (4.39 m m^{-1}) and late June (4.35 m m^{-1}),

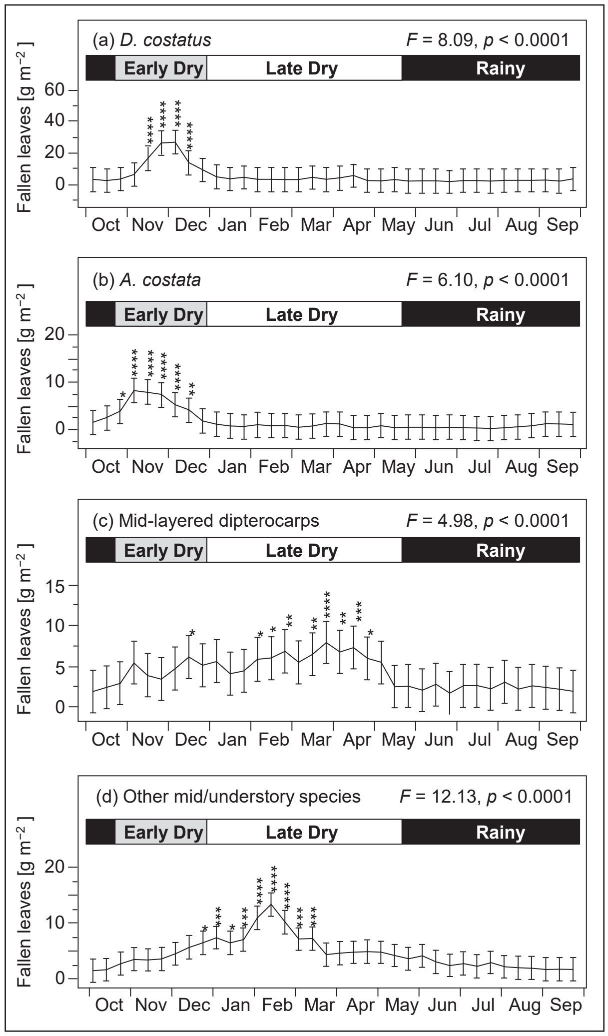

Fig. 8 GLM analysis of leaf shedding phenology in a lowland dry evergreen forest in Cambodia. Fallen leaf litter weights were estimated for each collection date (ten-day periods in each month, 36 dates per year) for four categories: (a) the tall dipterocarp *D. costatus*, (b) the tall dipterocarp *A. costata*, (c) the mid-layer dipterocarps *V. odorata* and *H. recopei*, and (d) other mid- and understory species. The line charts with error bars show the least squares means and the upper and lower 95% confidence intervals. Collection dates which showed significant positive values are indicated with asterisks: **** < 0.0001; *** < 0.001; ** < 0.01; and * < 0.05. Statistical F- and p-values are given in the upper right corner of each panel.

respectively. The lowest and second lowest LAI occurred in early March (3.53 m m^{-1}) and late November (3.55 m m^{-1}), respectively. Collection dates for which *t*-tests indicated significant positive or negative parameter values typically occurred during the rainy and dry seasons, respectively. In contrast, we identified two periods in the year when LAI gradually increased while continuously exhibiting neutral parameter values: mid-December to early January and late April to mid-May.

The GLM results also indicated no significant differences between the two data collection methods during 2003–2007, but significantly higher and lower LAI values were found for the plant canopy analyser relative to the hemispherical photographs in 2008 and 2009–2012, respectively (data not shown). As potential effects of mechanical aging of the plant canopy analyser and missing data in hemispherical photographs could not be accounted for, we do not discuss inter-annual variation in LAI.

Leaf mass per area

The mean LMA of *D. costatus* was 138.0 g m^{-2}. LMA showed slight but significant differences relative to leaf falling date ($F_{13,567.4} = 4.74$, $p < 0.0001$, Table 3). Post-hoc Tukey-Kramer HSD tests indicated that leaves that fell early in the dry season (10 November and 19 November, Table 3) had relatively high LMA values.

Discussion

Leaf phenology is discrete in lowland dry evergreen forests

Our study revealed discrete leaf shedding phenology in two tall dipterocarp tree species, which peaked in the early dry season, and low- to mid-forest layer species, which peaked in the late dry season (Figs 5–6, 8). We also assessed the leaf flushing phenology of two tall dipterocarp tree species based on the phenology of bud scale fall (Fig. 7) and canopy observations (Table 1). These flushed immediately after leaf shedding. That LAI decreased early in the dry season and increased soon after (Table 2, Fig. 9) is consistent with this observation.

The leaf flushing phenology of species in the low to middle tree layers was not directly assessed, but may be indirectly estimated based on seasonal changes in LAI. LAI gradually decreased in the later portions of the dry season (Table 2, Fig. 9), when species in the low to

Table 1 Leaf flushing phenology based on direct observations. Numbers of observed trees with newly flushed leaves in the crown are shown. '—' indicates a value of zero. Three individual trees of each species were observed. Direct observations were made three times per month from February to September, but no leaf flushing was observed.

Species	Year	Late Rainy Season			Early Dry Season						Mid Dry Season		
		October			November			December			January		
		10	20	30	10	20	30	10	20	30	10	20	30
A. costata	2004–05	–	–	–	–	2	3	1	–	–	–	–	–
	2006–07	–	–	–	1	3	3	3	3	–	–	–	–
	2007–08	–	1	2	3	1	–	–	–	–	–	–	–
	2008–09	–	–	–	1	2	3	2	–	–	–	–	–
	2009–10	–	–	–	3	3	3	2	2	1	–	–	–
	2010–11	–	–	–	–	2	3	2	2	–	–	–	–
	2011–12	–	–	–	1	2	3	2	2	2	–	–	–
D. costatus	2004–05	–	–	–	–	2	3	2	1	–	–	–	–
	2006–07	–	–	–	3	3	3	3	2	–	–	–	–
	2007–08	–	–	–	3	3	3	3	–	–	–	–	–
	2008–09	–	–	–	–	–	1	2	3	3	2	–	–
	2009–10	–	–	–	1	2	3	3	3	3	2	–	–
	2010–11	–	–	–	1	1	3	3	2	1	–	–	–
	2011–12	–	–	–	–	3	3	3	3	3	–	–	–

Table 2 Leaf area index (LAI, $m^2\ m^{-2}$) values obtained in the lowland dry evergreen forest, Cambodia. Values lacking a common superscript letter are significantly different at $p<0.05$ based on Tukey's honest significant difference.

Year	Date	Season	Mean (*n*=10)	SD
2003	Mar. 14	Late–Dry	3.96 ^{fgh}	0.72
	Apr. 10	Late–Dry	3.97 ^{efgh}	0.82
	May 18	Late–Dry	4.27 ^{bcde}	0.78
	Jun. 17	Rainy	4.46 ^{abc}	1.00
	Jul. 18	Rainy	4.66 ^{a}	0.90
	Aug. 17	Rainy	4.54 ^{ab}	0.94
	Sep. 14	Rainy	4.38 ^{abcd}	0.90
	Oct. 16	Rainy	4.40 ^{abc}	0.91
	Nov. 16	Early–Dry	4.15 ^{cdefg}	0.77
	Dec. 21	Early–Dry	4.18 ^{cdefg}	0.78
2004	Jan. 20	Late–Dry	4.26 ^{bcdef}	0.78
	Feb. 27	Late–Dry	4.07 ^{defgh}	0.84
	Mar. 27	Late–Dry	4.03 ^{efgh}	0.78
	Apr. 25	Late–Dry	3.85 ^{h}	0.72
	May 18	Late–Dry	3.88 ^{gh}	0.70
	Jun. 20	Rainy	4.02 ^{efgh}	0.73

Table 3 Seasonal changes in leaf mass per area (LMA, g m–2) of fallen leaves of *D. costatus*. Values lacking a common superscript letter are significantly different at $p<0.05$ based on Tukey's honest significant difference.

Year	Date	Season	LSM	*n*
2005	Aug. 30	Rainy	146.4 ^{abcd}	12
	Sep. 10	Rainy	129.8 ^{e}	26
	Sep. 29	Rainy	143.6 ^{abcde}	18
	Nov. 10	Early–Dry	151.1 ^{ab}	10
	Nov. 19	Early–Dry	146.2 ^{a}	48
	Dec. 10	Early–Dry	137.4 ^{bcde}	207
	Dec. 20	Early–Dry	137.8 ^{abcde}	62
	Dec. 30	Early–Dry	137.0 ^{bcde}	78
2006	Jan. 10	Late–Dry	135.8 ^{abcde}	24
	Jan. 30	Late–Dry	134.1 ^{abcde}	17
	Apr. 20	Late–Dry	137.5 ^{abcde}	16
	May 9	Late–Dry	130.9 ^{de}	20
	May 19	Late–Dry	132.8 ^{cde}	31
	Jun. 20	Rainy	146.9 ^{abc}	16
		Mean ± SD	138.0 ± 17.8	

middle layers had shed their leaves (Fig. 6), but began to increase shortly before the end of the late dry season and continued to increase gradually throughout the first half of the rainy season (Table 2, Fig. 9). This suggests that species in the low to middle layers flush, at the latest, during the last month of the dry season. However, it is unclear how long the flushing lasted, because the gradual increase in LAI during the first half of the rainy season may be attributable not only flushing but also leaf expansion.

Bimodal leaf shedding behaviour during the dry season has been observed optically in ca. 30% of the evergreen forests in Cambodia via analyses of satellite imagery (Ito *et al*., 2008). It is possible that the stand-scale leaf dynamics we observed are common in Cambodian evergreen forests.

Ecological advantages of leaf flushing in the early dry season

Leaf flushing in the early dry season was displayed by a few upper-canopy species in our study i.e., *D. costatus* and *A. costata* (Table 1, Fig. 5). Our LMA measurements for *D. costatus* may provide insights into the advantages of this behaviour (Table 3). The leaf characteristics of dipterocarp trees depend on tree height and thick and hard leaves are found in the upper part of the tree canopy (Kenzo *et al*., 2006, 2012), as in other forests (e.g., Cavaleri *et al*., 2010). High LMA values imply that fallen leaves originated in the upper canopy layers. Relatively high LMAs were observed in leaves that fell in early to mid-November, just after the onset of the dry season (Table 3). This suggests that the upper portion of the canopy sheds its leaves early in the dry season. Moreover, given the assumption of ca. 1-year leaf longevity (Ito *et al*., 2018), the elevated LMA of fallen leaves during the early dry season implies that the upper part of the tree canopy flushes leaves during the early dry season. Leaf expansion requires a large supply of water (Dale, 1988). The two tall dipterocarp tree species considered here commonly reach 30–35 m in height (Toyama *et al*., 2013). We have also found that they can reach maximum heights of 45 m and stem diameters of 130 cm (Ito *et al*., unpublished data). Thus, it may be advantageous to exchange upper-canopy leaves in the early dry season, when the groundwater level is still high (Fig. 4a; Araki *et al*., 2008).

Moreover, leaf flushing in the early dry season may be advantageous given seasonal variation in solar radia-

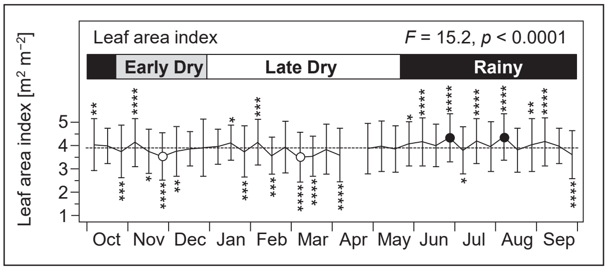

Fig. 9 Seasonal changes in leaf area index (LAI) in Cambodian lowland dry evergreen forests. The LSMs of LAI and 95% prediction intervals for each collection date are shown as connected straight lines and vertical lines, respectively. Collection dates which showed significant positive or negative parameter values are indicated with asterisks above and below the vertical lines, respectively: **** < 0.0001; *** < 0.001; ** < 0.01; and * < 0.05. Closed circles indicate the largest and second largest LAI. Open circles indicate the lowest and second lowest LAI. The horizontal dashed line indicates the mean value (3.93). No data were available for mid-April.

tion. The annual difference in solar radiation was generally small (<10%) but decreased by 20 % in the last two months of the rainy season (Fig. 4b). Therefore, the early dry season represents a period of increased solar radiation and relatively abundant soil moisture, wherein newly flushed leaves with high physiological activity may be advantageous to an individual tree.

Ecological advantages of leaf retention early in the dry season

For low and mid-canopy species, we observed leaf retention and gradual leaf shedding early and late in the dry season respectively (Fig. 6), and estimated leaf flushing from the last phase of the dry season (around mid-May in Table 2 and late April in Fig. 9). Flushing has been widely reported as occurring late in the dry season in tropical dry forests (Borchert, 1994; Elliott *et al*., 2006). The reasons why new leaves develop prior to rainfall have been discussed, and the phenomenon appears to be particularly common among species that are drought-tolerant (Reich & Borchert, 1984) or deeply rooted (Wright & van Schaik, 1994). The discrete leaf phenological patterns we observed raise an additional question: why does the phenology of low- and mid-canopy species differ from that of co-existing upper-canopy species? While we cannot fully answer this question, we discuss the ecological advantages of leaf retention in the early dry season below.

It should be noted that light resources for low- and mid-canopy species are influenced not only by climatic conditions, but also by the leaf mass of upper-canopy species. Our data indicate that the volume of leaves in the canopy is temporarily reduced early in the dry season by leaf shedding among upper-canopy species, whereas low- and mid-canopy species retain their leaves. It can be inferred that light availability for low- and mid-canopy species is optimal in the early dry season. Retaining leaves and continuing photosynthesis may be an adaptive behaviour for low- and mid-canopy species in the early dry season, when light conditions are most favourable. Light and water may be less severely limiting in lowland dry evergreen forests compared to other forests in tropical Asia (Huete *et al*., 2008) and the Neotropics (Saleska *et al*., 2003; Xiao *et al*., 2005; Huete *et al*., 2006; Hutyra *et al*., 2007), but the availability of these resources varies according to canopy position. Plants may exhibit a variety of adaptive phenological behaviours, and the main driver of leaf phenology in tropical East Asia remains unclear (Corlett, 2014). Further clarification of the proximate and ultimate factors driving leaf phenology will advance our understanding of how extreme weather events may influence lowland dry evergreen forests.

Anomalous leaf shedding phenology and its association with lengthy monsoon breaks

An anomalous, gradual leaf shed by tall dipterocarps occurred in the middle of the rainy season in August–September 2008 (Fig. 5, Phase II). The La Niña phase was identified during the 2008 rainy season, whereby a monsoon break began in early August 2008 and lasted 70 days (Fig. 5; Kabeya *et al*., 2021). This break was twice the mean length of monsoon breaks observed in the study area (36 days: Kabeya *et al*., 2021). Monsoon breaks are regarded as short dry seasons (Kabeya *et al*., 2021) and it is possible that the unusual shedding event that we observed was associated with this lengthy monsoon break. While this situation occurred only once during our study period, it may be indicative of a response to extreme weather conditions that could occur more frequently in the future.

Following the blunt peak in leaf shedding for tall dipterocarps in the early dry season in 2008 (Fig. 5, Phase II), we observed a relatively sharp peak in leaf shedding of low- and mid-canopy species in February 2009 (Fig. 6, Phase II). This may also be tied to the lengthy monsoon break. Plausible causes for the latter include the direct effect of water shortage during this period. Unfortunately, we do not have direct data on the quantity and timing of leaf flushing for low- and mid-canopy species during the 2008–2009 dry season. However, if the early and rapid leaf shedding was caused by water shortages, we can assume that the subsequent leaf flushing would have occurred later than usual, and that stand-scale leaf mass remained low until the onset of the rainy season provided sufficient moisture. Conversely, the early, gradual leaf shedding exhibited by upper-canopy dipterocarps may have created an unusually long period of favourable light conditions for low- and mid-canopy species. Other studies have noted the need for further investigation of the effects of anomalies in rainfall on forest water cycles (Tanaka *et al*., 2008). Comprehensive assessments of the impacts of long monsoon breaks on phenology and site environmental conditions is necessary to surmise how extreme weather events will affect lowland dry evergreen forest ecosystems.

Potential changes in leaf phenology resulting from forest degradation

Anthropogenic forest degradation cannot be ignored when assessing the future of lowland dry evergreen forest ecosystems in Cambodia. Deforestation in Cambodia has slowed, but not stopped (MoE, 2018). Due to rapid development in the region, evapotranspiration-related impacts of climate change on river flow in the Mekong River basin have become a concern (Thompson *et al*., 2013). Evergreen forests have been degraded by selective logging (FA, 2011). Dipterocarps, which are the dominant species in typical lowland dry evergreen forests (Rundel, 1999), are among the primary targets for illegal and unreported logging (Kim Phat *et al*., 2002). Forest degradation and phenological changes could have significant impacts on the regional water cycle due to feedbacks between vegetation and the climate system (Saleska *et al*., 2003; Richardson *et al*., 2013).

Degradation in lowland dry evergreen forests may affect local meteorological conditions in the following three respects. First, the removal of tall dipterocarp trees would inevitably reduce stand biomass, as dipterocarp trees account for more than 50% of the total volume of dense (>300 m^3 ha^{-1}) forests (Kim Phat *et al*., 2000; Kao & Iida, 2006). This is likely to influence total evapotranspiration at the stand level. Second, removing large trees may reduce transpiration late in the dry season because the remaining small trees are likely unable to access deep soil moisture (Tamai *et al*., 2008).

Third, forest degradation may alter stand-scale leaf phenology. Our results imply that the removal of tall dipterocarps would reduce newly flushing leaves in the early dry season. Tree-scale transpiration depends on the leaf age structure of the crown and leaf age-dependent physiological activity (Iida *et al*., 2013; Ito *et al*., 2018). Altering the proportions of young and old leaves within the canopy may affect transpiration. Our results also indicate that the selective logging of tall dipterocarps alters the bimodal seasonal pattern in total leaf area. Leaf area is a key parameter for assessing transpiration in forests (Stewart, 1988; Iida *et al*., 2016). Although seasonal changes in total leaf area at our study site were less pronounced than those observed in a deciduous dipterocarp forest (17–20% versus ca. 70%, Table 2, Fig. 9; Iida *et al*., 2020), this variation and further alterations, may affect transpiration at the stand scale. Furthermore, the effects of forest degradation may be compounded by climate change, as discussed in the previous section. As a consequence, further studies should incorporate factors related to leaf phenology into a multi-layer evapotranspiration model (e.g., Tanaka *et al*., 2002, 2003) to assess potential future forest ecosystems.

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References

Araki M., Shimizu A., Kabeya N., Nobuhiro T., Ito E., Ohnuki Y., Tamai K., Toriyama J., Tith B., Pol S., Lim S. & Khorn S. (2008) Seasonal fluctuation of groundwater in an evergreen forest, central Cambodia: experiments and two-dimensional numerical analysis. *Paddy and Water Environment*, **6**, 37–46.

Borchert, R. (1994) Soil and stem water storage determine phenology and distribution of tropical dry forest trees. *Ecology*, **75**, 1437–1449.

Brodribb, T.J. & Holbrook, N.M. (2005) Leaf physiology does not predict leaf habit; examples from tropical dry forest. *Trees*, **19**, 290–295.

Brun, S. (2013) Land cover and forest classification systems of Cambodia. UN-REDD Programme, Phnom Penh, Cambodia. Https://prais.unccd.int/sites/default/files/2018-08/Working_Paper_Land_cover_and_forest.pdf [accessed 18 August 2020].

Cavaleri, M.A., Oberbauer, S.F., Clark, D.B., Clark, D.A. & Ryan, M.G. (2010) Height is more important than light in determining leaf morphology in a tropical forest. *Ecology*, **91**, 1730-1739.

Chann S., Keth N., Nobuhiro T., Araki M., Tamai K., Shimizu T., Kabeya N., Iida S. & Shimizu A. (2011) Interannual variation in the evapotranspiration of an evergreen forest in Kampong Thom, central Cambodia. In *Proceedings of International Workshop on Forest Research in Cambodia*, November 2011 (eds Shimizu A., Chann S., Sawada H., Ohnuki Y. & Tamai K.), pp. 21–24. Forestry and Forest Products Research Institute, Japan and Forestry Administration, Cambodia, Phnom Penh, Cambodia.

Cleland, E.E., Chuine, I., Menzel, A., Mooney, H.A. & Schwartz, M.D. (2007) Shifting plant phenology in response to global change. *Trends in Ecology & Evolution*, **22**, 357–365.

Corlett, R.T. (2014) *The Ecology of Tropical East Asia* (2nd ed.). Oxford University Press, Oxford, UK.

Dale, J. (1988) The control of leaf expansion. *Annual Review of Plant Physiology and Plant Molecular Biology*, **39**, 267–295.

Elliott, S., Baker, P.J. & Borchert, R. (2006) Leaf flushing during the dry season: the paradox of Asian monsoon forests. *Global Ecology and Biogeography*, **15**, 248–257.

Field, C.B. (1987) Leaf-age effects on stomatal conductance. In *Stomatal Function* (eds E. Zeiger, G.D. Farquhar & I.R. Cowan), pp. 367–384. Stanford University Press, California, USA.

[FA] Forestry Administration (2011) *Cambodia Forest Cover 2010*. Forestry Administration, Phnom Penh, Cambodia.

[FA] Forestry Administration & Cambodia Tree Seed Project (2003) *Gene-Ecological Zonation of Cambodia*. Cambodia Tree Seed Project, Forestry Administration, Phnom Penh, Cambodia.

Ghazoul, J., (2016) *Dipterocarp Biology, Ecology, and Conservation*. Oxford University Press, New York, USA.

Huete, A.R., Didan, K., Shimabukuro Y.E., Ratana P., Saleska, S.R., Hutyra, L.R., Yang, W., Nemani, R.R. & Myneni, R. (2006) Amazon rainforests green-up with sunlight in dry season. *Geophysical Research Letters*, **33**, L06045.

Huete, A.R., Restrepo-Coupe, N., Ratana P., Didan, K., Saleska, S.R., Ichii K., Panuthai, S. & Gamo, M. (2008) Multiple site tower flux and remote sensing comparisons of tropical forest dynamics in Monsoon Asia. *Agricultural and Forest Meteorology*, **148**, 748–760.

Hutyra, L.R., Munger, J.W., Saleska, S.R., Gottlieb, E., Daube, B.C., Dunn, A.L., Amaral, D.F., De Camargo, P.B. & Wofsy, S.C. (2007) Seasonal controls on the exchange of carbon and water in an Amazonian rain forest. *Journal of Geophysical Research-Biogeosciences*, **112**, G03008.

Iida S., Ito E., Shimizu A., Nobuhiro T., Shimizu T., Kabeya N., Tamai K., Araki M., Chann S. & Nang K. (2013) Year-to-year differences in sap flow and crown-level stomatal conductance of two species in a lowland evergreen forest, central Cambodia. *Japan Agricultural Research Quarterly*, **47**, 319–327.

Iida S., Shimizu T., Tamai K., Kabeya N., Shimizu A., Ito E., Ohnuki Y., Chann S. & Keth N. (2016) Interrelationships among dry season leaf fall, leaf flush and transpiration: insights from sap flux measurements in a tropical dry deciduous forest. *Ecohydrology*, **9**, 472–486.

Iida S., Shimizu T., Tamai K., Kabeya N., Shimizu A., Ito E., Ohnuki Y., Chann S. & Levia, D.F. (2020) Evapotranspiration from the understory of a tropical dry deciduous forest in Cambodia. *Agricultural and Forest Meteorology*, **295**, 108170.

Ito E., Araki M., Tith B., Pol S., Trotter, C., Kanzaki M. & Ohta S. (2008) Leaf-shedding phenology in lowland tropical seasonal forests of Cambodia as estimated from NOAA satellite images. *IEEE Transactions on Geoscience and Remote Sensing*, **46**, 2867–2871.

Ito E., Tith B., Keth S., Chann S., Kanzaki M., Iida S., Shimizu T., Kenzo T., Tamai K. & Araki M. (2018) Leaf phenology effects on transpiration: leaf age-related stomatal conductance of *Dipterocarpus costatus* during the dry season in a Cambodian seasonally tropical evergreen forest. *Cambodian Journal of Natural History*, **2018**, 63–75.

Kabeya N., Shimizu A., Chann S., Tsuboyama Y., Nobuhiro T., Keth N. & Tamai K. (2007) Stable isotope studies of rainfall and stream water in forest watersheds in Kampong Thom, Cambodia. In *Forest Environments in the Mekong River Basin* (eds Awada H., Araki M., N.A. Chappell, J.V. LaFrankie & Shimizu A.), pp. 125–134. Springer, Tokyo, Japan.

Kabeya N., Shimizu A., Nobuhiro T. & Tamai K. (2008) Preliminary study of flow regimes and stream water residence times in multi-scale forested watersheds of central Cambodia. *Paddy and Water Environment*, **6**, 25–35.

Kabeya N., Shimizu A., Shimizu T., Iida S., Tamai K., Miyamoto A., Chann S., Araki M. & Ohnuki Y. (2021) Long-term hydrological observations in a lowland dry evergreen forest catchment area of the lower Mekong river, Cambodia. *Japan Agricultural Research Quarterly*, **55**, 177-190.

Kao D. & Iida S. (2006) Structural characteristics of logged evergreen forests in Preah Vihear, Cambodia, 3 years after logging. *Forest Ecology and Management*, **225**, 62–73.

Kenzo, T., Ichie T., Yoneda R., Watanabe Y., Ninomiya,I. & Koike,T. (2006) Changes in photosynthesis and leaf characteristics with height from seedlings to mature canopy trees in five dipterocarp species in a tropical rain forest. *Tree Physiology*, **26**, 865–873.

Kenzo, T., Yoneda R., Sano M., Araki M., Shimizu A., Tanaka-Oda A. & Chann S. (2012) Variations in leaf photosynthetic and morphological traits with tree height in various tree species in a Cambodian tropical dry evergreen forest. *Japan Agricultural Research Quarterly (JARQ)*, **46**, 167–180.

Kim Phat N., Ouk S., Uozumi Y. & Ueki T. (2000) Stand dynamics of dipterocarp trees in Cambodia's evergreen forest and management implications. A case study in Sandan District, Kampong Thom. *Journal of Forest Planning*, **6**, 13–23.

Kim Phat N., Kim S., Ouk S., Uozumi Y. & Ueki T. (2002) Management of mixed forest in Cambodia—A case study in Sandan district, Kampong Thom—. *Journal of the Faculty of Agriculture Shinshu University*, **38**, 45–54.

Langner, A., Hirata Y., Saito H., Sokh H., Leng C., Pak C. & Raši, R. (2014) Spectral normalization of SPOT 4 data to adjust for changing leaf phenology within seasonal forests in Cambodia. *Remote Sensing of Environment*, **143**, 122–130.

Matsumoto J. (1997) Seasonal transition of summer rainy season over Indochina and adjacent monsoon region. *Advances in Atmospheric Sciences*, **14**, 231–245.

[MoE] Ministry of Environment (2018) *Cambodia Forest Cover 2016*. Ministry of Environment, Phnom Penh, Cambodia. Https://redd.unfccc.int/uploads/54_3_cambodia_forest_cover_resource__2016_english.pdf [accessed 23 June 2021].

Nobuhiro T., Shimizu A., Tanaka K., Tamai K., Kabeya N., Ito E., Shimizu T., Araki M. & Chann S. (2009) Evapotranspiration characteristics of a lowland dry evergreen forest in central Cambodia examined using a multilayer model. *Journal of Water Resource and Protection*, **1**, 325-335.

Nobuhiro T., Shimizu A., Kabeya N., Tamai K., Iida S. & Shimizu T. (2010) Study of rainfall characteristics in a lowland dry evergreen forest, Cambodia. *Kanto Journal of Forest Research*, **61**, 203–206 [in Japanese].

Ohnuki Y., Kimhean C., Shinomiya Y. & Toriyama J. (2008a) Distribution and characteristics of soil thickness and effects upon water storage in forested areas of Cambodia. *Hydrological Processes*, **22**, 1272–1280.

Ohnuki Y., Shimizu A., Chann S., Toriyama, J., Kimhean C. & Araki M. (2008b) Seasonal change in thick regolith hardness and water content in a dry evergreen forest in Kampong Thom Province, Cambodia. *Geoderma*, **146**, 94–101.

Pallardy, S.G. (2010) *Physiology of Woody Plants*. Academic Press, Burlington, USA.

Pooma, R. (2002) Further notes on Thai Dipterocarpaceae. *Thai Forest Bulletin (Botany)*, **30**, 7–27.

Räsänen, T.A. & Kummu, M. (2013) Spatiotemporal influences of ENSO on precipitation and flood pulse in the Mekong River Basin. *Journal of Hydrology*, **476**, 154–168.

Reich, P.B. & Borchert, R. (1984) Water stress and tree phenology in a tropical dry forest in the lowlands of Costa Rica. *The Journal of Ecology*, **72**, 61–74.

Richardson, A.D., Keenan, T.F., Migliavacca, M., Ryu, Y., Sonnentag, O. & Toomey, M. (2013) Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. *Agricultural and Forest Meteorology*, **169**, 156–173.

Rundel, P.W. (1999) *Forest Habitats and Flora in Lao PDR, Cambodia, and Vietnam*. WWF Indochina Programme, Hanoi, Vietnam.

Scheiter, S., Kumar, D., Corlett, R.T., Gaillard, C., Langan, L., Lapuz, R.S., Martens, C., Pfeiffer, M. & Tomlinson, K.W. (2020) Climate change promotes transitions to tall evergreen vegetation in tropical Asia. *Global Change Biology*, **26**, 5106–5124.

Saleska, S.R., Miller, S.D., Matross, D.M., Goulden, M.L., Wofsy, S.C., da Rocha, H.R., de Camaro, P.B., Crill, P., Daube, B.C., de Freitas, H.C., Hutyra, L., Keller, M., Kirchhoff, V., Menton, M., Munger, J.W., Pyle, E.H., Rice, A.H. & Silva, H. (2003) Carbon in amazon forests: Unexpected seasonal fluxes and disturbance induced losses. *Science*, **302**, 1554–1557.

Stewart, J.B. (1988) Modelling surface conductance of pine forest. *Agricultural and Forest Meteorology*, **43**, 19–35.

Tamai K., Nobuhiro T., Kabeya N., Araki M., Iida S., Shimizu A., Shimizu T., Chann S. & Keth N. (2008) Effects of selective cutting of large trees on transpiration and surface temperature: A predictive study of evergreen broad-leaf forest in central Cambodia. In *From Headwaters to the Ocean: Hydrological Change and Water Management - Hydrochange 2008, 1-3 October 2008, Kyoto, Japan* (eds Taniguchi M., W.C. Burnett, Fukushima Y., M. Haigh & Umezawa Y., 1st ed.), pp. 3–7. CRC Press, London, UK.

Tanaka K., Kosugi Y. & Nakamura A. (2002) Impact of leaf physiological characteristics on seasonal variation in CO^2, latent and sensible heat exchanges over a tree plantation. *Agricultural and Forest Meteorology*, **114**, 103–122.

Tanaka K., Takizawa H., Tanaka N., Kosaka I., Yoshifuji N., Tantasirin, C., Piman, S., Suzuki M. & Tangtham N. (2003) Transpiration peak over a hill evergreen forest in northern Thailand in the late dry season: Assessing the seasonal changes in evapotranspiration using a multilayer model. *Journal of Geophysical Research*, **108**, 4533.

Tanaka K., Takizawa H., Kume T., Xu, J., Tantasirin C. & Suzuki M. (2004) Impact of rooting depth and soil hydraulic properties on the transpiration peak of an evergreen forest in northern Thailand in the late dry season. *Journal of Geophysical Research*, **109**, D23107.

Tanaka N., Kume T., Yoshifuji N., Tanaka K., Takizawa H., Shiraki K., Tantasirin, C., Tangtham, N. & Suzuki M. (2008) A review of evapotranspiration estimates from tropical forests in Thailand and adjacent regions. *Agricultural and Forest Meteorology*, **148**, 807–819.

Tani A., Ito E., Kanzaki M., Ohta S., Khorn S., Pith P., Tith B., Pol S. & Lim S. (2007) Principal forest types of three regions of Cambodia: Kampong Thom, Kratie, and Mondolkiri. In Forest Environments in the Mekong River Basin (eds Sawada H., Araki M., N.A. Chappell, J.V. LaFrankie & Shimizu A.), pp. 201–213. Springer, Tokyo, Japan.

Tani, A., Ito, E., Tsujino, M., Araki, M. & Kanzaki, M. (2011) Threshold determination by reference to open sky overcomes photographic exposure error in indirect leaf area index estimation. *Japanese Journal of Forest Environment*, 53, 41–52.

Thompson, J.R., Green, A.J. & Kingston, D.G. (2013) Potential evapotranspiration-related uncertainty in climate change impacts on river flow: an assessment for the Mekong River Basin. *Journal of Hydrology*, **510**, 1–30.

Toriyama J., Ohta S., Araki M., Ito E., Kanzaki M., Khorn S., Pith P., Lim S. & Pol S. (2007) Acrisols and adjacent soils under four different forest types in central Cambodia. *Pedologist*, **51**, 35–49.

Toriyama J., Ohta S., Araki M., Kanzaki M., Khorn S., Pith P., Lim S. & Pol S. (2008) Comparison of soil physical properties in evergreen and deciduous forests in central Cambodia. *Journal of Forest Research*, **13**, 15–24.

Toriyama J., Ohta S., Araki M., Kosugi K., Nobuhiro T., Kabeya N., Shimizu A., Tamai K., Kanzaki M. & Chann S. (2011) Soil pore characteristics of evergreen and deciduous forests of the tropical monsoon region in Cambodia. *Hydrological Processes*,

25, 714–726.

Toyama H., Tagane S., Chhang P., Kajisa T., Ichihashi R., Samreth V., Vuthy M., Sokh H., Katayama A. & Itadani H. (2013) Inventory of the woody flora in permanent plots of Kampong Thom and Kampong Chhnang Provinces, Cambodia. *Acta Phytotaxonomica et Geobotanica*, **64**, 45–105.

Venkatappa M., Sasaki N., Shrestha R.P., Tripathi N.K. & Ma H.-O. (2019) Determination of vegetation thresholds for assessing land use and land use changes in Cambodia using the Google Earth engine cloud-computing platform. *Remote Sensing*, **11**, 1514.

Wright, S.J. & van Schaik, C.P. (1994) Light and the phenology of tropical trees. *American Naturalist*, **143**, 192–199.

Wu, J., Albert, L.P., Lopes, A.P., Restrepo-Coupe, N., Hayek, M., Wiedemann, K.T., Guan, K., Stark, S.C., Christoffersen, B. & Prohaska, N. (2016) Leaf development and demography explain photosynthetic seasonality in Amazon evergreen forests. *Science*, **351**, 972–976.

Wu, J., Serbin, S.P., Xu, X., Albert, L.P., Chen, M., Meng, R., Saleska, S.R. & Rogers, A. (2017) The phenology of leaf quality and its within-canopy variation is essential for accurate modeling of photosynthesis in tropical evergreen forests. *Global Change Biology*, **23**, 4814–4827.

Xiao, X., Zhang, Q., Saleska, S., Hutyra, L., De Camargo, P., Wofsy, S., Frolking, S., Boles, S., Keller, M. & Moore Iii, B. (2005) Satellite-based modeling of gross primary production in a seasonally moist tropical evergreen forest. *Remote Sensing of Environment*, **94**, 105–122.

Annex 1 List of tree species in the study area with a DBH >5 cm

Family	Species	Tree density (trees ha-1)	Basal Area (m2 ha-1)	Maximum DBH (cm)
Anacardiaceae	*Mangifera duppereana* Pierre	33.3	0.44	22.2
Annonaceae	*Melodorum fruticosum* Lour.	4.2	0.01	5.5
Apocynaceae	*Willughbeia edulis* Roxb.	8.3	0.03	7.4
	Apocynaceae spp. (vine)	12.5	0.04	6.9
Calophyllaceae	*Calophyllum* sp.	4.2	0.03	9.8
Capparaceae	*Capparaceae* sp.	16.7	0.16	14.4
Celastraceae	*Lophopetalum duperreanum* Pierre	58.3	0.46	14.8
Clusiaceae	*Garcinia benthamii* Pierre	4.2	0.11	18.1
	Garcinia lanessanii Pierre	4.2	0.02	8.4
	Garcinia merguensis Wight	4.2	0.01	5.4
Connaraceae	*Ellipanthus tomentosus* Kurz	4.2	0.01	5.7
Dipterocarpaceae	*Anisoptera costata* Korth.	45.8	8.73	92.7
	Dipterocarpus costatus C.F.Gaertn.	25.0	10.86	129.8
	Hopea recopei Pierre ex Laness.	337.5	3.96	24.1
	Vatica harmandiana Pierre	8.3	0.10	16.8
	Vatica odorata (Griff.) Symington	275.0	4.04	26.5
Ebenaceae	*Diospyros filipendula* Pierre ex Lecomte	12.5	0.19	20.2
	Diospyros montana Roxb.	4.2	0.02	8.6
	Diospyros undulata Wall.	75.0	0.29	10.6
	Diospyros venosa Wall. ex A.DC.	145.8	0.92	15.4
Euphorbiaceae	*Croton poilanei* Gagnep.	8.3	0.12	18.5
	Suregada glomerulata Baill.	8.3	0.02	5.6
Fabaceae	*Albizia corniculata* (Lour.) Druce	4.2	0.05	12.7
	Sindora siamensis Teijsm. ex Miq.	29.2	2.23	70.4

Annex 1 Cont'd

Family	Species	Tree density (trees ha^{-1})	Basal Area (m^2 ha^{-1})	Maximum DBH (cm)
Fagaceae	*Lithocarpus harmandii* (Hickel & A.Camus) A.Camus	4.2	0.02	8.5
Irvingiaceae	*Irvingia malayana* Oliver ex A.Benn.	4.2	0.46	37.4
Lauraceae	*Beilschmiedia inconspicua* Kosterm.	12.5	0.10	13.8
Malvaceae	*Microcos tomentosa* Sm.	12.5	0.05	8.2
Melastomataceae	*Memecylon caeruleum* Jack	37.5	0.31	24.0
	Memecylon lilacinum Zoll. & Moritzi	12.5	0.05	8.8
	Memecylon sp.1	16.7	0.08	11.1
	Memecylon sp.2	41.7	0.17	8.9
Myristicaceae	*Knema globularia* (Lam.) Warb.	4.2	0.02	8.1
Myrtaceae	*Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C.Gaur	12.5	0.08	10.5
	Syzygium angkae (Craib) Chantaran. & J.Parn	12.5	0.21	21.2
	Syzygium chanlos (Gagnep.) Merr. & L.M.Perry	54.2	1.02	22.5
	Syzygium grande (Wight) N.P.Balakr.	8.3	0.15	19.5
	Syzygium oblatum (Roxb.) Wall. ex Cowan & Cowan	54.2	1.00	35.0
	Syzygium syzygioides (Miq.) Merr. & L.M. Perry	75.0	2.33	38.0
	Syzygium zeylanicum (L.) DC.	16.7	0.07	9.7
Ochnaceae	*Ochna integerrima* (Lour.) Merr.	12.5	0.03	5.4
Pentaphylacaceae	*Ternstroemia wallichiana* Ridl.	33.3	0.28	15.7
Peraceae	*Chaetocarpus castanocarpus* Thwaites	16.7	0.24	21.1
Phyllanthaceae	*Antidesma puncticulatum* Miq.	4.2	0.02	8.7
	Aporosa ficifolia Baill.	29.2	0.24	14.4
	Aporosa planchoniana Baill. ex Müll.Arg.	8.3	0.02	5.5
	Aporosa tetrapleura Hance	8.3	0.03	6.3
	Hymenocardia punctata Wall. ex Lindl.	4.2	0.02	6.9
Polygalaceae	*Xanthophyllum flavescens* Roxb.	95.8	1.80	35.0
Rhizophoraceae	*Carallia brachiata* (Lour.) Merr.	4.2	0.01	5.8
Rutaceae	*Clausena excavata* Burm.f.	4.2	0.01	5.0
Sapindaceae	*Nephelium hypoleucum* Kurz	12.5	0.11	14.0
	Xerospermum laevigatum Radlk. ssp. *laevigatum*	4.2	0.01	6.3
Schoepfiaceae	*Schoepfia fragrans* Wall.	8.3	0.03	6.9
Stemonuraceae	*Gomphandra* sp.	4.2	0.02	8.7
Symplocaceae	*Symplocos cochinchinensis* S.Moore ssp.*laurina* (Retz.) Noot.	8.3	0.11	17.4
Unknown	Unidentified sp.01	4.2	0.05	12.7
	Unidentified sp.02	4.2	0.04	11.2
	Unidentified sp.03	4.2	0.04	11.7
	Unidentified sp.04	4.2	0.02	8.7

Annex 1 Cont'd

Family	Species		Tree density (trees ha^{-1})	Basal Area (m^2 ha^{-1})	Maximum DBH (cm)
	Unidentified sp.05		4.2	0.02	7.1
	Unidentified sp.06		4.2	0.10	17.7
	Unidentified vein sp.01		12.5	0.03	6.4
	Unidentified vein sp.02		8.3	0.04	9.2
		Total	**1817**	**42.3**	**129.8**

Snaring epidemic threatens an Endangered banteng *Bos javanicus* population of global conservation significance in southwest Cambodia

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ទន្សោង (*Bos javanicus*) គឺជាប្រភេទសត្វជិតផុតពូជ ដែលកំពុងទទួលរងការគំរាមកំហែងយ៉ាងធ្ងន់ធ្ងរ ដោយសារការរីករាលដាលនៃអន្ទាក់ នៅទូទាំងអាស៊ីអាគ្នេយ៍។ តំបន់ភាគឦសាននៃប្រទេសកម្ពុជា គឺជាទីតាំងមួយក្នុងចំណោមទីតាំងផ្សេងទៀតក្នុងសកលលោក ដែលសម្បូរទៅដោយប្រភេទសត្វកម្រ ចំណែកភាគនិរតីឯណោះវិញ បានក្លាយជាទីតាំងបន្ទាប់ដ៏សំខាន់សម្រាប់ពពួកសត្វទន្សោងរស់នៅ។ អរគុណដល់ក្រុមល្បាតរបស់សហគមន៍ ដែលបាន និងកំពុងធ្វើការល្បាតនៅទូទាំងតំបន់ព្រៃសហគមន៍ប្រាំបីមុម និងចម្ការដែលនៅជុំវិញតំបន់នោះ តាំងពីឆ្នាំ២០០៣មក។ នៅដើមឆ្នាំ២០២០ ការងារល្បាតត្រូវបានធ្វើកំណែទម្រង់ថ្មី ជាមួយនឹងវិធីសាស្ត្រល្បាតរបស់កងកម្លាំងសហគមន៍ទប់ស្កាត់ការបរបាញ់ខុសច្បាប់ ហៅកាត់ថា (CAPU) និង កិច្ចស្រាវជ្រាវតាមរយៈការបង្កប់ម៉ាស៊ីនថតស្វ័យប្រវត្តិ។ ការស្រាវជ្រាវនេះ ធ្វើឡើងក្នុងគោលបំណងកំណត់ចំនួន និងរក្សាទុកជាឯកសារ អំពីបម្រែបម្រួលអន្ទាក់ រួមទាំងផលប៉ះពាល់របស់វា ក្នុងការគំរាមកំហែងដល់ជីវិតសត្វទន្សោងដែលរស់នៅក្នុងតំបន់នោះ តាមរយៈការប្រៀបធៀបទិន្នន័យដែលមាននាអំឡុងពេលដូចគ្នា ក្នុងឆ្នាំ២០២០ និងឆ្នាំ២០២១។ ដើម្បីវាស់ស្ទង់បម្រែបម្រួលនៃកិច្ចខិតខំល្បាតនេះ អាត្រានៃម៉ោងល្បាត/ការដោះអន្ទាក់ប្រចាំខែ ត្រូវបានគណនាដោយប្រើប្រាស់នូវទិន្នន័យរបស់ (CAPU) ចាប់ពីខែកុម្ភៈ ដល់ កក្កដា ក្នុងឆ្នាំ២០២០ និង ២០២១។ នៅចន្លោះពេលនេះ អាត្រានៃការដោះអន្ទាក់បានកើនឡើង៥៥% ពោលគឺកើនពី ០.៥អន្ទាក់ ដល់ ១.១អន្ទាក់ ក្នុងរយៈពេលល្បាតមួយម៉ោង។ និន្នន័យចាស់អំពីការស្លាប់ និងរបួសរបស់ទន្សោងដោយសារអន្ទាក់ចេញពីម៉ាស៊ីនថតស្វ័យប្រវត្តិ ធៀបនឹងទិន្នន័យថ្មី ក៏បង្ហាញការកើនឡើងផងដែរ។ កំណើននៃអន្ទាក់នេះ កើតឡើងស្របពេលជាមួយគ្នានឹងកំណើននៃជម្ងឺកូវីត១៩ ហើយវាកាន់តែជះឥទ្ធិពលអាក្រក់ដល់សេដ្ឋកិច្ច និងសង្គម ដែលបណ្ដាលមកពីការឆ្លងរីករាលដាល ក្នុងប្រទេសកម្ពុជា។ ប្រសិនបើកំណើននេះនៅតែបន្ត ចំនួនសត្វទន្សោងនៅក្នុងតំបន់ប្រាំបីមុមអាចនឹងត្រូវបាត់បង់ទាំងស្រុង លុះត្រាតែរដ្ឋបាលព្រៃឈើជំរុញបន្ថែមដល់ការអនុវត្តច្បាប់របស់ខ្លួនសម្រាប់សហគមន៍ល្បាត។

Abstract

Banteng *Bos javanicus* is an Endangered wild cattle species that is highly threatened by the Southeast Asian snaring epidemic. While northeast Cambodia is one of the species' global strongholds, an important banteng subpopulation has survived in southwest Cambodia thanks to a group of community rangers who have patrolled the Prambei Mom Community Forest and surrounding plantations since 2003. In early 2020, the patrols were formalized using the Community Anti-Poaching Unit (CAPU) approach and a camera trap survey was initiated. The aim of our study was to quantify and document changes in snaring intensity and its impacts on the local banteng population by comparing

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available data for 2020 with the same period in 2021. To account for variations in ranger patrol efforts, monthly rates of snare removal/patrol-hour were calculated over time using CAPU data for February–July 2020 and 2021. Between these periods, the rate of snare removal increased 55% from 0.5 snares/patrol-hour to 1.1 snares/patrol-hour. Camera trap data for bantengs with old versus new snare wounds and documented deaths also showed upward trends. This surge in snaring coincides with significant growth in COVID-19 cases and worsening socio-economic impacts from the pandemic in Cambodia. If these trends continue, the banteng population at Prambei Mom will likely be extirpated unless the Forestry Administration can increase its law enforcement support for community ranger patrols.

Keywords Banteng, Cambodia, community anti-poaching, COVID-19 impacts, patrolling, snaring epidemic.

Introduction

Southeast Asian wildlife faces an unprecedented snaring epidemic that is driving defaunation of forest habitats (Belecky & Gray, 2020) and studies have shown that "near total loss of certain groups of taxa, particularly large mammals" is increasing, even in remaining areas of good quality forest (Gray *et al*., 2021). Snares made of affordable and easily available materials such as cord or wire are widely used for hunting (O'Kelly *et al*., 2018). These are almost indiscriminate and when heavily distributed in large numbers throughout the forest floor pose an especially high threat to ground-dwelling mammals such as bantengs *Bos janavicus* (Dobson *et al*., 2019b; Gray *et al*., 2021). Snares are one of the cruelest forms of hunting, as animals can be held for days before eventually perishing from dehydration or starvation. They are also extremely wasteful, with one study finding up to 60% of animals found in snares were decomposed (Gray *et al*., 2021). Even animals that manage to escape often die afterwards from infections or injuries. This is particularly the case for larger mammals that break free, as the snare noose can remain around the leg, constricting the flow of blood. This causes infection, usually the loss of the lower part of the snared limb, and ultimately the death of the animal. Rescues of snared animals brought for treatment to Phnom Tamao Wildlife Rescue Centre, Takeo Province, Cambodia, often die if the injury is long-standing because appropriate treatment has not been administered soon enough (N. Marx, pers. obs.).

Cambodia is a global stronghold for bantengs, an Endangered species of wild cattle which is rapidly declining due to extensive habitat loss and hunting. Gardener *et al*. (2016) estimated the remaining global population of bantengs at 8,000 individuals, around 60% of which occur in northeastern Cambodia. While the latter authors confirmed bantengs as Endangered, they also stated "Declines in the Indochinese population are likely to approach the threshold (80% ongoing decline) rate for listing as Critically Endangered". In addition, following a multi-year survey of ground-dwelling mammals in southwestern Cambodia, it was concluded bantengs had been extirpated (Gray *et al*., 2017). However, Wildlife Alliance (WA) staff learned from Facebook posts in 2018 that a substantial banteng population still existed at the edge of this region in Prambei Mom (Kampong Speu Province), thanks to the vigilant protection of several herds by a group of local community rangers since 2003 (Fig. 1).

Long-term dedication to voluntary patrolling is rare in Indochina, or indeed anywhere. The community rangers at Prambei Mom persevere because they genuinely value 'their' bantengs and because, like the bantengs and other wildlife present, they also depend on the remaining forests. Local people harvest non-timber forest products (NTFP) from the area, although these are a diminishing resource as surrounding forests have been converted into sugarcane plantations by wealthy outsiders. Despite their best efforts, local villagers estimate approximately 14 bantengs were killed by hunters between 2003 and early 2018 (Sassoon & Phak, 2018). Additionally, the banteng population in Prambei Mom is now severely threatened by sudden and significant increases in snaring which began in 2021.

The 16 community rangers at Prambei Mom protect its banteng population from hunting parties and snares set by poachers in the forest and adjacent plantations. With support from the Forestry Administration (FA), the rangers created the Prambei Mom Community Forest (PMCF) in 2003 to gain management rights over a patch of forest used by the bantengs. An official agreement was signed in March 2018 which designated 937 ha as belonging to the PMCF and an additional 253 ha were added in September 2018 (Fig. 1). Wildlife Alliance began providing technical and financial support in early 2018 when the community requested help to capture an adult bull banteng that had been injured by a snare and broken free. In addition to poaching and snaring by locals, the banteng herds in Prambei Mom were targetted by safari-style hunting expeditions arranged by powerful outsiders until professional rangers apprehended an individual in

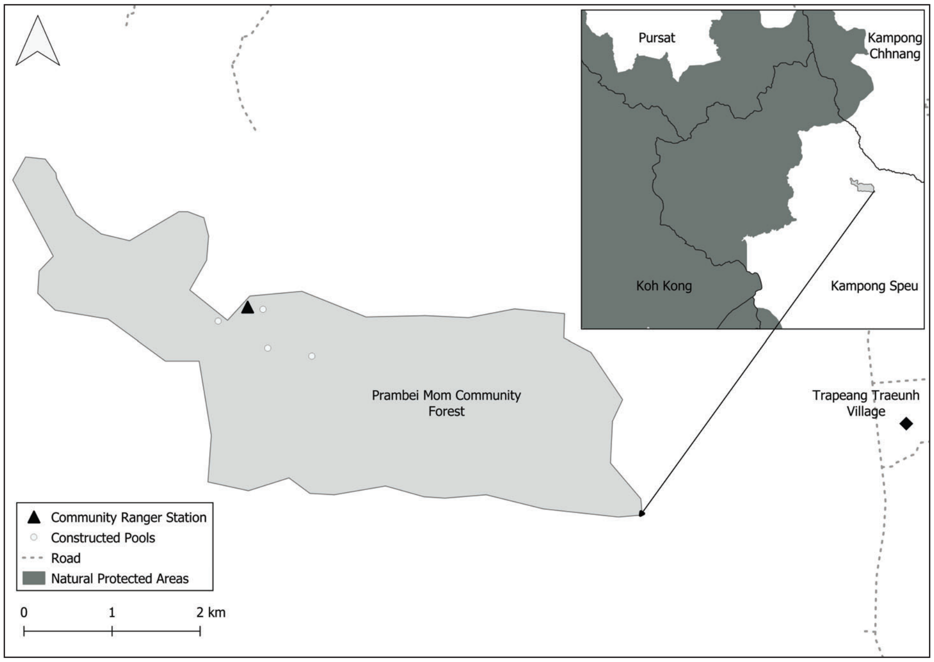

Fig. 1 Location of Prambei Mom Community Forest and nearby protected areas in southwest Cambodia.

2018 who eventually served jail-time for his crime. While this case effectively ended large-scale shooting incidents at the site, snares remain a grave threat.

The banteng population in Prambei Mom moves between a patch of dry deciduous dipterocarp forest in Thboung District and surrounding areas which have been converted into sugarcane plantations. Initial estimates based on interviews with community members in 2019–2020 suggest the population numbers approximately 50 individuals across at least three herds, and an ongoing camera trap survey is being conducted to provide a robust estimate (Marx, 2021). Given the threat posed by snares, WA support has focused on strengthening patrols by providing the rangers with professional patrol equipment, introducing new patrol techniques and strategies, and training them to systematically collect data on their results following the Community Anti-Poaching Unit (CAPU) approach developed by WA to safeguard its release sites for rescued animals.

The PMCF is the only CAPU site supported by WA that does not from part of a larger protected area managed by the FA or Ministry of Environment (MoE) and WA does not directly manage the site. The FA is the governing authority responsible for protecting wildlife within the PMCF and the surrounding sugarcane plantations used by the bantengs. Most snares removed by rangers are located in the latter area and increasing numbers of snares were detected and removed in 2021 compared to 2020, suggesting that banteng populations at the PMCF now face a greater risk of extirpation.

Few studies have been published on the impacts and reach of snaring in Southeast Asia, despite the significant threat this poses to the region's biodiversity (Gray *et al*., 2018). Bantengs are highly susceptible to snaring and more research is needed on the species-specific impacts of snaring (Groenenberg *et al*., 2020; Figel *et al*., 2021), especially studies based on patrols and analyses that account for imperfect detection rates, such as Linkie *et al*. (2015) who assessed the impact of snare removal on a population of tiger *Panthera tigris* in Sumatra. Although the available patrol data for the PMCF does not include variables that would allow us to control for snare detection rates or evaluate the effectiveness of patrols, our work contributes to a growing body of research on the impact of snaring on a specific large mammal species.

This study documents a rapid increase in snaring in and around the PMCF and estimates its immediate impacts on the local banteng population. To this end, we compare monthly CAPU patrol data for February–July 2021 to data for the same period in 2020 to quantify the changes in snaring that have occurred. These data are supplemented by evidence from camera trap photos taken between March 2020 and August 2021 to illustrate the impact of increased snaring on banteng herds by providing a rough estimate of the numbers of animals with snare wounds, specifically individuals with wounds newly identified in March–August 2020 versus the same period in 2021.

The surge in snaring described in this article coincides with the COVID-19 pandemic, which originated from a novel virus that emerged in late 2019 in Wuhan, China and spread to 100 countries by early 2020 (Shereen *et al*., 2020). While many countries experienced rapid increases in cases and implemented severe domestic measures to curb the spread of the virus in 2020, Cambodia opted to essentially seal its borders by severely limiting international arrivals and introducing strict quarantine protocols for entrance. This devastated the international tourism sector, but largely spared Cambodia from the health crisis and measures designed to prevent the spread of COVID-19 that disrupted life elsewhere in 2020. Following the first severe community outbreak in February 2021 and rapid growth in COVID-19 cases however, the government introduced lockdowns in the capital and major cities, inter-provincial travel restrictions and widespread closures of local markets where outbreaks were identified (Tatum, 2021). As the timing of our work coincides with worsening socio-economic impacts experienced in Cambodia due to the pandemic in 2021, we discuss our findings in the context of the COVID-19 pandemic, thus responding to the recent call for "ground truthing efforts to assess whether the reported impacts of COVID-19 have resulted in heightened poaching" (Waithaka, 2020).

Methods

Community anti-poaching unit patrols

Members of the CAPU at Prambei Mom are paid a small monthly stipend to patrol each week and ensure the bantengs are protected. The team patrols on foot and on motorcycles to remove snares and prevent further forest encroachment. They also ensure that natural resource use within the PMCF accords with its management plan (e.g., that people harvest NTFPs in the correct season and respect permitted quantities, etc.). Patrol data are collected in the field by CAPU members using a basic worksheet in Khmer language and submitted each month to a WA staff member who checks the data, translates it into English and tabulates this in Excel. Variables recorded include: date, number of calendar days patrolled, number of patroller-days (patrollers x calendar days), start and end times, locations, number of snares removed, length of snares (if applicable), and relevant notes (e.g., if an animal was removed from a snare or time was spent on other activities). The data are then reviewed periodically by a different staff member, who checks for errors, clarifies as needed, finalizes the data and analyses results. The CAPU patrol reports include all time spent on the project, including activities such as fighting wildfires, constructing pools to provide water for bantengs and meetings with FA officials to resolve conflicts with neighbouring sugarcane plantations. As these are essential to conserve the banteng herds but do not involve patrolling the forest to detect and remove snares, all time spent on such activities were excluded from our analysis.

The number of days and time spent patrolling on a given day by the CAPU can vary greatly. For example, the number of calendar days patrolled per month ranged from 6–26 and the number of patroller-days per month ranged from 61–244 in February–July 2020 and February–July 2021. Numerous studies have pointed out the need to control for variations in ranger patrol effort (RPE) when assessing patrol results (Dong *et al*., 2021). Because measures such as the number of days patrolled do not account for the amount of time actually spent patrolling each day (O'Kelly, 2013), we employed the number of hours patrolled as a measure for RPE (Table 1). These were calculated from the reported start and end times of the patrols and the number of snares removed were divided by the number of hours patrolled to generate the rate of snare removal per month.

Known banteng fatalities and camera trap evidence

A number of fatalities due to snaring have been documented in the PMCF since March 2018 and evidence from camera traps suggests that numbers of bantengs with visible snare wounds (e.g., swollen and infected hooves, missing feet, abrasions and scars around legs from snares) or snares still attached to their legs have increased. As sample sizes were insufficient for statistical analysis however, we employed the number of confirmed banteng deaths from March 2018 to August 2021 as a measure of the impact of increased snaring on banteng herds at the site.

Table 1 Variables selected to quantify the rate of snare removal at Prambei Mom Community Forest.

Variable	Definition	Calculation
Ranger patrol effort	Number of hours patrolled	End time - start time = total hours
Snare volume	Total number of snares removed	N/A (provided on patrol sheets)
Rate of snare removal	Number of snares removed/patrol-hour	Snare hours = snares/patrol-hour

Eight camera traps (Bushnell HD Model 119739, Illinois, USA) were installed in the PMCF in March 2020 as part of a capture-mark-recapture study to estimate the population size, herd demographics and health of bantengs in the area. To maximise detection rates, the cameras were placed at least 0.5 km apart in locations that bantengs were known by the community rangers to frequent, such as waterholes and trails with consistent sightings of dung and footprints. To photograph a greater proportion of the herd and defining features of individual animals as they moved in front of cameras (e.g., differences in horns, coat colour, rips in ears and scars), each camera was set at least 1 m above ground level and activated by heat and movement, triggering bursts of three consecutive photographs at one second intervals. Two cameras were stolen, one in July 2020 and a second in August 2020 which was later replaced at a nearby location. A third camera was retrieved after a section of forest was cleared to expand the bordering sugarcane plantation and deployed in a different location within the forest boundary in October 2020. Camera trap effort (equalling the sum of cameras x operational days) was partitioned between years and was calculated from the date a camera was set in March 2020 until 31 December 2020 (or in the case of one camera, the last date images were retrieved before it was stolen) and from 1 January 2021 to 31 August 2021. Periods that cameras were not in operation due to malfunction, theft or interference were excluded from analysis.

Photographs taken between March 2020 and August 2021 were analysed, and distinct individuals with clearly visible wounds from snares were counted the first time they appeared in a photo. Wounds included in counts were as follows: snares around legs, abrasions or scars in a single line around the leg indicating contact with a snare, swollen and infected hoofs and missing feet. Animals that could not be distinguished from a previously recorded individual with a similar wound were omitted to avoid double counts. Snare wounds were categorized as either 'old' or 'new'. 'New' wounds were defined as either the first photographs of an identifiable individual seen in previous months without a wound or a wound that had a newly visible clear cut or blood from a snare, whereas 'old' wounds were defined as distinct individuals photographed for the first time with a swollen or infected hoof, missing foot or scarring from a snare with no blood present. Wounds were then classified as 'active' or 'stable' as of August 2021, based on progression of the injury and the body condition of an individual over the study period. 'Active' wounds were defined as infections that remained open, increased swelling, loss of hoof or limb, or where the banteng's weight decreased consistently and dramatically over the study period (as opposed to minor seasonal fluctuations in body weight seen in the population). 'Stable' wounds were defined as injuries that did not progress over the study period or reduced in severity and where the individuals' body condition appeared unaffected. Wounded bantengs only photographed on a few occasions or with new wounds in 2021 were classified as 'unknown' because progression could not be determined. Numbers of old and new snare wounds registered in each year were compared. Whereas old wounds could have been inflicted by snares laid at any time in the past, new wounds were assumed to be due to snares laid more recently because the CAPU team regularly patrols and removes any snares encountered.

Limitations

Dobson *et al*. (2019a) have pointed out the challenges of determining to the extent to which patrolling deters hunters from setting snares in the future. Measuring the degree of deterrence is beyond the scope of our analysis. However, the level of support for the CAPU team and the patrolling methods adopted did not change substantially during the study period and the same methods of data collection and analysis were applied throughout the study. As such, there is no reason to suspect significant changes occurred in the degree of deterrence or effectiveness of patrols in detecting snares. Similarly, the legal penalties applied for setting snares did not change during the study period. As such, we assumed any increase in the number of snares removed in 2021 compared to 2020 was due to greater numbers of snares being set, as opposed to improved snare detection rates in patrols or any changes in their deterrence to poachers, such as reduced penalties.

Our patrol data does not include any variables that can be used to measure the quality of patrols, as opposed to their quantity. However, while many patrol teams comprise full-time professionals who are paid to do the job and may be assigned to other areas by their employer (e.g., a government agency or NGO), all patrols in the PMCF are undertaken by local volunteers, most of whom have been continuously engaged at the site since 2003. There is no reason to suspect declines in patrol quality due to decreased motivation, although it may have increased as a result of better equipment and support since 2018 and the introduction of the CAPU approach in early 2020. Nonetheless, since the patrol methods and team composition did not change significantly during the study period, the influence of any changes in patrol quality on our results is likely to be marginal.

Due to their movement and the limited time animals spend in front of camera traps, there are limitations in our ability to recognize and define wounds, as well as distinguishing animals that have similar wounds and no defining physical characteristics. This could potentially have led to under-counting of snared individuals in our analysis. Determining the progression of wounds from camera trap data also makes it difficult to define when animals have come into contact with snares. Categorizing wounds as 'active' or 'stable' is limited to interpretations of the progression of injuries in photographs and confined to a short period. As infections progress, more serious injuries have a higher detection likelihood, so the early stages of infections when a snare has initially broken off and constricted the end of a hoof could have been overlooked in analysis. Continued monitoring of the herd will provide a clearer understanding of individual outcomes and impact of snares on the population.

Results

By all measures examined, the number of snares threatening the PMCF banteng population was greater in February–July 2021 than the same period in 2020. It is not possible to compare numbers of snares removed from the PMCF with the surrounding sugarcane plantations over the entire study period because the CAPU team only began to track snares removed from inside vs. outside the PMCF in January 2021. However, based on the data for 2021 and discussions with the rangers throughout 2020–2021, it is clear the majority of the snares were removed from the surrounding plantations and not from the PMCF itself. For example, of the 448 snares removed in February–July 2021, only 66 were removed from the PMCF whereas 382 were removed from the sugarcane plantations.

Community anti-poaching unit patrols

The total number of snares removed by the PMCF CAPU in February–July 2021 was almost 200% higher than the same period in 2020 (Table 2). Due to concerns in early 2021 about what appeared to be a significant increase in snaring however, the rangers increased their RPE by 37% compared to 2020. Using the rate of snare removal to control for the increased RPE, numbers of snares removed per patrol hour in 2021 were 55% greater than in 2020.

The time dedicated to patrols (and possibly also the time poachers have to set snares) in Prambei Mom varies seasonally more than at many other sites because the PMCF CAPU team consists of local volunteers who are subsistence farmers, whereas in other areas ranger teams typically receive salaries comparable to full-time employment. For example, the patrol schedule for the PMCF is affected by the rice sowing and harvesting seasons and in February–March of 2020 and 2021, the CAPU team conducted fewer patrols because more time was spent fighting wildfires. Notwithstanding this, the number

Table 2 Ranger patrol effort (RPE), snare volume and rate of snare removal at Prambei Mom Community Forest in February–July of 2020 and 2021.

Month	2020				2021				% Change		
	RPE	Snare Volume		Rate	RPE	Snare Volume		Rate	Snare Volume		Rate
	No. of Patrol Hours	Length of Snares (m)	Total Snares Removed	Snares/ Patrol-Hour	No. of Patrol Hours	Length of Snares (m)	Total Snares Removed	Snares/ Patrol-Hour	Total Snare Length	Total Snares/ Month	Snares/ Patrol-Hour
Feb.	42.5	0	0	0	65.8	24.0	33	0.5	NA	NA	NA
Mar.	31.5	40.0	15	0.5	68.9	50.0	69	1.0	25.0	360.0	110.0
Apr.	34.7	75.0	48	1.4	57.9	220.0	100	1.7	193.3	108.3	24.8
May	18.0	0	0	0	56.4	52.0	25	0.4	NA	NA	NA
Jun.	88.5	0	0	0	74.9	90.0	85	1.1	NA	NA	NA
Jul.	68.6	220.0	87	1.3	65.9	238.0	136	2.1	8.2	56.3	62.7
Total	**283.7**	**335.0**	**150**		**389.8**	**674.0**	**448**		**101.2**	**198.7**	
Mean				**0.5**				**1.1**			**54.5**

of snares removed per patrol hour was higher in every month in 2021 than 2020 (Fig. 2).

Known banteng fatalities and camera trap evidence

As of August 2021, at least five bantengs have been killed in the PMCF by hunters and/or snares since early 2018 (Table 3). Following the arrest of a hunter who shot an adult male banteng in March 2018, no further safari-style shooting incidents have occurred at the site. However, local hunters with rifles were recorded by camera traps in May 2020, which resulted in their apprehension the following month.

Over a total of 2,076 camera trap nights in 2020, six distinct bantengs were photographed with wounds between March and May, with only one newly inflicted snare injury (Table 4). Of these six individuals, one has likely died from the injuries (Table 3, No.5) and two infections remained active on individuals as of August 2021. No wounds fully healed over the study period. Seven new individuals were photographed with injuries in April–August 2021, of which six appeared to be new wounds or distinct bantengs not previously identified with any injury over 1,592 camera trap nights (Table 4). Figure 3 shows examples of different animals photographed during the study period with old or new snare wounds. Four of the six individuals identified in 2020 were male, compared to two of the seven animals registered in 2021. Although calves and juveniles were photographed during the study period, including eight distinct calves, none showed evidence of injuries due to snares.

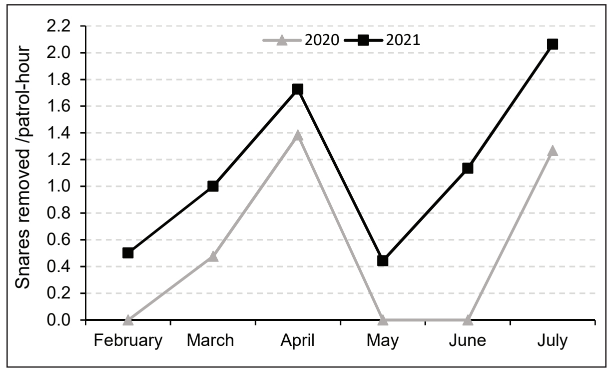

Fig. 2 Variation in snare removal rates in Prambei Mom Community Forest in February–July of 2020 and 2021.

Discussion

By every measure, threats posed by snares to the banteng population in the PMCF escalated alarmingly between February–July 2020 and the same period in 2021. The volume of snares detected within the PMCF and surrounding sugarcane plantations increased almost 200% in 2021 and despite additional patrol efforts the same year, the hourly rate at which snares were detected and removed increased almost 55%. More bantengs were also identified with snaring wounds or broken snares on their legs from camera trap images in 2021, despite greater sampling effort in 2020. In addition, two were killed by snares in 2018–2019 and one was shot, and two more have died since the CAPU approach was introduced in 2020. Furthermore, because the banteng population moves between the PMCF and surrounding

Table 3 Documented fatalities of adult bantengs in Prambei Mom Community Forest in 2018–2021.

No.	Year	Month	Sex	Cause of Death	Details
1	2018	Mar.	Male	Shot	Rangers called WA when they heard shots fired, and a law enforcement team apprehended the hunter.
2	2018	Apr.	Male	Snare injury	Banteng was snared but broke free and was wandering around injured. WA staff and rangers ultimately captured and treated the animal, but it died under sedation.
3	2019	Mar.	Female	Snare injury	Banteng was snared but broke free and was wandering around injured. WA staff and rangers ultimately captured and treated the animal, but it died under sedation.
4	2020	Feb.	Male	Snare injury	Found dead in a snare. Had also lost a leg due to a previous snare injury.
5	2021	Aug.	Male	Snare injury	A male banteng frequently captured on three cameras with a swollen front right hoof and missing front left foot was last photographed 5 July 2021. Rangers discovered an old carcass near the pool where this male was last photographed on 13 August. This was too decomposed to determine if it was the same male although this is highly likely.

Table 4 Banteng with snare injuries detected by camera traps in Prambei Mom Community Forest in March 2020–August 2021.

No.	First Record	Details of Wound	Age of Wound	Status of Injury [1]	Age of animal	Sex (M/F)	Distinguishing features of animal (if present)
1	Mar.'20	Swollen front left hoof, line of blood from snare	New	Active	Adult	M	Yellow coat, large slit in lower left ear
2	Mar.'20	Swollen and infected front left hoof	Old	Active	Adult	M	Dark brown, slit in upper left ear
3	Apr.'20	Swollen front right hoof, missing front left foot	Old	Death from injury suspected	Adult	M	Fig. 3, upper left image
4	May'20	Swollen front right hoof, scar line on leg from snare	Old	Stable	Adult	M	Dark brown, small tear on upper right ear
5	May'20	Scar line on upper front right leg, swollen front left hoof	Old	Stable	Adult	F	Long, curved horns, left horn curved under right
6	May'20	Missing front left foot	Old	Unknown	Adult	F	Short upright horns, no curve
7	Apr.'21	Swollen and infected front left hoof, open wound	Old	Active	Adult	M	Yellow coat, tear on upper and lower left ear (Fig. 3, upper right image
8	Apr.'21	Infected lower front right leg, raw skin in line from snare	New	Unknown	Adult	F	
9	Jun.'21	Swollen front left hoof	New	Unknown	Adult	F	
10	Jun.'21	Front right leg, open bleeding wound and visible snare still attached to leg	New	Unknown	Adult	F	Broken left horn (Fig. 3, lower left image)
11	Jun.'21	Infected back right foot, open wound	New	Unknown	Adult	F	
12	Jul.'21	Straight line cut into right front leg, snare possibly still attached to leg, no visible infection	New	Unknown	Sub-adult	M	
13	Aug.'21	Left back leg, line cut from snare, blood visible	New	Unknown	Adult	F	Fig. 3, lower right image

[1] As of August 2021.

sugarcane plantations, it is also likely some deaths were not discovered by patrols such that the true number of fatalities is higher than presently documented.

Similar increases in the number of snares, hunting camps and live animals discovered in snares have been documented at other sites patrolled by CAPU's and professional ranger teams in Cambodia. For example, the Chi Phat CAPU operates in southwest Cambodia, patrolling forests that surround a wildlife release station in Tatai Wildlife Sanctuary. In February–July 2021, the rate of snare removal at Chi Phat increased >85%, while the quantity of normal (non-civet) snares detected increased almost 360% compared to the same period in 2020 (WA, unpublished data). In just 5-weeks in April–May 2021, the Chi Phat CAPU discovered two hunting camps with snare lines set nearby, evidence of hunting dogs, and separate bands of hunters with their dogs, a rare occurrence in previous years. In addition, whereas the CAPU team in the Phnom Tamao Protected Forest did not find any live animals snared in February–July 2020, a live sambar *Rusa unicolor* stag was found snared around the neck during the same period in 2021. Similarly, professional ranger patrols undertaken by the Cardamom Forest Protection Program removed greater numbers of snares in February–July 2021 compared with the same period in 2020. In this case, the volume of snares removed increased 22% from 9,422 snares in 2020 to 11,517 snares in 2021, whereas the length of wildlife netting removed increased 55% (WA, unpublished data). Taken together, these results indicate that the number of snares set, detected and removed in sites across Cambodia increased markedly in February–July 2021 compared with the same period in 2020.

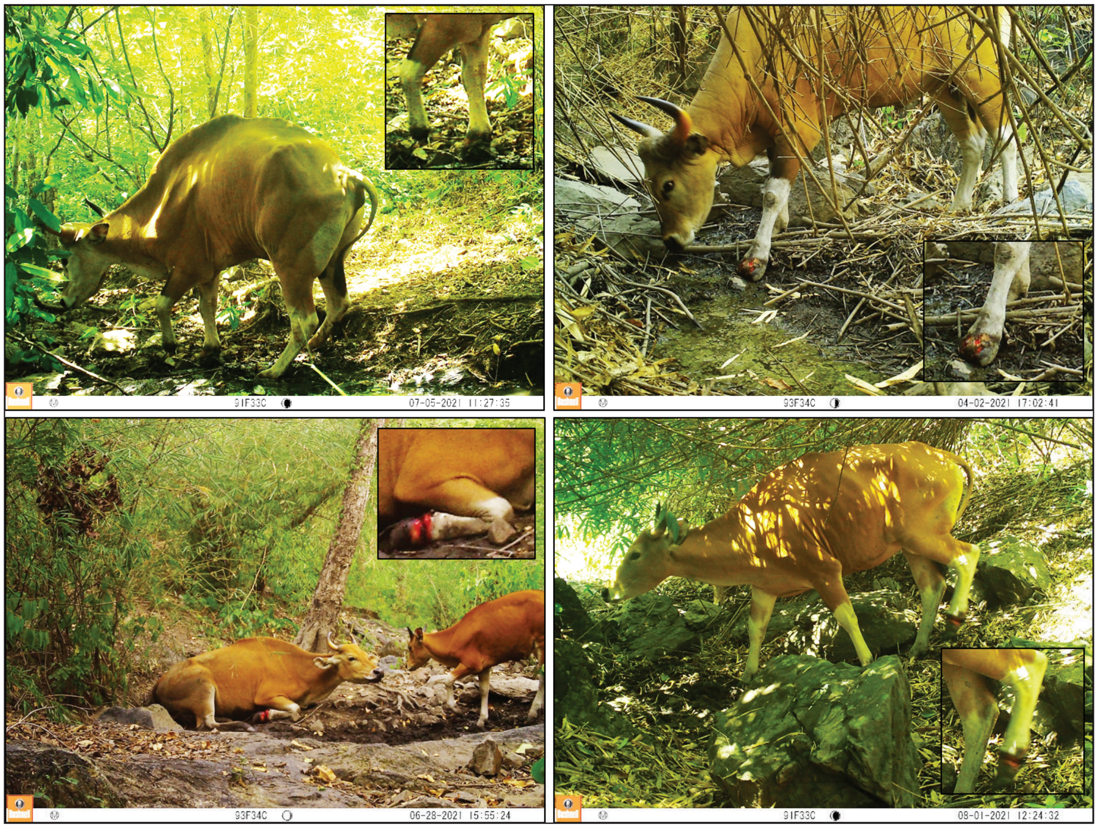

Fig. 3 Camera trap photos of wounded banteng detailed in Table 4: (upper left) No. 3, male with missing left front foot—old wound, dead; (upper right) No. 7, male with swollen, infected left front foot—old wound, active; (lower left) No. 10, female with bloody right front foot—new wound; (lower right) No. 13, female with bleeding wound on back left leg—new wound.

Studies around the world have found that measures to contain the pandemic have resulted in devastating socio-economic impacts (Park *et al*., 2020; Shrestha *et al*., 2020; Usui *et al*., 2020). The timing of the surge in snaring we document coincides with the period when COVID-19 cases in Cambodia increased significantly due to the country's first major community outbreak and as the socio-economic impacts of the pandemic worsened. Largely spared from the effects of the pandemic in 2020 and austerity measures taken in other countries to prevent its spread, Cambodia began to experience these in early 2021 when case numbers suddenly rose from fewer than 500 on 1 February to over 77,000 on 31 July (Worldometer, 2021). The tourism, export manufacturing and construction sectors that have been hit hardest employ 40% of the workforce (Kuntear, 2021). Disaggregated data on socio-economic measures in Cambodia is sparse, particularly for our study period. However, findings from quarterly household surveys undertaken by the World Bank since early 2020 indicate the socio-economic impacts of COVID-19 were greater in 2021 than 2020. For example, almost half of respondents reported their economic status was worse in March 2021 than the previous year and "moderate-or-severe food insecurity" increased from 34% in December 2020 to 55% among poor households (Karamba *et al*., 2021).

Our study adds to a growing body of research examining the links between the socio-economic impacts of the pandemic and increased exploitation of wildlife and forests in Africa and Asia (Brancalion *et al*., 2020; Waithaka, 2020; Koju *et al*., 2021). Several studies have found that after lockdowns and travel restrictions were introduced at specific sites, livelihoods were impacted and illegal exploitation of nearby wildlife and forest resources increased (Cherkaoui *et al*., 2020; Aditya *et al*., 2021; Koju *et al*., 2021; Rahman *et al*., 2021). We posit that the same has occurred in the PMCF after strict prevention measures were introduced in Cambodia in 2021.

Given the large numbers of Khmer who migrate domestically or internationally for jobs in sectors that have been heavily impacted by COVID-19 containment measures (e.g., hospitality, construction and manufacturing), pressure on natural resources has likely increased at sites across Cambodia as unemployed workers return to rural communities. Approximately 200,000 migrant workers have returned to Cambodia since the pandemic began and a recent United Nations survey found over 50% are indebted and nearly 30% have no household income (Anon, 2021). Remittances from people who migrate to urban centres or abroad for work are essential to the Cambodian rural economy (Hutt, 2021) and in disrupting work migrations, COVID-19 created a surplus of domestic labour as people returned from abroad, making it more difficult for families to service household debts (Res, 2021). In this context, decreasing household income may be a driver for increased wildlife snaring as rural people return to natural resource exploitation to make ends meet. In the face of this growing pressure, more must be done to safeguard Cambodia's remaining wildlife, especially important populations such as the bantengs at the PMCF, both within and outside of protected areas.

The banteng population at the PMCF is currently the only known population of the species remaining in the entire Cardamom Mountains rainforest eco-region. The ongoing camera trap survey at the PMCF may show this population exceeds 50 individuals, which would make it one of 6–8 remaining subpopulations of this size outside of northeastern Cambodia (Gardener *et al*., 2016). Although deaths of adult bantengs have been recorded at the PMCF, one hopeful sign is that newborns continue to be identified, none of which show evidence of snaring injuries. Given the location of the PMCF, hundreds of kilometres from the banteng stronghold in northeast Cambodia and its isolation from other subpopulations, its banteng population may be genetically distinct as well. Bottlenecking effects have been found in populations of non-native bantengs and it has been suggested that this may occur in isolated wild populations (Bradshaw *et al*., 2007). Eld's deer *Cervus eldi* represents another Endangered species at risk of inbreeding due to isolation, and geneticists have recommended transferring individuals between populations where possible to reduce the degree of inbreeding (Balakrishnan *et al*., 2003). Should bantengs need to be translocated in the future for such purposes, the population at the PMCF could represent an important reservoir of genetic diversity for species conservation efforts.

Bantengs belong to the class of Southeast Asian megafauna described by Figel *et al*. (2021) for which hunting has surpassed habitat loss as the primary driver of species decline. With over 100,000 snares removed from the Southern Cardamom National Park alone in 2010–2015 (Gray *et al*., 2018) and no records of bantengs generated by a multi-year survey of ground-dwelling mammals in seven protected areas in southwest Cambodia (Gray *et al*., 2017), it had been assumed these were extirpated in the region until the community rangers at the PMCF requested outside help. Our analysis of camera trap data from the PMCF to date suggests increasing numbers of bantengs are wounded by snares, with a larger number of injured animals declining in condition over time. Combined with at least four snare-related deaths since 2018, this suggests a large portion of snared bantengs ultimately die from their injuries. In such a relatively small and isolated subpopulation, even a small number of deaths each year could devastate the herds within a few generations. Indeed, studies have shown that mortalities from snaring have significantly affected lion *Panthera leo* and spotted hyena *Crocuta crocuta* populations in southern Africa, with "evidence for population declines and extirpation of large carnivores in the most heavily affected areas" (Loveridge *et al*., 2020). Where industrial-scale snaring has occurred in Laos and Vietnam, species once reasonably common have become barely detectable by camera traps within just a few years (W. Duckworth, pers. comm.).

It is not a stretch to conclude that unless further action is taken immediately to address the problem, snaring could extirpate the banteng subpopulation in the PMCF. Between 2010 and 2020, populations of bantengs declined by 81% and 60% in the Srepok and Phnom Prich Wildlife Sanctuaries respectively in eastern Cambodia, whereas the rate patrols encountered and removed snares increased more than a hundredfold from 0.04 to 6.46 per 100 km (Groenenberg *et al*., 2020). This massive increase in snaring is believed to be a significant driver in the rapid decline of this population (Gray *et al*., 2021). If the world's largest population can be so reduced across several massive protected areas patrolled by professional rangers within a decade, the impact of a >50% increase in snaring on the small and highly vulnerable subpopulation in the PMCF is likely to be catastrophic.

Loss of bantengs from the PMCF would be extremely painful for the local rangers who have worked for almost two decades to ensure the survival of this socially and culturally unique subpopulation. Though the rangers continue to do everything they can to protect the remaining animals, increased patrol efforts do not necessarily result in higher detection of snares (Ibbett *et al*., 2020). With additional pressures generated by the pandemic and related measures to limit the spread of the virus, the community rangers cannot compete with the increasing volumes of snares set in the forest and surrounding area without further support. As concluded by Brunner *et al.* (1999): "Communities are best at preventing and detecting forest crimes, but once detected, it is the responsibility of the state's law enforcement agencies to suppress them.".

Cambodia has two main laws which govern the use of snares. These are the 2002 Forestry Law which is applied by the FA in community forests such as the PMCF and unprotected state forests (FA, 2003), and the 2008 Protected Areas Law which is applied by the MoE on state-protected lands (MoE, 2008). Article 49 of the former law strictly prohibits hunting, harming or harassing wildlife, with particular mention that it is prohibited to "hunt, net, trap or poison" rare and Endangered species such as bantengs. Article 97 of the same law states that the penalty for Class I offences (which include hunting, killing, trading or exporting Endangered species) is 5–10 years in prison and confiscation of all evidence. Article 98 states penalties for Class II offences against wildlife (such as hunting in protected zones, hunting rare species and hunting wildlife by dangerous means) include a prison term of 1–5 years and a fine of 10,000,000–100,000,000 riel (FA, 2003) (equivalent to $2,500–25,000 USD). The Protected Areas Law similarly prohibits wildlife hunting. For instance, article 61 of the law stipulates that it is an offence to "Catch, trap, hunt, cause injury, poison, kill, take out, collect eggs and offsprings from their original habitats of any Vulnerable, rare, or Critically Endangered wildlife species" and article 58 sets a penalty of 100,000 to 1,000,000 for these acts (MoE, 2008). These provisions should be sufficient to guard against snares in theory.

Yet despite this legal framework, Cambodian laws, like those in neighbouring countries, do not "include provisions that clearly prohibit the possession of materials (like metal wires or nylon ropes) that can be quickly fashioned into snares" (Gray *et al*., 2021). Snares are made from commonplace materials such as nylon, wire or cord and are usually attached to natural anchors in the forest or countryside, such as small trees. Patrol teams seldom meet hunters while they are setting the snares and unless they possess wildlife at the time of apprehension, prosecutions and penalties are generally not applied (N. Marx, pers. obs.). This makes it difficult even for professional ranger teams to punish hunters effectively unless they are caught in the act of snare setting or holding wildlife. Fines for hunters apprehended while setting snares also do not appear to be an effective deterrent, although prison sentences are (B. Davis, pers. comm.). Unfortunately, these options are not available to the PMCF CAPU team however, since this comprises a group of community volunteers without law enforcement authority. Only with greater government support can the likelihood of apprehending offenders be increased, existing laws be more strictly applied, and courts encouraged to prosecute offenders and apply maximum penalties.

In the longer term, policy and legislative reforms that increase legal penalties and prohibitions on snaring and improve enforcement of existing laws are key to solving the snaring epidemic in Southeast Asia (Gray *et al*., 2018, 2021; Figel *et al*., 2021). The kouprey *Bos sauveli*, a species closely related to bantengs, is likely extinct (Hassanin & Ropiquet, 2007), whereas tigers have now been extirpated from the country and snaring has proven to be a major cause of declines of such megafauna species (Figel *et al*., 2021). If authorities do not act swiftly to counter the current increase in snaring, banteng populations in the PMCF and northeast Cambodia may follow the same path. If the banteng population in the PMCF is to survive, the rangers need greater government support, increased law enforcement presence and stronger penalties for offenders who set snares in the PMCF and neighbouring plantations.

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References

Aditya, V., Goswami, R., Mendez, A. & Roopa, R. (2021) Scale of the issue: mapping the impact of the COVID-19 lockdown on pangolin trade across India. *Biological Conservation*, **257**, 109136.

Anon (2021) *Cambodia: UN Claims That 30% of 200,000 Returning Migrants Have No Incomes While Over 50% Are Indebted*. Https://www.business-humanrights.org/ar/%D8%A3%D8%AD%D8%AF%D8%AB-%D8%A7%D9%84%D8%A3%D8%AE%D8%A8%D8%A7%D8%B1/cambodia-un-claims-that-30-of-200000-returning-migrants-have-no-incomes-while-over-50-are-indebted/ [accessed 20 September 2021].

Balakrishnan, C.N., Monfort, S.L., Gaur, A., Singh, L. & Sorenson, M.D. (2003) Phylogeography and conservation genetics of Eld's deer (*Cervus eldi*). *Molecular Ecology*, **12**, 1–10.

Belecky, M. & Gray, T.N.E. (2020) *Silence of the Snares: Southeast Asia's Snaring Crisis*. WWF International, Gland, Switzerland.

Bradshaw, C.J.A., Isagi Y., Kaneko S., Brook, B.W., Bowman, D.M.J.S. & Frankham, R. (2007) Low genetic diversity in the bottleneck population of endangered non-native banting in northern Australia. *Molecular Ecology*, **16**, 2998–3008.

Brancalion, P.H.S., Broadbent, E.N., de-Miguel, S., Cardil, A., Rosa, M.R., Almeida, C.T., Danilo Almeida, D.R.A., Chakravarty, S., Zhou M., Gamarra, J.G.P., Liang J., Crouzeilles, R., Hérault, B., Aragão, L.E.O.C., Silva, C.A. & Almeyda-Zambrano, A.M. (2020) Emerging threats linking tropical deforestation and the COVID-19 pandemic. *Perspectives in Ecology and Conservation*, **18**, 243–246.

Brunner, J., Seymour, F. & Badenoch, N. (1999) *Forest Problems and Law Enforcement in Southeast Asia: The Role of Local Communities*. Resources Policy Brief, World Resources Institute, Washington DC, USA.

Cherkaoui, S.I., Boukherouk, M., Lakhal, T., Aghzar, A. & El Youssfi, L. (2020) Conservation amid COVID-19 pandemic: ecotourism collapse threatens communities and wildlife in Morocco. *E3S Web of Conferences*, **183**, 01003.

Dobson, A.D.M, Milner-Gulland, E.J., Beale, C.M., Ibbett, H. & Keane, A. (2019a) Detecting deterrence from patrol data. *Conservation Biology*, **33**, 665–675.

Dobson, A.D.M., Milner-Gulland, E.J., Ingram, D.J. & Keane, A. (2019b) A framework for assessing impacts of wild meat hunting practices in the tropics. *Human Ecology*, **47**, 449–64.

Dong L.K., Hoa A.X., Luyen N.T., Nha T.H.N. & Techato, K. (2021) Monitoring of field patrolling efforts, Vietnam: insights from a forest station in Pu Hu Nature Reserve. *Sustainability*, **13**, 8407.

[FA] Forestry Administration (2003) *Law on Forestry, NS/RKM/0802/016*. Royal Government of Cambodia, Phnom Penh, Cambodia.

Figel, J.J., Hambal, M., Krisna, I., Putra, R. & Yansyah, D. (2021) Malignant snare traps threaten an irreplaceable megafauna community. *Tropical Conservation Science*. DOI 10.1177/1940082921989187.

Gardner, P., Hedges, S., Pudyatmoko, S., Gray, T.N.E. & Timmins, R.J. (2016) *Bos javanicus. The IUCN Red List of Threatened Species 2016: e.T2888A46362970*. Https://www.iucnredlist.org/species/2888/46362970 [accessed 28 October 2021].

Gray T.N.E., Belecky, M., O'Kelly, H.J., Madhu, R., Roberts, O., Tilker, A., Signs, M. & Yoganand, K. (2021) Understanding and solving the South-East Asian snaring crisis. *The Ecological Citizen*, **4**, 129–41.

Gray, T.N.E, Billingsley, A., Crudge, B., Freschette, J.L., Rosu, R., Herranz-Muñoz, V., Holden, J., Keo O., Kong K.,Macdonald, D., Neang T., Ou R., Phan C. & Sim, S. (2017) Status and conservation significance of ground-dwelling mammals in the Cardamom Rainforest Landscape, southwestern Cambodia. *Cambodian Journal of Natural History*, **2017**, 38–48.

Gray, T.N.E., Hughes, A.C., Laurance, W.F., Long, B., Lynam, A.J., O'Kelly, H., Ripple, W.J., Seng T., Scotson, L. & Wilkinson, N.M. (2018) The wildlife snaring crisis: an insidious and pervasive threat to biodiversity in Southeast Asia. *Biodiversity and Conservation*, **27**, 1031–1037.

Groenenberg, M., Crouthers, R. & Yoganand, K. (2020) *Population Status of Ungulates in the Eastern Plains Landscape. Srepok Wildlife Sanctuary and Phnom Prich Wildlife Sanctuary, Cambodia*. WWF-Cambodia, Phnom Penh, Cambodia.

Hassanin, A. & Ropiquet, A. (2007) What is the taxonomic status of the Cambodian banteng and does it have close genetic links with the kouprey? *Journal of Zoology*, **271**, 246–252.

Hutt, D. (2021) *In Cambodia, the End of COVID-19 Will Heighten the Economic Contradictions*. Https://thediplomat.com/2021/06/in-cambodia-the-end-of-covid-19-will-heighten-the-economic-contradictions/ [accessed 3 November 2021].

Ibbett, H., Milner-Gulland, E.J., Beale, C., Dobson, A.D.M., Griffin, O., O'Kelly, H.J. & Keane, A. (2020) Experimentally assessing the effect of search effort on snare detectability. *Biological Conservation*, **247**, 108581.

Karamba, W., Salcher, I. & Tong K. (2021) *The Socioeconomic Impacts of COVID-19 on Households in Cambodia: Results from the High-Frequency Phone Survey of Households Round 5 (1–21 March 2021)*. World Bank, Washington DC, USA.

Koju N.P., Kandel, R.C., Acharya, H.B., Dahkal, B.K. & Bhuju D.R. (2021) COVID-19 lockdown frees wildlife to roam but increases poaching threats in Nepal. *Ecology and Evolution*, **11**, 9198–9205.

Kuntear M. (2021) *Informal Economy May Lose Over 6M Jobs by Covid's End*. Https://www.phnompenhpost.com/national/informal-economy-may-lose-over-6m-jobs-covids-end [accessed 28 October 2021].

Linkie, M., Martyr, D.J., Harihar, A., Risdianto, D., Nugraha, R.T., Maryati, Leader-Williams, N. & Wong W. (2015) Safeguarding Sumatran tigers: evaluating effectiveness of law enforcement patrols and local informant networks. *Journal of Applied Ecology*, **52**, 851–860.

Loveridge, A.J., Sousa, L.L., Seymour-Smith, J., Hunt, J., Coals, P., O'Donnell, H., Lindsey, P.A., Mandisodza-Chikerema, R. & Macdonald, D.W. (2020) Evaluating the spatial intensity and demographic impacts of wire-snare bush-meat poaching on large carnivores. *Biological Conservation*, **244**, 108504.

Marx, N. (2021) Local community protects an important population of Endangered *Bos javanicus* in Kampong Speu Province. *Cambodian Journal of Natural History*, **2021**, 30.

[MoE] Ministry of Environment (2008) *Protected Area Law, NS/RKM/0208/007*. Royal Government of Cambodia, Phnom Penh, Cambodia.

O'Kelly, H.J. (2013) *Monitoring conservation threats, interventions and impacts on wildlife in a Cambodian tropical forest*. PhD thesis, Imperial College, London, UK.

O'Kelly, H.J., Rowcliffe, J.M., Durant, S.M. & Milner-Gulland, E.J. (2018) Robust estimation of snare prevalence within a tropical forest context using N-mixture models. *Biological Conservation*, **217**, 75–82.

Park, C.-Y., Villafuerte, J., Abiad, A., Narayanan, B., Banzon, E., Samson, J., Aftab, A. & Tayag, M.C. (2020) An updated assessment of the economic impact of COVID-19. *ADB Briefs*, **133**, 1–16.

Rahman, Md.S., Alam, Md.A., Salekin, S., Belal, Md.A.H. & Rahman, Md.S. (2021) The COVID-19 pandemic: a threat to forest and wildlife conservation in Bangladesh? *Trees, Forests and People*, **5**, 100119.

Res P. (2021) *Microfinance in Times of COVID-19: Consumer Protection and the Loan Restructuring Process in Cambodia*. Center for Khmer Studies report for Australian Aid and The Asia Foundation, Phnom Penh, Cambodia.

Sassoon, A.M. & Phak S. (2018) *Banteng Poacher Arrested, Pangolins Rescued in Separate Busts*. Https://www.phnompenhpost.com/national/banteng-poacher-arrested-pangolins-rescued-separate-busts [accessed 28 October 2021].

Shereen, M.A., Khan, S., Kazmi, A., Bashir, N. & Siddique, R. (2020) COVID-19 infection: origin, transmission, and characteristics of human coronaviruses. *Journal of Advanced Research*, **24**, 91–98.

Shrestha, N., Shad, M.Y., Ulvi, O., Khan, M.H., Karamehic-Muratovic, A., Nguyen U.S.D.T., Baghbanzadeh, M., Wardrup, R., Aghamohammadi, N., Cervantes, D., Nahiduzzaman, Kh. Md., Zaki, R.A. & Haque, U. (2020) The impact of COVID-19 on globalization. *One Health*, **11**, 100180.

Tatum, M. (2021) Cambodia ends controversial COVID-19 restrictions. *The Lancet*, **397**, P2035.

Usui, R., Sheeran, L.K., Asbury, A.M., Blackson, M. (2020) Impacts of the COVID-19 pandemic on mammals at tourism destinations: a systematic review. *Mammal Review*, **2020**, 1–16.

Waithaka, J. (2020) *The Impacts of COVID-19 Pandemic on Africa's Protected Areas Operations and Programmes*. IUCN, World Commission on Protected Areas, African Wildlife Foundation and African Protected Areas Congress.

Worldometer (2021) *Total Coronavirus Cases in Cambodia*. Https://www.worldometers.info/coronavirus/country/cambodia/ [accessed 28 October 2021].

Agricultural land use and economic efficiency around the Tonle Sap Lake and Cambodian Mekong River

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មូលន័យសង្ខេប

ប្រទេសកម្ពុជាបានផ្លាស់ប្តូរជាញឹកញាប់នូវរបបនយោបាយ និងសេដ្ឋកិច្ចក្នុងរយៈពេលប៉ុន្មានទសវត្សរ៍ចុងក្រោយនេះ។ ទន្ទឹមនឹងនេះ ការប្រើប្រាស់ដីកសិកម្មក្នុងប្រទេសក៏មានការប្រែប្រួលដែរ។ ការសិក្សានេះធ្វើការវាយតម្លៃលើនិន្នាការនៃការប្រើប្រាស់, ប្រសិទ្ធភាពសេដ្ឋកិច្ច និងការអនុវត្តន៍ដីកសិកម្មពីអតីតកាល (១៩៨០-១៩៨៩), បច្ចុប្បន្ន (២០១០-២០១៩) និងពេលអនាគត នៅតំបន់ជុំវិញបឹងទន្លេសាប, ទន្លេមេគង្គលើ និងទន្លេមេគង្គក្រោមកម្ពុជា។ ការសិក្សានេះធ្វើឡើងក្នុងឆ្នាំ២០១៩ តាមរយៈការសម្ភាសន៍ជាមួយកសិករគោលដៅចំនួន ៧៦គ្រួសារ។ លទ្ធផលបង្ហាញថា កសិករគោលដៅភាគច្រើនអនុវត្តកសិកម្មដំណាំស្រូវ (៧១% នៃអ្នកឆ្លើយតប) និងកសិកម្មដំណាំផ្សេងៗមិនមែនស្រូវ (២៩%) ដែលក្នុងនោះមានដំណាំកៅស៊ូ ១១% និងបន្លែ ៩%។ ទំហំដីកសិកម្មជាមធ្យមមានភាពខុសគ្នារវាងតំបន់សិក្សាទាំង៣។ ផ្ទៃដីកសិកម្មដំណាំស្រូវដែលធំជាងគេគឺនៅតំបន់ជុំវិញបឹងទន្លេសាប។ គ្រួសារនីមួយៗប្រើប្រាស់ដីជាមធ្យម ១.៩ហិកតា សម្រាប់កសិកម្មដំណាំស្រូវ ដែលផ្តល់ប្រាក់ចំណូលប្រចាំឆ្នាំជាមធ្យម ៩២៣ដុល្លារ (៤៨៦ដុល្លារ/ហិកតា) និង ១.៤ហិកតា សម្រាប់ដំណាំមិនមែនស្រូវ ដែលផ្តល់ប្រាក់ចំណូលប្រចាំឆ្នាំជាមធ្យម ៩០២ដុល្លារ (៦៤៤ដុល្លារ/ហិកតា)។ ទំហំដីកសិកម្មមានទំនាក់ទំនងជាវិជ្ជមានជាមួយនឹងប្រាក់ចំណូល ហើយកត្តាប្រឈមសំខាន់ៗក្នុងការធ្វើកសិកម្មមាន គ្រោះរាំងស្ងួត និងសត្វល្អិតចង្រៃ។ ទំហំដីកសិកម្មបានកើនឡើងពី២៨% ក្នុងទសវត្សរ៍ឆ្នាំ១៩៨០ ដល់៣១% ក្នុងទសវត្សរ៍ឆ្នាំ២០១០ ខណៈដែលការអនុវត្តន៍កសិកម្មគ្រួសារបានកើនឡើងពី៧២% ទៅ៨៦%។ ការអនុវត្តន៍កសិកម្មគ្រួសារនេះ ត្រូវបានព្យាករណ៍ថានឹងថយចុះមកត្រឹម៤២% នាពេលអនាគត ចំណែកការអនុវត្តន៍កសិកម្មខ្នាតមធ្យម (ការជួលកម្លាំងពលកម្ម និងគ្រឿងយន្តកសិកម្ម) អាចកើនឡើងដល់៣២% នៃកសិករគោលដៅ។ ការសិក្សារបស់យើងបង្ហាញទៀតថា កសិករគោលដៅ២០% មានប្រាក់ចំណូលច្រើនជាងផលិតផលក្នុងស្រុកសរុបសម្រាប់មនុស្សម្នាក់ (GDP) ដែលបញ្ជាក់ពីប្រសិទ្ធភាពខ្ពស់នៃសេដ្ឋកិច្ចដីកសិកម្មសម្រាប់កសិករទាំងនេះ។ តែទោះជាយ៉ាងនេះក្តី ប្រាក់ចំណូលនាពេលបច្ចុប្បន្ន និងអនាគត របស់កសិករគោលដៅដទៃទៀត ត្រូវបានព្យាករណ៍ថានឹងនៅមានកម្រិតទាបជាង GDP។ លទ្ធផលរបស់យើងក៏បានបញ្ជាក់ថា ការអភិវឌ្ឍន៍ប្រព័ន្ធធារាសាស្ត្រ, បច្ចេកទេសដាំដុះ និងទីផ្សារកសិផលទូលំទូលាយ គឺជាកត្តាដែលត្រូវដោះស្រាយ ដើម្បីលើកកម្ពស់វិស័យកសិកម្មនៅកម្ពុជា។

Abstract

Cambodia has experienced political and economic changes in recent decades and the same is true of agricultural land use in the country. We assessed past (1980–1989), present (2010–2019) and potential future trends in agricultural land-use, economic efficiency and management practices around the Tonle Sap Lake (TSL) and upper and lower sections of the Cambodian Mekong river basin. Interviews were undertaken to this end with 76 households in 2019. Our results

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indicate that two broad categories of agriculture are practiced, rice-farming (71% of respondents) and non-rice farming (29%), with the latter mainly comprising rubber plantations (11%) and vegetable cropping (9%). The average size of farms differed between study areas, with larger areas devoted to rice-farming around the TSL. On average, households used 1.9 ha for rice-farming and 1.4 ha for non-rice farming, which provided mean annual incomes of US$ 923 (486 USD/ha) and US$ 902 (644 USD/ha), respectively. Farm size was positively associated with income. Drought and pests were reported as the greatest farming challenges. Farm areas increased from 28% in the 1980s to 31% in the 2010s, whereas family-scale farming practices increased from 72% to 86%. The latter were projected to decrease to 42% in the future, whereas medium-scale practices (use of hired labour and agricultural machinery) were projected to increase to 32%. Our study indicates that only 20% of respondents have incomes greater than the country's current per capita GDP, suggesting greater economic efficiency in these cases. However, the present and potential future incomes of the remainder were lower than this. Our results suggest that development of irrigation systems and cropping techniques and diversification of markets are required to improve the agricultural sector in Cambodia.

Keywords Agricultural economics, cropping techniques, farming business, productivity and management.

Introduction

Agriculture is one of the most important economic sectors in the Lower Mekong Basin and Cambodia (MRC, 2016). During the 1990s, 2000s and 2010s, the average proportion of Cambodia occupied by agricultural land was approximately 25.8%, 29.3% and 30.9%, respectively (World Bank, 2021). This is cultivated for various crops, with some areas under temporary rice cultivation and other areas cropped for coffee, rubber and fruit trees (ADB, 2021).

Agricultural land use in Cambodia mainly comprises irrigated rice, rubber plantations and corn and cassava cultivation (Lonn *et al*., 2016) and the nature of ownership varies between different types of farms. For example, most irrigated rice farms are managed by local households, whereas rubber plantations, which typically occupy larger areas, are mostly managed by agri-businesses. This results in different yields and thus different contributions to the national economy.

The overall contribution of agricultural sector to the Cambodian economy has gradually decreased in recent years (NIS, 2015). Notwithstanding this, the annual value of the sector grew from an average of 2.1 billion USD in the 2000s to 4.8 billion USD in the 2010s (World Bank, 2020a). Most rice production is undertaken by households surrounding the Tonle Sap River and lower sections of the Mekong basin (NIS, 2013; MAFF, 2016), whereas rubber plantations are prevalent in the country's northeast, in the upper section of the Mekong basin (NIS, 2013). As a consequence, the relative contribution of each crop type to the agricultural sector varies between regions.

This study assesses past (1980–1989), present (2010–2019) and potential future trends in agricultural land-use, economic efficiency and management practices in three regions of Cambodia: the Tonle Sap Lake and river system, and the lower and upper sections of the Cambodian Mekong river basin. Our specific aims were to 1) investigate the status of agricultural land use and evaluate the influence of farm size on economic output, 2) determine the extent to which agricultural land use practices contribute to improving farmer livelihoods, 3) identify major challenges for agriculture, and 4) evaluate land use practices to identify opportunities to improve their effectiveness and economic value to local farmers.

Methods

Study areas

Our study included parts of 13 provinces located around the Tonle Sap Lake (TSL) and its river systems (Kampong Chhnang, Pursat, Battambang, Banteay Meanchey, Siem Reap and Kampong Thom), the upper section of the Cambodian Mekong river basin (CUM) (Kampong Cham, Tbong Khmum, Kratie and Stung Treng) and the lower section of the Cambodian Mekong river basin (CLM) (Prey Veng, Kandal and Takeo) (Fig. 1, Table 1).

Data collection

We developed a semi-structured questionnaire which was tested and revised prior to the study. Data collection was undertaken from 23 August to 10 September 2019. The number of households targeted in each study region varied according to the size of the region, with a sampling target of 30–40 households adopted for the TSL region and 20–30 households apiece in the CLM and the CUM regions. In each region, individual households were selected for interviews using a combination of

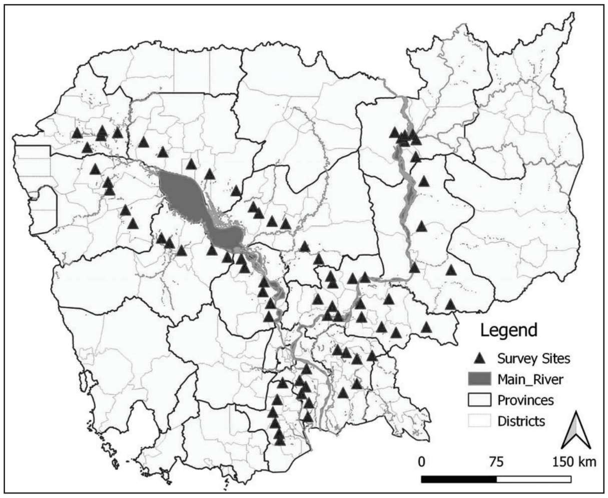

Fig. 1 Study sites in the upper and lower sections of the Mekong basin and around the Tonle Sap Lake, Cambodia.

stratified (by distance) and random sampling to ensure diverse representation. All households interviewed were selected based on their active involvement in agricultural activities, irrespective of their gender.

Four major categories of agricultural activities were recognised during data collection: 1) rice-farming, 2) non-rice farming, 3) rice-farming and non-rice crop types, and 4) other—no species response. Interview data were also arranged in three subsections: 1) agricultural land use and economic values, 2) agricultural challenges, and 3) past, present, and future management practices. Farmer responses regarding the contribution of agriculture to their incomes were categorized as low, medium or high and were solely based on their reported perceptions (as opposed to adopting pre-defined ranges of income for each category). Responses regarding the scale of farming practices were arranged in three categories: 1) family-scale—comprising farms that solely employ the labour of family members who consume most of the produce, 2) medium-scale—farms that employ hired labourers and agricultural machinery and whose yield is mostly for sale, and 3) Other—holdings whose farmers did not directly own the land.

Data analysis

Descriptive statistics were used to quantify the relative proportions of individual agricultural land uses in the three regions and overall incomes generated by respondents for each land use. One-way ANOVA or Kruskal-Wallis tests were employed as appropriate to the data to compare these between regions. Linear regression was used to assess the influence of farm size on incomes. All analysis was performed in R (R Core Team, 2019) and employed a p value of ≤0.05 as the theshold for significance.

Table 1 Number of respondents in each study region. TSL: Tonle Sap Lake, CLM: lower Cambodian Mekong river basin, CUM: upper Cambodian Mekong river basin.

Region	No. Sites	Male	Female	Ages
TSL	32 (42%)	13	19	22–53
CLM	18 (24%)	7	11	24–56
CUM	26 (34%)	7	19	24–53
Total	76	27 (36%)	49 (64%)	22–56

Results

Agricultural land uses and incomes

The majority of respondents (71.1%) surveyed across the three study regions practiced rice farming (Table 2), although the relative proportion varied between regions, ranging from 54% in CUM to 72% in CLM and 85% in TSL region. The proportion of respondents engaged in non-rice farming in each region was correspondingly low, although 31% farmed rubber plantations in the CUM region and 28% cropped vegetables in the CLM region (Table 2).

On average, each rice farmer cultivated 1.9 ± 1.4 ha and earned 486 ± 248 USD/ha and 923 ± 811 USD/year. Average incomes from rice farming did not differ significantly between regions (p=0.43, Fig. 2). The equivalent figures for non-rice farmers were 1.4 ± 2.2 ha, 644 ± 350 USD/ha and 902 ± 1,414 USD/year (Table 3) and average incomes for these differed significantly between regions (p=0.002, Table 3, Fig. 2). In both cases, farm size was positively associated with income (Fig. 3).

Contribution of agriculture to livelihoods and major challenges

Most rice farmers and non-rice farmers ranked the contribution of agriculture to their incomes as low or medium; only five rice farmers regarded this as high, whereas no non-rice farmers ranked it as such (Table 4). Within these categories, the average income for rice-farmers was 543 USD/year (low), 1,313 USD/year (medium) and 3,098 USD/year (high) respectively, whereas for non-rice farmers it was 1,408 USD/year (low) and 2,810 USD/year (medium). Across all study regions and farm types, the

Table 2 Relative proportions of respondents cultivating rice and non-rice crops in each study region. TSL: Tonle Sap Lake, CLM: lower Cambodian Mekong river basin, CUM: upper Cambodian Mekong river basin.

Region	Rice Farming	Non-Rice Farming		Rice Farming & Rubber	Other
		Rubber	Vegetables		
TSL	85% (27)	–	6% (2)	–	9% (3)
CLM	72% (13)	–	28% (5)	–	–
CUM	54% (14)	31% (8)	–	11% (3)	4% (1)
All	71.1% (54)	10.5% (8)	9.2% (7)	3.9% (3)	5.3% (4)

Table 3 Median, mean and standard deviation for farm sizes (ha) and annual incomes (USD) of respondents in each study region. TSL: Tonle Sap Lake, CLM: lower Cambodian Mekong river basin, CUM: upper Cambodian Mekong river basin.

Strategy	Metric	TSL	CLM	CUM	Overall
Rice farms	Land area	1.5 / 2.2 / 1.8	1.0 / 1.5 / 0.8	2.0 / 1.9 / 0.9	1.8 / 1.9 / 1.4
	Annual income	625 / 960 / 818	700 / 727 / 513	500 / 1,012 / 947	663 / 923 / 811
Non-rice farms	Land area**	0.0 / 0.9 / 2.3	1.0 / 1.4 / 1.0	0.5 / 1.9 / 2.4	0.0 / 1.4 / 2.2
	Annual income**	0 / 467 / 1,128	1,200 / 1,430 / 1,366	250 / 1,162 / 1,602	0 / 902 / 1,414

** indicates a significant difference (p<0.01) between regions.

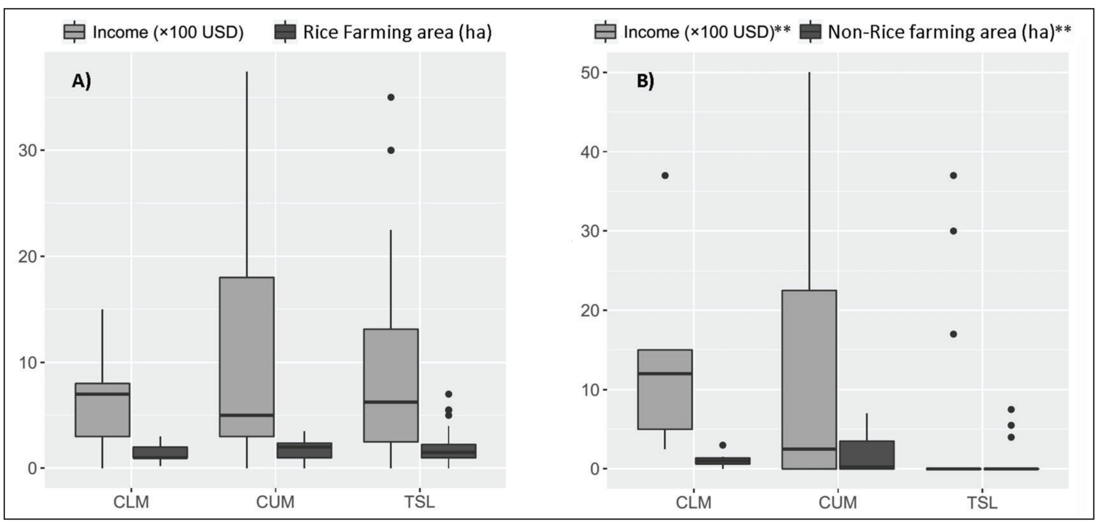

Fig. 2 Variation in farm size and annual incomes in each region for A) rice farmers and B) non-rice farmers. TSL: Tonle Sap Lake, CLM: lower Cambodian Mekong river basin, CUM: upper Cambodian Mekong river basin. ** indicates a significant difference (p<0.01) between regions.

study respondents earned 549 USD/year with 2.5 ha of land on average.

Drought was reported as the greatest challenge affecting rice farming in the study areas and particularly in the TSL region (Fig. 4). Pest damage was reported by non-rice farmers as the most challenging factor, particularly in the CUM region, followed by drought and pest damage combined.

Past, present and future agricultural practices

Farming areas increased from 28% in the 1980s to 31% in the 2010s. Across all respondents, 72% reported growing rice and other crops in the 1980s, whereas 86% reported the same in the 2010s. During the latter period, the remaining 14% reported practicing medium-scale farming involving the use of hired labour and agricultural machinery (Fig. 5). When asked about their future

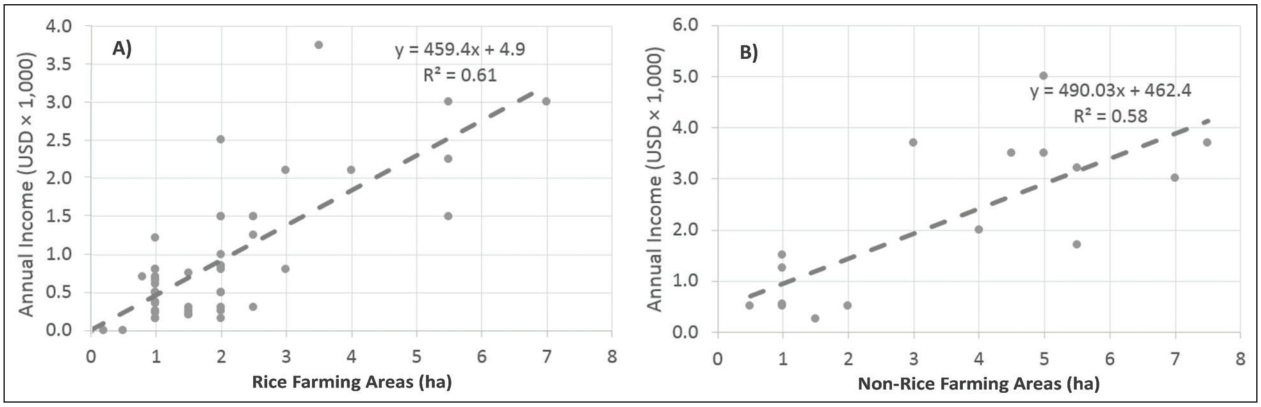

Fig. 3 Relationship between farm size and annual income for A) rice farmer and B) non-rice farmers.

Table 4 Respondent perceptions on the contribution of agriculture to their livelihoods. Figures for farm size and annual income represent mean ± standard deviation values. Data presented excludes respondents who reported 'no contribution'.

Rank	Rice Farmers			Non-Rice Farmers		
	n	Farm Size (ha)	Income (USD)	*n*	Farm Size (ha)	Income (USD)
High	5	5.3 ± 1.3	3,098 ± 572	–	–	–
Medium	16	2.3 ± 1.2	1,313 ± 641	10	4.7 ± 1.9	2,810 ± 1,350
Low	27	1.5 ± 0.6	543 ± 348	8	2.1 ± 1.6	1,408 ± 1,311

plans, 42% of respondents expected to continue farming at a family-scale, whereas 32% expected to farm at a medium-scale and the remainder were uncertain (Fig. 5).

When asked how the agricultural sector might be improved in future, 28% of rice farmers suggested this would require better irrigation systems, 15% suggested better market conditions were needed and 57% suggested both. When asked the same question, 82% and 18% of non-rice farmers suggested better market conditions and improved farming techniques were required, respectively.

Discussion

Agricultural land uses and incomes

The majority of respondents in our study were rice farmers, followed by rubber farmers and vegetable farmers. This is unsurprising given these crops are effectively traditional, having been cultivated since the French colonial era (Lonn *et al*., 2016). It also reflects the specific suitability of areas for different crop species. For instance, because the TSL and CLM regions receive large volumes of sediment from the Mekong River each year, these are well known for their high fertility and productivity for rice (Kummu *et al*., 2005). Similar to Goletti & Sin (2016), we also encountered study respondents in the CLM that cultivate vegetables for supply to Phnom Penh. Additionally, because the CUM region is characterised by highlands and mountainous areas which are suitable for rubber cultivation (MAFF, 2016; Mak, 2017), 31% of respondents in this region dedicated their efforts to this crop type.

The land holdings and incomes possessed by rice farmers varied between regions although these differences were not significant. On average, households around the TSL region had more land but lower incomes (ca. 436 USD/ha), whereas those in the CUM region had less land but greater incomes (ca. 533 USD/ha; Table 3). Previous studies have documented higher incomes from rice farming in the northwest area of the TSL region (ca. 513 USD/ha) (Srean *et al*., 2018). Our results are consistent with previous studies which indicate that the TSL region is highly productive and represents a sizeable portion of the contribution made by the agriculture sector to the national economy (Lonn *et al*., 2016; MAFF, 2016; MRC, 2016; World Bank, 2020). It is also highly favourable in

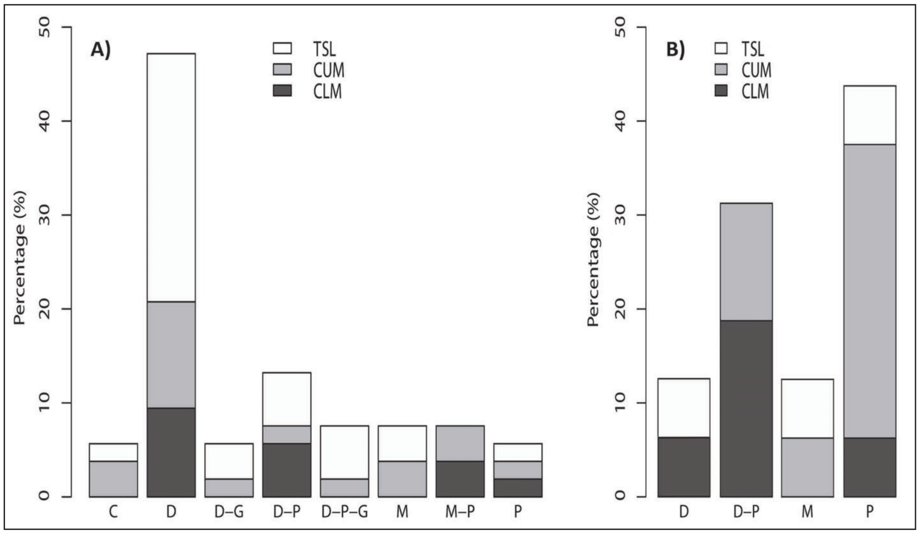

Fig. 4 Relative proportions of respondents who indicated different challenges for A) rice farming and B) non-rice farming in the three study regions (TSL: Tonle Sap Lake, CLM: lower Cambodian Mekong river basin, CUM: upper Cambodian Mekong river basin). Key: C=High costs, D=Drought, G=Weed problems, M=Lack of markets, P=Pest damage.

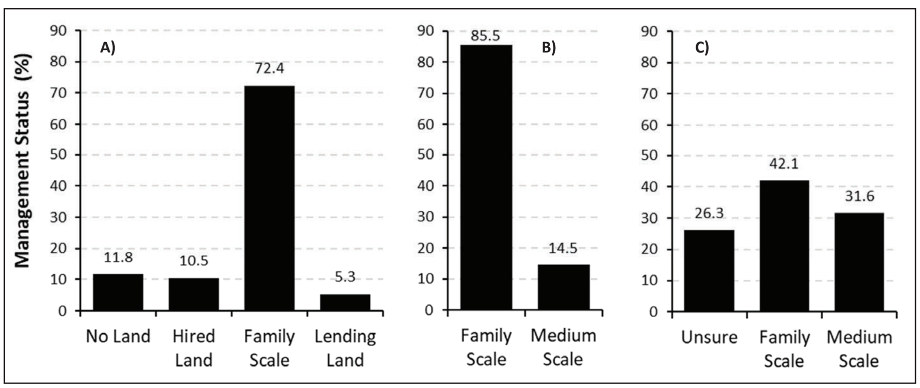

Fig. 5 Status of land ownership and farm management among study respondents in the A) past (1980–1989), B) present (2010–2019) and C) future.

terms of its fisheries (Sor *et al*., 2017; Ngor *et al*., 2018a, 2018b). Unlike rice farmers however, the land holdings and incomes possessed by non-rice farmers differed significantly between regions. On average, households in the TSL region had smaller land holdings and lower incomes compared to those in the CLM and CUM regions. This is most likely due to the differing suitability of regions for specific crops, the TSL region being less suited to crops such as rubber or cassava compared to the CUM region (Kummu *et al*., 2005; Mak, 2017).

As expected, farm size was positively associated with annual income for both rice and non-rice farmers. Partly as a result, households with small holdings coupled with a lack of labour often rent their lands to neighbours who are better equipped to cultivate these due to their access to hired labour and agricultural machinery. Consistent with this, a gradually increasing trend in small scale rice-farming businesses was observed across the three study regions and particularly the TSL region.

Contribution of agriculture to livelihoods and major challenges

We found that rice farming provides lower incomes (486 USD/ha) compared to non-rice farming practices (644 USD/ha). Crops cultivated in the latter category include rubber, cassava, corn, fruit trees and vegetables (Lonn *et al*., 2016). Our data suggests that incomes generated from rice farming are low and thus insufficient for over half of the households we interviewed, whereas relatively small proportions rated their incomes as medium or high (Table 4). Within the non-rice farming category, none of the study respondents rated their agricultural incomes as high, whereas slightly more than half rated these as medium and slightly less than half rated them as low. This is reflected in our finding that on the whole, the study respondents earned 549 USD/year with 2.5 ha of land on average, which is far below the per capita GDP for Cambodia in 2019 (1,643 USD/year) (World Bank, 2020b).

Farmer responses regarding the contribution of agriculture to their incomes (and thus their economic efficiency) were highly variable and entirely dependent personal perceptions which differed between rice and non-rice farmers. For example, an average income of 543 USD/year was considered low by rice farmers, whereas an average income of 1,408 USD/year was rated as low by non-rice farmers and these groups respectively rated average incomes of 1,313 USD/year and 2,810 USD/year as medium. This suggests that expectations or standards of income among rice farmers are somewhat lower than the non-rice farmers. Nonetheless, our data suggest that only 20% of study respondents (five rice farmers and ten non-rice farmers: Table 4) had incomes greater than the per capita GDP of Cambodia in 2019. At a national level, the contribution of agriculture to economic growth decreased from 30% in the 2000s to 21% in 2018 (NIS, 2015). While this could be partly due to labour shifting from family-scale farming to the garment or other sectors, incomes generated from rice and non-rice farming largely remain below the per capita GDP in Cambodia. Regardless, given the continuing importance of agriculture to the country's economy, development of the sector must be considered an urgent necessity (Lonn *et al*., 2016).

Drought was the most challenging factor affecting rice production in the three study regions. The TSL region was the most affected area with 28% of respondents identifying this as a major issue, whereas approximately 10% of respondents in both the CUM and CLM regions similarly regarded it as a major issue. This suggests that irrigation systems within these regions and the TSL particularly still need improvement and risk management practices would be beneficial in building community resilience (Lonn et al., 2016), not least because drought events are increasing in the lower Mekong basin (Thilakarathne & Sridhar, 2017; Null *et al*., 2021). For non-rice farmers, a combination of pest damage and drought were regarded as the greatest challenges. These findings are consistent with previous studies (e.g., United Nations, 2011; Lonn *et al*., 2016) and actions addressing these issues should be accorded high priority in future efforts to develop the agriculture sector in Cambodia.

Past, present and future agricultural practices

Our results indicate that agricultural practices have changed over time in the study regions. During the 1980s, 11.8% of respondents had no land for agriculture, whereas 10.5% hired land from others for farming purposes. This is no longer the case, as all respondents owned land and 14.5% have upgraded their farming practices by employing hired labour and agricultural machinery. Additionally, when questioned on their likely farming practices in future, 42% responded they would continue farming at a family scale, whereas 32% reported they would upgrade their practices to include hired labour and agricultural machinery. However, 26% of respondents were not sure what they would do in future, suggesting that these could potentially benefit from further training and other support from the government and agricultural agencies.

Overall, better irrigation and markets for agricultural products were identified by most study respondents as being required to improve livelihoods of rice- and non-rice farmers. Reform of the agricultural sector in Cambodia would seem inevitable and land use planning is recognised as key to sustainable agriculture (De Wrachien, 2001). In addition to improved irrigation systems and markets, development of appropriate cropping techniques is required to adapt to ongoing climate change, as is the adoption of crop species best suited to specific environmental circumstances of different areas (Ironside, 2010; Lonn *et al*., 2016).

In conclusion, our study indicates that most farmers currently earn less than the per capita GDP for Cambodia and will likely continue to depend on agriculture for their livelihoods. This suggests that a large of portion agricultural activities are economically inefficient at present and that policy reforms and investments to improve irrigation systems and cropping techniques and diversify markets are required to develop the livelihoods of farmers residing around the Tonle Sap Lake and Cambodian Mekong River.

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References

[ADB] Asian Development Bank (2021) *Cambodia Agriculture, Natural Resources, and Rural Development Sector Assessment, Strategy, and Road Map*. Asian Development Bank, Manila, Philippines.

De-Wrachien, D. (2001) Land use planning: a key to sustainable agriculture. In *Conservation Agriculture: Environment, Farmers Experiences, Innovations, Socio-Economy, Policy* (eds L. Garcia-Torres, J. Benites, A. Martinez-Viela & A. Holgado-Cabrera), p. 471–483. Springer, Dordrecht, Netherlands.

Goletti, F. & Sin S. (2016) *Development of Master Plan for Crop Production in Cambodia by 2030*. Report for the Ministry of Agriculture Forestry and Fisheries (MAFF), Tonle Sap Poverty Reduction and Smallholder Development Project, Cambodia.

Ironside, J. (2010) *The Outbreak of Peace: Communal Land Management and Traditional Governance in a Remote Cambodian Province*. Proceedings of the CAPRI Workshop on Collective Action, Property Rights, and Conflict in Natural Resources Management, 28 June–1 July, Siem Reap, Cambodia.

Kummu, M., Koponen, J. & Sarkkula, J. (2005) *Assessing Impacts of the Mekong Development in the Tonle Sap*. Proceedings of the International Symposium on the Role of Water Sciences in Transboundary River Basin Management, 10–12 March, Ubon Ratchathani, Thailand.

Lonn P., Mey K. & Touch V. (2016) *Agricultural Policy and Institutional Reforms in Cambodia: Experiences, Impacts and Lessons*. Southeast Asian Regional Center for Graduate Study and Research in Agriculture, Los Banos, Philippines.

[MAFF] Ministry of Agriculture, Forestry and Fisheries (2016) *The Annual Report on Agriculture, Forestry and Fisheries in 2016 and Future Implementation Targets*. MAFF, Phnom Penh, Cambodia [in Khmer].

Mak, S. (2017) Water governance in Cambodia: from centralized water Governance to farmer water user community. *Resources*, **6**, 44.

[MRC] Mekong River Commission (2016) *Thematic Assessment Interim Report, Agriculture and Land Use Change*. MRC, Vientiane, Lao PDR.

Ngor P.B., McCann, K., Grenouillet, G., So N., McMeans, B., Fraser, E. & Lek, S. (2018a.) Evidence of indiscriminate fishing effects in one of the world's largest inland fisheries. *Scientific Reports*, **8**, 8947.

Ngor P.B., Sor R., Prak L.H., So N., Hogan, Z.S. & Lek S. (2018b) Mollusc fisheries and length – weight relationship in Tonle Sap flood pulse system, Cambodia. *International Journal of Limnology*, **54**, 34.

[NIS] National Institute of Statistics (2013) *Census of Agriculture of the Kingdom of Cambodia*. NIS, Phnom Penh, Cambodia.

[NIS] National Institute of Statistics (2015) *Census of Agriculture of the Kingdom of Cambodia 2013, Preliminary Report*. NIS, Phnom Penh, Cambodia.

Null, S.E., Farshid, A., Goodrum, G., Gray, C.A., Lohani, S., Morrisett, C.N., Prudencio, L. & Sor R. (2021) A meta-analysis of environmental tradeoffs of hydropower dams in the Sekong, Sesan, and Srepok (3S) rivers of the Lower Mekong Basin. *Water*, **13**, 13010063.

R Core Team (2019) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Sor R., Boets, P., Chea R., Goethals, P. & Lek, S. (2017) Spatial organization of macroinvertebrate assemblages in the Lower Mekong Basin. *Limnologica*, **64**, 20–30.

Srean P., Eang B., Rien R. & Martin, R.J. (2018) Paddy rice farming practices and profitability in northwest Cambodia. *Asian Journal of Agricultural and Environmental Safety*, 2018, 1–5.

Thilakarathne, M. & Sridhar, V. (2017) Characterization of future drought conditions in the Lower Mekong River Basin. *Weather and Climate Extremes*, **17**, 47–58.

United Nations (2011) *UN Expert Makes Case for Ecological Farming Practices to Boost Food Production*. Https://news.un.org/en/story/2011/03/368352-un-expert-makes-case-ecological-farming-practices-boost-food-production#:~:text=UN expert makes case for ecological farming practices to boost food production,-8 March 2011&text="Today's scientific evidence demonstrates that,unfavourable environments%2C" he added. [Accessed 13 March 2020].

World Bank (2020a) *Cambodian Agriculture in Transition: Opportunities and Risks*. World Bank, Washington, USA.

World Bank (2020b) *GDP Per Papita (Current US$) - Cambodia*. Https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?end=2019&locations=KH&start=1960&view= [Accessed 10 January 2021].

World Bank (2021) *Agricultural Land (% of Land Area) - Cambodia*. Https://data.worldbank.org/indicator/AG.LND.AGRI.ZS?locations=KH [Accessed 23 November 2021].

Recent Master's Theses

This section presents the abstracts of research theses produced by Royal University of Phnom Penh graduates recently awarded the degree of Masters of Science in Biodiversity Conservation. The abstracts have been edited for English and brevity.

Assessing habitat connectivity to prioritize sites for protection of wild bear populations in Cambodia

CHOEURN Chhenghong

មូលន័យសង្ខេប

ប្រទេសកម្ពុជា ជាប្រទេសដែលសម្បូរធនធានធម្មជាតិ រួមមានព្រៃឈើ និងសត្វព្រៃ។ នៅក្នុងប្រទេសកម្ពុជា មានប្រភេទសត្វព្រៃជាច្រើនប្រភេទ ក្នុងនោះក៏មានសត្វខ្លាពីរប្រភេទដែរគឺ៖ ខ្លាឃ្មុំតូច (*Helarctos malayanus*) និងខ្លាឃ្មុំធំ (*Ursus thibetanus*)។ សត្វប្រភេទនេះ និងសត្វប្រភេទផ្សេងៗជាច្រើនទៀតកំពុងទទួលរងនូវការរំខាន និងការបាត់បង់ទីជម្រកធម្មជាតិ ដូចនេះការបន្តសិក្សាស្រាវជ្រាវប្រកបដោយប្រសិទ្ធភាព គឺត្រូវការជាចាំបាច់ ដើម្បីពង្រឹងដល់ការការពារ និងការប្រើប្រាស់ធនធានធម្មជាតិដោយនិរន្តរភាពនៅក្នុងប្រទេស។ គោលបំណងនៃការសិក្សារបស់ខ្ញុំគឺ ធ្វើការកំណត់តំបន់ស្នូលអាទិភាព និងផ្លូវទៅកាន់ទីជម្រកប្រកបដោយសក្តានុពលដល់ការអភិរក្សប្រភេទសត្វខ្លាឃ្មុំក្នុងប្រទេសកម្ពុជា និងស្វែងរកពីរបៀបដែលអាចមានការផ្លាស់ប្តូរទាំងនេះនាអនាគត ដោយកត្តាប្រែប្រួលអាកាសធាតុ។ ដើម្បីទទួលបានជោគជ័យ ខ្ញុំបានប្រើប្រាស់ ប្រព័ន្ធព័ត៌មានភូមិសាស្ត្រ និង ធាតុអតិបរមា ម៉ូដែល (MaxEnt) ដែលមានបញ្ចូលនូវទីតាំងភូមិសាស្ត្រ អថេរអាកាសធាតុ និងកំណត់ត្រាទីតាំងប្រភេទសត្វខ្លាឃ្មុំ ដោយផ្អែកទៅលើការថតរូបដោយម៉ាស៊ីនស្វ័យប្រវត្តិ ដែលថតបានដោយអង្គការអភិរក្សជាច្រើន។ ការកំណត់បាននូវតំបន់ដែលសមស្របជាងគេបំផុត និងទីជម្រកសម្រាប់ការអភិរក្ស ហើយលទ្ធផលនៃការសិក្សាស្រាវជ្រាវនេះ អាចប្រើប្រាស់ជាព័ត៌មានដល់កិច្ចខិតខំប្រឹងប្រែងអភិរក្សសត្វខ្លាឃ្មុំនាពេលអនាគតក្នុងប្រទេសកម្ពុជា។

Abstract

Cambodia is rich in natural resources including forests and wildlife. There are many species of wildlife in Cambodia, including two species of bear: the sun bear *Helarctos malayanus* and the Asiatic black bear *Ursus thibetanus*. As these and many other species suffer from ongoing loss and disturbance of their natural habitats, continued research efforts are needed to strengthen protection and sustainable use of natural resources in the country. The purpose of my study was to identify priority core areas and potential habitat corridors for bear conservation in Cambodia and predict how these might alter in future due to climatic factors. To achieve this, I employed GIS and maximum entropy models (MaxEnt) which included geographical and climatic variables and the locations of confirmed records of bears which were based on camera trapping efforts undertaken by several conservation organisations. In identifying the most appropriate areas and habitats for protection, the results of this research can be used to inform future conservation efforts for wild bears in Cambodia.

Factors influencing the spatial distributions and temporal dynamics of mosquito species in Phnom Penh, Cambodia

KHIN Chandara

មូលន័យសង្ខេប

ជំងឺឆ្លងតាមរយៈភ្នាក់ងារចម្លង មានជាង ១៧% នៃជំងឺឆ្លងទូទាំងពិភពលោក និងបណ្តាលឲ្យមនុស្សស្លាប់ជាងមួយលាននាក់ជារៀងរាល់ឆ្នាំ។ ក្នុងបណ្តាជំងឺឆ្លងតាមរយៈសត្វនៅក្នុងសាខាអាត្រូប៉ូត ជំងឺឆ្លងតាមរយៈសត្វមូស បានបង្ហាញឲ្យឃើញនូវសារសំខាន់មួយចំនួនដូចជា ជំងឺគ្រុនឈាម គ្រុនឈីក ហ្សីកា គ្រុនលឿង អ៊ែនសីហ្វាលីទីសជប៉ុន គ្រុនវ៉ាសណ្តូល និងជំងឺឆ្លងផ្សេងៗទៀត។ នៅក្នុងប្រទេសកម្ពុជា ជំងឺគ្រុនឈាមជាប្រភេទជំងឺកើតឡើងតាមតំបន់ និងនៅក្នុងឆ្នាំ២០១៨ ក្នុងទីក្រុងភ្នំពេញ មានអ្នកជំងឺឆ្លង ៩,៤៤៥ ករណី និងស្លាប់៦ករណី។ ការសិក្សាទៅលើភ្នាក់ងារចម្លងជំងឺ នៅមានកម្រិតនៅឡើយក្នុងប្រទេសកម្ពុជា ទោះបីជាមានការសិក្សាមួយ ចំនួនទៅលើភ្នាក់ងារជំងឺតាមរយៈមូស *Aedes aegypti* ។ ការសិក្សានេះ មានគោលបំណង ចង់ដឹងអំពី ឥទ្ធិពលនៃកត្តាបរិស្ថានលើវត្តមានប្រភេទសត្វមូសដែលជាភ្នាក់ងារចម្លងជំងឺគ្រុនឈាម៖ *A. aegypti,* និង *A. albopictus* លទ្ធភាពនៃភ្នាក់ងារចម្លងជំងឺតាមរយៈសត្វមូសក្នុងទីក្រុងភ្នំពេញ។ យើងបានជ្រើសរើស វត្តចំនួន៤០ ដោយជម្រើសចៃដន្យ និងប្រមូលដង្កូវទឹក រយៈពេល៤៨សប្តាហ៍ បន្តបន្ទាប់គ្នា ចាប់ពីឆ្នាំ២០១៩ ដល់ឆ្នាំ ២០២០ ដោយប្រើប្រាស់វិធីសាស្ត្រអន្ទាក់ដាក់ស៊ុត។ មានសត្វមូស១០ប្រភេទ ត្រូវបានធ្វើអត្តសញ្ញាណកម្ម ក្នុងចំណោមសំណាករបស់យើង ហើយមាន ៨៧% នៃមូសពេញវ័យ ស្ថិតនៅក្នុងពួក *Aedes* ។ មូស *Aedes aegypti* ភាគច្រើនប្រមូលចុងរដូវប្រាំង (មីនា-ឧសភា) ហើយ *A. albopictus* នៅចុងរដូវវស្សា (កញ្ញា-តុលា)។ មូស *Aedes aegypti* ភាគច្រើនរកឃើញ នៅតាមបណ្តាវត្តនៅកណ្តាលទីក្រុង ខណៈដែលមូស *A. albopictus* ភាគច្រើនរកឃើញនៅតាមបណ្តាវត្តជាយទីក្រុង។ លទ្ធផលនៃការសិក្សាចង្អុលបង្ហាញថា ការប្រឈមនៃជំងឺគ្រុនឈាមអាចកើតមានឡើងនៅរដូវខុសៗគ្នា និងតំបន់ខុសៗគ្នាក្នុងទីក្រុង រួមផ្សំឡើងដោយកត្តាវត្តមានរបស់ភ្នាក់ងារ ស្ថានភាពទីក្រុង និងលក្ខខណ្ឌអាកាសធាតុ។

Abstract

Vector-borne diseases account for more than 17% of all infectious diseases and cause over one million deaths annually. Among diseases transmitted by arthropods, diseases transmitted by mosquitoes represent some of the most important and include dengue, chikungunya, zika, yellow fever, Japanese encephalitis, west Nile fever, and other diseases. Dengue is an endemic disease in Cambodia and in 2018, 9,445 cases including six deaths occurred in Phnom Penh alone. Studies on vectors of dengue are still limited in Cambodia, although several studies have been done on *Aedes aegypti*. This study aimed to understand the influence of environmental factors on the presence of dengue vectors such as *A. aegypti*, *A. albopictus* and other possible mosquito vectors in Phnom Penh. We randomly selected 40 pagodas and used ovitraps to collect mosquito larvae at these for 48 consecutive weeks in 2019 and 2020. Ten mosquito species were identified in our samples and 87% of all adult mosquitoes belonged to the *Aedes* genus. *Aedes aegypti* mosquitoes were mostly collected during the late dry season (March–May), whereas *A. albopictus* mosquitoes were mostly collected during the late rainy season (September–October). The former mostly occurred in pagodas in the central area of the city, whereas the latter mostly occurred in peripheral areas of the city. The results of the study indicate that risks of dengue fever tend to emerge in different seasons and parts of the city as a result of differences in species' occurrence, urban landscapes and climatic factors.

Roost site preferences and roosting ecology of white-shouldered ibis (*Pseudibis davisoni*) in Cambodia

LAY Darith

មូលន័យសង្ខេប

ត្រយ៉ងចង្កំកស *Pseudibis davisoni* ជាប្រភេទរងគ្រោះថ្នាក់ជិតផុតពូជបំផុត ហើយមានវត្តមាននៅក្នុងប្រទេសកម្ពុជា ឥណ្ឌូនេស៊ី និងផុតពូជពីប្រទេសថៃ វៀតណាម ហើយបានផុតពូជពីប្រទេសចិន ម៉ាឡេស៊ី និងភូមា។ ចំនួនប៉ូពុឡាស្យុងត្រយ៉ងចង្កំកសក្នុងពិភពលោកប្រមាណ ៩៥% មានវត្តមាននៅភាគខាងជើង និងខាងកើតប្រទេសកម្ពុជា ហើយប្រឈមយ៉ាងខ្លាំង ដោយការបាត់បង់ព្រៃឈើ (ជាពិសេសបានបាត់បង់យ៉ាងធំធេងនូវដើមសម្បុកពងកូន) ការបរបាញ់ ការប្រមូលពង និងកូន ព្រមទាំងការបំពុលដោយថ្នាំពុល។ ការសិក្សានេះ បានប្រមូលទិន្នន័យជំរឿន ដើម្បីវាយតម្លៃស្ថានភាពត្រយ៉ងចង្កំកស ទីតាំងទ្រនំ អេកូឡូស៊ីនៃទ្រនំរបស់ពួកវាក្នុងប្រទេសកម្ពុជា។ ទិន្នន័យទាំងនេះចង្អុលបង្ហាញថា ចំនួនត្រយ៉ងចង្កំកសបានថយចុះពីមួយឆ្នាំទៅមួយឆ្នាំ និងរកឃើញចំនួន៦៩០ក្បាលក្នុងខែកញ្ញា ឆ្នាំ២០២០។ ប្រភេទសត្វនោះមាន៥០% មានទីតាំងទ្រនំស្ថិតក្នុងតំបន់ការពារធម្មជាតិ។ កំណត់ត្រាភាគច្រើនប្រភេទសត្វនេះមានវត្តមានក្នុងខេត្តស្ទឹងត្រែង និងនៅតាមបណ្តោយព្រៃលិចទឹកទន្លេមេគង្គចាប់ពីខេត្តក្រចេះ ដល់ខេត្តស្ទឹងត្រែង។ ចង្កំកស ចូលចិត្តទ្រនំដែលជាប្រភេទដើមរស់ ប៉ុន្តែដើមដែលមានទ្រង់ទ្រាយមិនសូវល្អ(៣៣.៩%) ដើមងាប់មានមែកនិងរបកសំបក(២១.០%) ដើមងាប់មិនមានមែកឬសំបក(១២.៩%) និងដើមងាប់(៩.៧%)។ វាពេញចិត្តដើមទ្រនំដូចជា ត្រាច(៤០.៣%) ធ្នឹក(១៩.៤%) ពពេល(៨.១%) និងប្រភេទដើមឈើផ្សេងទៀតរួមមាន ត្បែង ខ្លុង ចំបក់ ចែង សុក្រមជាដើម។ ដើមទ្រនំភាគច្រើនកំពុងប្រឈមនឹងរំខានដោយសកម្មភាពមនុស្ស(៣៥.៩%) ភ្លើងឆេះដើមទ្រនំ(២៦.៣%) ការបរបាញ់(១៧.៣%) ការកាប់ឈើខុសច្បាប់(១៤.៧%) ការទន្ទ្រានដីព្រៃជាកម្មសិទ្ធិ(៥.៨%)។ ការរស់រានរបស់ត្រយ៉ងចង្កំកស មានការប្រឈមជាខ្លាំងដោយសកម្មភាព មនុស្ស ហើយក្រោមការខិតខំប្រឹងប្រែងនានាប្រកបដោយនិរន្តភាពដើម្បីអភិរក្សសត្វចង្កំកស ដោយរួមបញ្ចូលនូវយុទ្ធនាការនៃការអប់រំផ្សព្វផ្សាយជាសាធារណៈ និងគម្រោងអេកូទេសចរណ៍ ពិតជាមានការចាំបាច់ដល់ការបង្កើនចំនួនឡើងវិញនៃប្រភេទសត្វនេះ។

Abstract

The white-shouldered ibis *Pseudibis davisoni* is listed as Critically Endangered and is extant in Cambodia and Indonesia, extinct in Thailand and Viet Nam and possibly extinct in China, Malaysia and Myanmar. Ninety-five percent of the global population is thought to occur in northern and eastern Cambodia and threats to the species include forest loss (particularly the loss of large nesting trees), hunting, egg and chick collection and incidental poisoning. This study employed census data to assess the status of white-shouldered ibises and evaluate their roost site preferences and roosting ecology in Cambodia. These data indicate that numbers of individuals have declined in the country in recent years and suggest 690 individuals remained in September 2020. They also indicate that only 52% of known roosts are located inside nationally protected areas. Most records of the species stem from Stung Treng Province and along the Mekong flooded forests from Kratie Province to Stung Treng Province. For roosting purposes, white-shouldered ibises appear to favour live but usually unhealthy trees (33.9% of all roosts), dead trees with branches and lost bark (21.0%), dead trees with no branches or bark (12.9%) and completely dead trees (9.7%). Favoured tree species include *Dipterocarpus intricatus* (40.3% of all roosts), *Shorea obtusa* (19.4%) and *Acacia caesia* (8.1%), alongside *D. obtusifolius*, *D. tuberculatus*, *Irvingia malayana*, *Niebuhria mucronata* and *Xylia dolabriformis*. Most roosts are threatened by a variety of factors including human disturbance (35.9%), forest fires (26.3%), hunting (17.3%), illegal logging (14.7%) and land encroachment (5.8%). The survival of white-shouldered ibises is strongly challenged by human activities and a variety of sustained conservation efforts including public education campaigns and ecotourism projects are essential for recovery of the species.

Diversity, community structure and distribution of small mammals in Cambodia

NUON Sithun

មូលន័យសង្ខេប

លក្ខណៈជីវសាស្ត្រ និងអេកូឡូស៊ីនៃថនិកសត្វតូច ត្រូវបានទទួលស្គាល់ដើរតួនាទីយ៉ាងសំខាន់ ទោះបីជាមានការសិក្សាតិចតួចអំពីនានាភាព និងរបាយនៃភាពខុសគ្នាក្នុងប្រទេសកម្ពុជាក្តី។ យោងទៅតាមការសិក្សាទូទាំងប្រទេស មាន១៨២ទីតាំង ចាប់ពីឆ្នាំ២០១៧ ដល់ឆ្នាំ២០១៩ ក្នុងគោលបំណងសិក្សាអំពីភាពចម្រុះ រចនាសម្ព័ន្ធសហគមន៍ និងរបាយនៃថនិកសត្វតូច កំណត់របាយទាំងនេះរវាងទីជម្រក និងសមាសធាតុផ្សំ ដោយបញ្ជាក់ពីវត្តមានរបស់ពួកវាដែលមានទីជម្រករស់នៅជាក់លាក់។ ជាលទ្ធផល យើងរកឃើញថនិកសត្វតូចៗចំនួន ២០ប្រភេទ ដែលមាន១៣ពូក ៤អំបូរ និង៣លំដាប់ ត្រូវបានកំណត់ត្រា។ អំបូរកណ្តុរ Muridae មានច្រើនជាងគេ បន្ទាប់មកគឺ អំបូរ Sciuridae, Soricidae និង Tupaiidae ។ កណ្តុរ *Rattus tanezumi* ជាប្រភេទដែលមានច្រើនជាងគេ បន្ទាប់មកគឺ កណ្តុរប្រភេទ *Mus caroli*, *M. cervicolor*, *Maxomys surifer* និង *Bandicota indica* ចំណែកឯកណ្តុរប្រភេទ *Suncus murinus* មានចំនួនតិចជាងគេ។ របាយនៃភាពសម្បូរបែបនៃប្រភេទនេះ និងភាពចម្រុះគឺមិនមានលក្ខណៈដូចគ្នាទេ។ ភាពសម្បូរបែបនៃប្រភេទនេះមានច្រើននៅក្នុងព្រៃល្បោះ និងជម្រកព្រៃស្រោង ហើយមានតិចជាងគេនៅក្នុងតំបន់ព្រៃគុម្ពោត។ ចំពោះលក្ខណៈសម្បូរបែបនៃប្រភេទមិនមានភាពខុសប្លែកគ្នារវាងទីជម្រកទេ ហើយខុសគ្នាតិតតួចរវាងសមាសធាតុនៃថនិកសត្វតូចៗ។ ប្រភេទ *Tupaia belangeri* មានច្រើននៅក្នុងព្រៃល្បោះ ហើយប្រភេទ *Niviventer cremoriventer* ក៏មានច្រើនដែរនៅក្នុងព្រៃស្រោង ចំណែកឯប្រភេទ *B. indica* វិញក៏មានច្រើននៅតំបន់វាលស្រែ។ លើសពីនេះទៅទៀត ប្រភេទកណ្តុរ *M. surifer* មានវត្តនៅតាមវាលស្រែ និងព្រៃគុម្ពោត ហើយប្រភេទកណ្តុរ *M. cervicolor* និង *M. caroli* មានរស់នៅទាំងក្នុងតំបន់ដីកសិកម្ម វាលស្រែ និងគុម្ពោតព្រៃ ចំណែកឯ *M. shortridgei* ត្រូវបានរកឃើញច្រើននៅក្នុងព្រៃស្រោង ព្រៃរបោះ និងព្រៃគុម្ពោតផងដែរ។ ជាលទ្ធផល ទីជម្រកដ៏ជាក់លាក់ បានដើរតួនាទីយ៉ាងសំខាន់សម្រាប់ភាពសម្បូរបែបនៃប្រភេទ ភាពសម្បូរបែបនៃចំនួនឯកត្តៈ និងសមាសធាតុនៃថនិកសត្វតូចៗក្នុងប្រទេសកម្ពុជា។ ការសិក្សានេះមានសារៈសំខាន់បំផុតដល់ការត្រួតពិនិត្យ គ្រប់គ្រង និងសកម្មភាពអភិរក្សប្រភេទថនិកសត្វតូចៗទាំងនេះ។

Abstract

The biological and ecological importance of small mammals is widely accepted, although little is known about their diversity and distributions in Cambodia. Based on a nationwide field survey undertaken over 182 sampling days in 2017–2019, this study investigated the diversity, assemblage structure and distributions of small mammals, compared these between habitats and assessed which species are indicative of specific habitat types. Twenty species belonging to 13 genera, four families and three orders were recorded. Species belonging to the Muridae were dominant, followed by members of the Sciuridae, Soricidae and Tupaiidae. *Rattus tanezumi* was the most abundant species, followed by *Mus caroli*, *M. cervicolor*, *Maxomys surifer* and *Bandicota indica*, whereas *Suncus murinus* was the least abundant. The distribution of species richness, abundance and diversity was not homogeneous. Species richness was highest in dipterocarp forests, followed by evergreen forests, and lowest in shrublands, whereas species abundance was highest in rice fields, followed by evergreen forests, and lowest in dipterocarp forests and shrublands. Species diversity did not differ significantly between habitats, although slight differences were observed in assemblage composition. *Tupaia belangeri* was more abundant in deciduous forests, whereas *Niviventer cremoriventer* was more abundant in evergreen forests and *B. indica* was most abundant in rice fields. Additionally, *M. surifer* was common in rice fields and shrublands, whereas *M. cervicolor* and *M. caroli* were abundant in several habitats including (non-rice) agriculture, rice fields and shrublands and *M. shortridgei* was frequently found in deciduous forests, evergreen forests and shrublands. These results suggest that habitat type plays a crucial role in shaping the species richness, abundance and composition of small mammal assemblages in Cambodia. This information is of paramount importance for monitoring species and informing future management decisions and conservation actions.

The effect of incubation temperature on sex determination and hatching success rates of hybrid *Crocodylus siamensis* at Phnom Tamao Zoological Park and Wildlife Rescue Center

ORK Kruy

មូលន័យសង្ខេប

ក្រពើភ្នំ *Crocodylus siamensis* ជាប្រភេទកំពុងរងគ្រោះធ្ងន់ធ្ងរក្នុងចំណោមពពួកក្រពើដែលទទួលរងការគម្រាមកំហែងបំផុតជាសកល ហើយការបន្តពូជរបស់វាត្រូវបានគេដឹងតិចតួចនៅឡើយ។ ការសិក្សានេះ មានគោលបំណងចូលរួមចំណែកក្នុងការបំពេញចន្លោះចំណេះដឹង តាមរយៈការស្វែងយល់ពីឥទ្ធិពលសីតុណ្ហភាពលើរយៈពេលភ្ញាស់ អត្រាជោគជ័យនៃការញាស់ ការកំណត់ភេទ និងការវាស់វែងកូនក្រពើ។ ការសិក្សានេះធ្វើនៅរដូវទំលាក់ពងឆ្នាំ២០២០ (ខែកុម្ភៈ ដល់ខែ សីហា) នៅកន្លែងបង្កាត់ពូជអភិរក្សនៃគម្រោងអភិរក្សសត្វក្រពើកម្ពុជានៅឧទ្យានសួនសត្វភ្នំតាម៉ៅ និងមជ្ឈមណ្ឌលសង្គ្រោះសត្វព្រៃ។ ដោយសារពងក្រពើភ្នំពូជសុទ្ធ *C. siamensis* មានចំនួនតិចតួច និងមានតម្លៃអភិរក្សខ្ពស់ ការពិសោធន៍បានប្រើពងក្រពើភ្នំកូនកាត់ *C. siamensis* x *porosus* និង/ ឬ *rhombifer* ចំនួន៥៥គ្រាប់។ ពងក្រពើទាំងនោះត្រូវបានដាក់ភ្ញាស់នៅសីតុណ្ហភាព១១កម្រិតផ្សេងៗគ្នា ដោយការបង្កើន០.៥អង្សាសេទៅលើសីតុណ្ហភាពចន្លោះពី២៩ទៅ៣៤អង្សាសេ។ ស៊ុតចំនួន៣៦ក្នុងចំណោមស៊ុត៥៥គ្រាប់បានញាស់ដោយជោគជ័យ ដោយប្រើរយៈពេលភ្ញាស់ចន្លោះពី៦៩ទៅ៨៧ថ្ងៃ។ លទ្ធផលបង្ហាញថា សីតុណ្ហភាពមានឥទ្ធិពលទៅលើអត្រាញាស់ជោគជ័យ និងរយៈពេលភ្ញាស់ ដោយមានទំនាក់ទំនងវិជ្ជមានរវាងសីតុណ្ហភាពនិង អត្រាញាស់ជោគជ័យ ហើយនិងមានទំនាក់ទំនងអវិជ្ជមានរវាងសីតុណ្ហភាព និងរយៈពេលភ្ញាស់។ សីតុណ្ហភាពភ្ញាស់គ្មានឥទ្ធិពលទៅលើការកំណត់ភេទ ព្រោះញាស់បានកូនញីតែមួយក្បាលប៉ុណ្ណោះ។ គ្មានទំនាក់ទំនងរវាងសីតុណ្ហភាព និងប្រវែងសរុបរបស់កូនក្រពើទេ ប៉ុន្តែសីតុណ្ហភាពមានឥទ្ធិពលទៅលើប្រវែងពីក្លូអាក់មកក្បាល ប្រវែងក្បាល និងទម្ងន់របស់កូនក្រពើ។ ទោះបីជាការសិក្សានេះរួមចំណែកដល់ការយល់ដឹងរបស់យើងអំពីឥទ្ធិពលនៃសីតុណ្ហភាពទៅលើរយៈពេលភ្ញាស់ និងប៉ារ៉ាម៉ែត្រញាស់របស់កូនក្រពើភ្នំកូនកាត់ក៏ពិតមែន តែទំហំសំណាកគឺនៅតូច ហើយសំខាន់ជាងនេះទៀតគឺការត្រួតពិនិត្យសីតុណ្ហភាពត្រឹមត្រូវមិនអាចធ្វើទៅបានដោយសារតែបញ្ហាដាច់ចរន្តអគ្គីសនី។ កត្តាទាំងនេះត្រូវតែយកមកពិចារណាមុនធ្វើសេចក្តីសន្និដ្ឋានពីលទ្ធផល និងការសិក្សានាពេលអនាគតដែលដំណោះស្រាយនៃដែនកំណត់ទាំងនេះត្រូវបានរាប់បញ្ចូល។

Abstract

The Critically Endangered Siamese crocodile *Crocodylus siamensis* is one of the most threatened crocodilians globally, although its reproductive biology remains poorly known. This study aimed to contribute to filling gaps in knowledge by investigating the effect of incubation temperature on incubation periods, hatching success rates, sex determination and hatchling measurements. The study was carried out during the 2020 nesting season (February to August) at the conservation breeding facility of the Cambodian Crocodile Conservation Project in the Phnom Tamao Zoological Park and Wildlife Rescue Center. Given the relatively small number and conservation importance of *C. siamensis* eggs, the experiment employed 55 eggs obtained from specimens of mixed ancestry (*C. siamensis* x *porosus* and/or *rhombifer*). These were incubated at 11 different temperatures, increasing in 0.5 °C increments from 29 °C to 34 °C. Thirty-six of the 55 eggs hatched, with incubation periods ranging from 69 to 87 days. Results indicate that incubation temperature influences hatching success rates and incubation periods, with a positive correlation between temperature and success rates and a negative correlation between temperature and incubation periods. The influence of incubation temperature on sex determination could not be evaluated as only one female was produced. No correlation was found between incubation temperature and the total length of hatchlings, but temperature appears to influence snout vent-length, head length and weight. While this study contributes to understanding of the effect of temperature on incubation periods and hatchling parameters for hybrid *C. siamensis*, the sample size was small and accurate temperature control was not possible due to logistical challenges including power cuts. These caveats must be considered before firm conclusions are drawn from the results and further studies that address these limitations are warranted.

Diversity of microfungi inhabiting palmaceous plants in Cambodia (*Borassus flabellifer*) and Japan (*Trachycarpus fortunei*)

PEN Kaknika

មូលន័យសង្ខេប

ត្នោតជារុក្ខជាតិបៃតងម៉ូណូកូទីលេដូន ស្ថិតនៅក្នុងអំបូរ Palmaceae (Arecaceae) លំដាប់ Arecales នៃរុក្ខជាតិអង់ស្យូស្ពែម។ ត្នោតជាក្រុមរុក្ខជាតិដែលមានភាពសម្បូរបែប មានរបាយនៅក្នុងតំបន់ត្រូពិច រហូតដល់តំបន់ក្បែរត្រូពិច និងជារុក្ខជាតិមានតម្លៃសេដ្ឋកិច្ចយ៉ាងសំខាន់ត្រូវបានមនុស្សប្រើប្រាស់ក្រោមទម្រង់ផ្សេងៗ។ ក្នុងទសវត្សចុងក្រោយនេះ ផ្សិតដែលដុះនៅលើដើមត្នោតត្រូវបានសិក្សាតាមរយៈការពណ៌នាផ្នែករូបសាស្ត្រ និងប្រវត្តិពូជអំបូរម៉ូលេគុលសេនេទិច។ គោលបំណងនៃការសិក្សានេះគឺដើម្បីកំណត់ភាពសម្បូរបែបនៃផ្សិតតូចៗដែលដុះលូតលាស់លើរុក្ខជាតិអំបូរត្នោតនៅប្រទេសកម្ពុជា និងប្រទេសជប៉ុន និងផ្តល់ការពិពណ៌នាពីណែកថ្នាក់របស់ផ្សិតទាំងនោះ។ ស្លឹកត្នោតចំនួន ២៥សំណាកត្រូវបានប្រមូលពីទីតាំងចំនួន ២៥កន្លែងខុសៗគ្នា ដែលរួមមាននៅប្រទេសជប៉ុនចំនួន ១៥ទីតាំង ប្រមូលនៅខែសីហា ឆ្នាំ២០២០ និង១០ទីតាំងនៅក្នុងប្រទេសកម្ពុជា ប្រមូលនៅខែវិច្ឆិកា ឆ្នាំ២០២០។ ដើម្បីរកវត្តមានផ្សិតដុះលើសំណាកស្លឹកត្នោតទាំងនេះ វិធីសាស្ត្រពីរយ៉ាងត្រូវបានប្រើប្រាស់គឺ ការលាងសម្អាតផ្នែកខាងក្រៅ និងការលាងសម្អាតដោយសម្លាប់មេរោគ។ បន្ទាប់ពីប្រើវិធីសាស្ត្រលាងសម្អាតរួច សំណាកស្លឹកត្នោតត្រូវបាន កាត់ជាចំណែកតូចៗ ហើយដាក់លើមជ្ឈដ្ឋានបណ្តុះ (agar plate) និងរក្សាទុកនៅសីតុណ្ហភាព ២០ អង្សាសេ ចំនួន៣ ទៅ ៧ថ្ងៃ។ ជាលទ្ធផល ផ្សិតចំនួន ៤៦ប្រភេទ ស្ថិតក្នុង ៣៤ពូកត្រូវបានកត់ត្រាពីការសិក្សានេះ។ ផ្សិតចំនួន ២២ប្រភេទ ស្ថិតក្នុង ២០ពូកត្រូវបានរកឃើញនៅកម្ពុជា រួមមាន៖ ពូក *Acremonium*, *Alternaria*, *Aspergillus*, *Candida*, *Colletotrichum*, *Curvularia*, *Diaporthe*, *Fusarium*, *Gliocladium*, *Mucor*, *Nigrospora*, *Papulaspora*, *Penicillium*, *Periconia*, *Pestalotiopsis*, *Phaeotrichoconis*, *Phomopsis*, *Rhizopus*, *Trichoderma* និងពូក *Trichothecium* ខណៈដែលនៅប្រទេសជប៉ុនមានផ្សិតចំនួន ៤៥ប្រភេទ ស្ថិតក្នុង៣៣ពូកត្រូវបានកត់ត្រា។ មានផ្សិតចំនួន ១៥ពូក ដែលមានវត្តមាននៅប្រទេសទាំងពីរគឺ៖ ពូក *Acremonium, Alternaria, Aspergillus, Colletotrichum, Curvularia, Fusarium, Gliocladium, Mucor, Nigrospora, Papulaspora, Penicillium, Periconia, Pestalotiopsis, Phomopsis* និងពូក *Trichoderma*។ ចំនួនប្រភេទ ចំនួនឯកត្តៈ និងភាពសម្បូរបែបនៃសហគមន៍ផ្សិតនៃប្រទេសទាំងពីរត្រូវបានធ្វើការប្រៀបធៀបគ្នារវាងប្រទេសទាំងពីរ ដោយបានបង្ហាញថាមានភាពខុសគ្នានៃភាពសម្បូរបែបរបស់ផ្សិតនៅក្នុងប្រទេសទាំងនេះ។ ទោះបីជាយ៉ាងណា ការសិក្សាស្រាវជ្រាវបន្ថែមទៀតជាតម្រូវការចាំបាច់ ជាពិសេសការប្រៀបធៀបរវាងជាលិកាស្លឹកខ្ចី និងចាស់ ដោយធ្វើឡើងក្នុង រយៈពេលយូរ (ការប្រមូលសំណាកប្រចាំខែ ក្នុងរយៈពេលច្រើនឆ្នាំ) នឹងអាចជួយបំភ្លឺអំពីកត្តាបរិស្ថានផ្សេងៗទៅលើសហគមន៍ផ្សិតនៅ ប្រទេសកម្ពុជា។

Abstract

Palms are evergreen perennial monocot plants belonging to the Palmaceae (Arecaceae) in the Arecales order of the Angiosperms. These are a highly diverse group of plants mainly distributed in tropical to subtropical areas and include many economically important plants which are utilized in various ways by humans. Over the last decade, the fungal flora associated with palms has been studied using descriptive morphological and molecular phylogenetic approaches. The aim of this study was to determine the diversity of microfungi inhabiting palmaceous plants in Cambodia and Japan and provide taxonomic descriptions of these. Twenty-five leaves were collected from 25 sampling sites, including 15 sites in Japan in August 2020 and ten sites in Cambodia in November 2020. Surface washing and sterilization methods were used to detect the fungi present on samples. Following this, sample leaves were cut into small pieces and placed on agar plates. All cultures were stored at 20 °C for three to seven days in an incubator. A total of 46 microfungal species belonging to 34 genera were recorded from the samples. Twenty-two species in 20 genera were identified in the Cambodian samples including: *Acremonium*, *Alternaria*, *Aspergillus*, *Candida*, *Colletotrichum*, *Curvularia*, *Diaporthe*, *Fusarium*, *Gliocladium*, *Mucor*, *Nigrospora*, *Papulaspora*, *Penicillium*, *Periconia*, *Pestalotiopsis*, *Phaeotrichoconis*, *Phomopsis*, *Rhizopus*, *Trichoderma* and *Trichothecium*, whereas 45 taxa in 33 genera were recorded in Japan. Fifteen genera were recorded from both countries: *Acremonium*, *Alternaria*, *Aspergillus*, *Colletotrichum*, *Curvularia*, *Fusarium*, *Gliocladium*, *Mucor*, *Nigros-*

pora, *Papulaspora*, *Penicillium*, *Periconia*, *Pestalotiopsis*, *Phomopsis* and *Trichoderma*. The species richness, abundance and diversity of fungal communities was compared between countries and significant differences were found in diversity. However, further studies are warranted. In particular, comparison of young and old palm tissues and temporal surveys (monthly sampling over several years) may help to elucidate the influence of different environmental factors on Cambodian fungal communities.

The effectiveness of Bengal florican (*Houbaropsis bengalensis*) conservation in the Northern Tonle Sap Protected Landscape in the Kampong Thom and Siem Reap provinces, Cambodia

SAN Sovannary

មូលន័យសង្ខេប

សត្វខ្សឹប (*Houbaropsis bengalensis*) ជាប្រភេទទទួលរងគ្រោះធ្ងន់ធ្ងរបំផុតដែលរស់នៅក្នុងតំបន់វាលស្មៅមានដីល្បាប់នៃប្រទេសឥណ្ឌា នេប៉ាល់ និងប្រទេសកម្ពុជា។ តំបន់អភិរក្សសត្វខ្សឹប (BFCAs) គ្របដណ្តប់លើផ្ទៃដី ៣១.១៥៩ ហិចតា (ស្មើនឹង ៣១២ គីឡូម៉ែត្រការ៉េ) មានទីតាំងស្ថិតនៅតំបន់ការពារទេសភាពបឹងទន្លេសាបខាងជើង (រួមមានខេត្តកំពង់ធំ និងសៀមរាប)។ ការសិក្សាស្រាវជ្រាវនេះមានគោលបំណងដើម្បីប៉ាន់ស្មានពីនិន្នាការចំនួនសត្វខ្សឹបនៅតំបន់អភិរក្សសត្វខ្សឹបចំនួនបី ពីឆ្នាំ២០១០ ដល់ ឆ្នាំ២០១៩ និងដើម្បីកំណត់រកកត្តាគម្រាមកំហែង ព្រមទាំងស្វែងយល់ពីទស្សនៈទានរបស់ប្រជាជនលើការអភិរក្សសត្វខ្សឹប។ ទិន្នន័យស្ថិតិប្រចាំឆ្នាំត្រូវបានប្រើប្រាស់ដើម្បីវាយតម្លៃពីប៉ូប៉ុយឡាស្យុងរបស់សត្វខ្សឹប រីឯទិន្នន័យទាក់ទងនឹងកត្តាគម្រាមកំហែង និងទស្សនៈទានរបស់ប្រជាជនមូលដ្ឋានត្រូវបានបង្ហាញតាមរយៈការសង្កេតដោយផ្ទាល់ដោយប្រើវិធីសាស្ត្រដើរជាខ្សែបន្ទាត់ តាមរយៈការសម្ភាសន៍ប្រជាជនចំនួន៩៧គ្រួសារ និងការរៀបចំក្រុមពិភាក្សាចំនួនបីក្រុមដែលមានអ្នកចូលរួម ៤០រូប។ តាមរយៈទិន្នន័យស្ថិតិ បង្ហាញថាចំនួនសត្វខ្សឹបមានការថយចុះនៅតំបន់បារាយស្ទឹងជីក្រែង និងតំបន់អភិក្សសត្វខ្សឹបចុងដូងនៅចន្លោះពីឆ្នាំ២០១០ ដល់ឆ្នាំ២០១៩ ខណៈពេលដែលចំនួនសត្វខ្សឹបហាក់មានស្ថេរភាពនៅតំបន់អភិរក្សស្ទឹងជីក្រែងនៅចន្លោះឆ្នាំ២០១៧ ដល់ ឆ្នាំ២០១៩។ តាមរយៈការសង្កេតដោយដើរជាខ្សែបន្ទាត់បង្ហាញថា កត្តាគម្រាមកំហែងទៅដល់របាយរបស់សត្វខ្សឹបរួមមាន៖ ការលែងសត្វគោ-ក្របីអោយស៊ីស្មៅនៅក្នុងតំបន់អភិរក្សស្ទឹងជីក្រែង(៣៦,១%) ផលរំខានពីវត្តមានរបស់មនុស្សនៅបារាយ (៣៨,៧%) និងនៅចុងដូង (៣៩,២%)។ ចំណែកឯកត្តាគម្រាមកំហែងដល់ការអភិរក្សរួមមាន ការបរបាញ់ (៣០,៧%) ការប្រើប្រាស់ថ្នាំពុលកសិកម្ម (១៦,៤%) ការបាត់បង់ទីជម្រកដោយការទន្ទ្រានយកដី (១៥,៦%) ការធ្វើស្រែប្រាំង (១៣,១%) ព្រមទាំងការប៉ះពាល់ដោយសារខ្សែបណ្តាញបញ្ជូនអគ្គិសនី (១០,៧%)។ ទោះបីជាយ៉ាងណាក៏ដោយ មាន៨០,៤% នៃអ្នកចូលរួមបានយល់អំពីគោលបំណងនៃការអភិរក្សសត្វខ្សឹប និងមាន ៧៨,៤% បានយល់ជាវិជ្ជមានអំពីការគ្រប់គ្រងការអភិរក្ស។ សកម្មភាពជាច្រើនត្រូវបានណែនាំដើម្បីពង្រឹងការអភិរក្សប៉ូពុយឡាស្យុងសត្វខ្សឹបនៅក្នុងតំបន់សិក្សា។

Abstract

The Bengal florican *Houbaropsis bengalensis* is a Critically Endangered bustard which inhabits alluvial grasslands in India, Nepal and Cambodia. Bengal Florican Conservation Areas (BFCAs) covering 31,159 ha (312 km^2) exist in the Northern Tonle Sap Protected Landscape (Kampong Thom and Siem Reap provinces) of Cambodia. This study aimed to assess population trends for the species in three BFCAs in 2010–2019, as well as to identify threats to its survival and explore local perceptions regarding ongoing conservation initiatives. Annual census data were used to assess population trends, whereas threats and local perceptions were investigated through a mixture of observations on line transects, 97 household interviews, three key informant interviews and three focus group discussions involving 40 local residents. Census data suggest that the species declined in the Stoung-Chikraeng, Baray and Chong Doung BFCAs between 2010 and 2019, although the population appeared more stable in the Stoung-Chikraeng BCFA in 2017–2019. According to transect observations, the most common threats to the species were disturbance from cattle grazing in the Stoung-Chikraeng BCFA (registered on 36.1% of transects) and human presence in the Baray and Chong Doung BFCAs (38.7%

and 34.2% respectively). Conservation threats most commonly identified by local residents included hunting (30.7% of households), use of agricultural chemicals (16.4%), habitat loss due to land grabbing (15.6%), rice planting during the dry season (13.1%) and collisions with overhead power lines (10.7%). Notwithstanding this, 80.4% of study respondents understood the purpose of the BFCAs and 78.4% regarded their management positively. A variety of actions are recommended to strengthen conservation of Bengal florican populations within the study landscape.

Distribution and habitat characteristics of Endangered *Paphiopedilum spp.* and *Phalaenopsis* spp. in the Shinta Mani Wild Conservation Concession, Cambodia

VENG Sreyleak

មូលន័យសង្ខេប

កេសរកូលគឺជារុក្ខជាតិដែលមានរបាយយ៉ាងទូលំទូលាយនិងមានដុះលូតលាស់នៅតំបន់ត្រូពិច ដែលមានអាកាសធាតុក្តៅ-សើម។ ការសិក្សានេះមានគោលបំណងដើម្បីកំណត់រករបាយ ព្រមជាមួយនឹងទីជម្រកនៃកេសរកូលប្រភេទ *Paphiopedilum* spp. និង *Phalaenopsis* spp. នៅក្នុងតំបន់សម្បទានអភិរក្សព្រៃ Shinta Mani ដែលមានផ្ទៃដីសរុប ៣គម² ស្ថិតនៅក្នុងខេត្តព្រះសីហនុ នាភាគខាងត្បូងនៃប្រទេសកម្ពុជា។ គោលបំណងរួមនៃការសិក្សាស្រាវជ្រាវនេះគឺដើម្បីរួមចំណែកដល់ការអភិរក្សកេសរកូលនៅប្រទេសកម្ពុជា។ ការសិក្សាស្រាវជ្រាវនេះត្រូវបានធ្វើឡើងចាប់ពីខែមេសា ដល់ខែសីហា ឆ្នាំ២០២០ ដោយប្រើប្រាស់វិធីសាស្ត្រ ខ្សែបន្ទាត់ ការស្វែងរកដោយឱកាស និងដោយចៃដន្យ ដើម្បីស្វែងរកទីតាំងដែលកេសរកូលទាំងពីរពួកនេះដុះលូតលាស់។ សំរាប់ការសិក្សានេះ ទិន្នន័យអេកូឡូស៊ីមួយចំនួនដូចជា រយៈកម្ពស់ សំណើម សីតុណ្ហភាព មជ្ឈដ្ឋានធ្នូល ចម្ងាយពីប្រភពទឹក និងគម្របព្រៃឈើត្រូវបានកត់ត្រានៅទីតាំងដែលកេសរកូលដុះលូតលាស់។ កេសរកូលពីរប្រភេទនៃពួក *Phalaenopsis* (ប្រភេទ *P. difformis* និង *P. pulcherrima*) ត្រូវបានរកឃើញនៅទីតាំងចំនួន ៥៦កន្លែង ចំណែកឯកេសរកូលមួយប្រភេទនៃពួក *Paphiopedilum* (ប្រភេទ *P. callosum*) ត្រូវបានរកឃើញនៅទីតាំងចំនួន ៧កន្លែង។ កេសរកូលប្រភេទ *Phalaenopsis difformis* ដែលជាប្រភេទរុក្ខជាតិផ្ញើរប្រាណឬដុះលូតលាស់លើរុក្ខជាតិដទៃ (epiphyte) ត្រូវបានរកឃើញនៅតែមួយទីតាំង ដែលស្ថិតនៅតាមដងស្ទឹង នៅរយៈកម្ពស់ ១២៩ម៉ែត្រពីនីវ៉ូទឹកសមុទ្រ និងកេសរកូល *P. pulcherrima* (ជាកេសរកូលដែលអាចដុះលូតលាស់នៅលើរុក្ខជាតិដទៃ ឬអាចដុះលូតលាស់នៅលើថ្ម) ត្រូវបានរកឃើញនៅតំបន់ព្រៃមាត់ស្ទឹង នៅរយៈកម្ពស់ចន្លោះពី ៥០ ទៅ២០០ ម៉ែត្រពីនីវ៉ូទឹកសមុទ្រ ដែលភាគច្រើនដុះលូតលាស់នៅតំបន់ស្រឡះ មានលាយឡំជាមួយឬស្សីព្រិច និងជាកន្លែងដែលមានពន្លឺថ្ងៃចាំងចូលដល់។ រីឯកេសរកូលប្រភេទ *P. callosum* គឺជាកេសរកូលដុះលូតលាស់នៅលើថ្ម និងដុះលូតលាស់ល្អនៅរយៈកម្ពស់ ២០០ម៉ែត្រពីនីវ៉ូទឹកសមុទ្រ។ កេសរកូលប្រភេទនេះ ត្រូវបានរកឃើញភាគច្រើនដុះលូតលាស់នៅទីតាំងដែលមានសំណើមលាយជាមួយស្លឹករុក្ខជាតិរលួយនៅក្បែរព្រៃបៃតង ហើយកេសរកូលនេះបច្ចុប្បន្នត្រូវបានគេចាត់ថ្នាក់ថាជាប្រភេទទទួលរងគ្រោះជាសាកល។

Abstract

Orchids are widely distributed across tropical regions with warm and humid climates. This study aimed to determine the distribution and habitat preferences of *Paphiopedilum* spp. and *Phalaenopsis* spp. within the Shinta Mani Wild Conservation Concession which covers an area of 3 km^2 in Sihanoukville Province, southern Cambodia. The overall purpose of the study was to contribute to conservation efforts for orchids in Cambodia. Field research was undertaken in May–August 2020 and included transect lines, opportunistic and random searches to locate orchids within these genera. On finding these, a variety of ecological data were recorded including elevation, humidity, temperature, host substrate, distance from the water and forest cover. Two species of *Phalaenopsis* (*P. difformis* and *P. pulcherrima*) were recorded in a total of 56 locations, whereas one species of *Paphiopedilum* (*P. callosum*) was recorded in seven locations. *Phalaenopsis difformis*, an epiphyte, was only recorded at a single location along a stream at 129 m above sea level, whereas *P. pulcherrima* (which can grow as an epiphyte or lithophyte) was recorded in riparian forests between 50 and 200 m above sea level, mostly in open areas including dwarf bamboo with direct sunlight. The remaining species, *P.*

callosum, is a lithophyte and appeared to prefer elevations above 200 m above sea level. It was recorded on moist boulders among decayed leaves near to evergreen forest and is currently regarded as globally Endangered.

Factors influencing the dynamics and distribution of mosquito species in five provinces, Cambodia

YIM Chanmuneneath

មូលន័យសង្ខេប

ភ្នាក់ងារបង្កជំងឺតាមរយៈវ៉ិចទ័រ គឺជាមូលហេតុចម្បងនៃការបង្កជំងឺលើមនុស្ស និងសត្វចិញ្ចឹម ដែលមានការរីករាលដាលជាសកល ដោយសារតែទំនើបកម្មនៃការដឹកជញ្ជូន និងសកលភាវូបនីកម្ម។ យ៉ាងហោចណាស់វីរុសអាត្រូប៉ូតចំនួន ១៣៥ប្រភេទ ដែលបង្កជំងឺដល់មនុស្សតាមរយៈវដ្តនៃការចម្លងរវាងសត្វឆ្អឹងកង និងការខាំបឺតឈាមរបស់សត្វអាត្រូប៉ូត ដូចជា មូស រុយ សុច និងចៃតុកកែ។ ដើម្បីបញ្ចប់វដ្តនៃការចម្លង វីរុសត្រូវផលិតចំនួនវីរុសនៅក្នុងឈាមរបស់សត្វឆ្អឹងកងដែលជាផ្ទូលរបស់វាក្នុងកម្រិតមួយគ្រប់គ្រាន់ដែលអាចឱ្យមានការចម្លងរោគបានងាយស្រួលនៅពេលពួកអាត្រូប៉ូតខាំបឺតឈាមរបស់សត្វឆ្អឹងកង។ នៅក្នុងប្រទេសកម្ពុជាមានមូសចំនួន ២៦៩ប្រភេទ ស្ថិតក្នុង ២៥ពូក ត្រូវបានគេស្គាល់ថាមានសារៈសំខាន់នៅក្នុងផ្នែកវេជ្ជសាស្ត្រ ហើយហានិភ័យនៃការផ្ទុះឡើងនូវជំងឺដែលចម្លងដោយសត្វ គឺមានអត្រាខ្ពស់នៅក្នុងតំបន់ព្រៃត្រូពិច ដោយសារតែតំបន់ដែលសម្បូរទៅដោយជីវចម្រុះនេះកំពុងរងការប្រែប្រួលតាមរយៈការផ្លាស់ប្តូរការប្រើប្រាស់ដី។ ការសិក្សានេះបានប្រើប្រាស់អន្ទាក់ចំនួនពីរប្រភេទ (BG-Sentinel and homemade CDC light) ដើម្បីចាប់មូសនៅទីតាំងសិក្សា ចាប់ពីតំបន់ព្រៃ រហូតដល់ទីប្រជុំជន នៅខេត្តចំនួនប្រាំនៃប្រទេសកម្ពុជា (ដូចជា ខេត្តពោធិ៍សាត់ ប៉ៃលិន ព្រះវិហារ កំពង់ធំ និងខេត្តព្រះសីហនុ)។ ការសិក្សានេះបានរកឃើញមូសចំនួន ៨៨ប្រភេទ ស្ថិតនៅក្នុង ១៦ពូក។ មូស៤ប្រភេទមានវត្តមាន ៨១ភាគរយ នៃសំណាកមូសដែលបានប្រមូលទាំងអស់ រួមមានប្រភេទ *Culex vishnui*, *C. quinquefasciatus*, *Anopheles peditaeniatus* និង *Aedes albopictus*។ មូសចំនួន ១២ប្រភេទក្នុងចំណោមមូសទាំង ៨៨ប្រភេទត្រូវបានរកឃើញថាជាផ្ទូលចម្លងរោគ (ប្រភេទមូសដែលជាបណ្តាញភ្នាក់ងារចម្លងរោគទៅផ្ទូលសត្វឆ្អឹងកងថ្មីផ្សេងទៀត រួមមានទាំងមនុស្សផងដែរ) ដែលមានវត្តមានរស់នៅក្នុងព្រៃ និងទីប្រជុំជននៅក្នុងខេត្តនីមួយៗ រួមមានប្រភេទ *A. albopictus*, *A. vexans*, *Armigeres subalbatus*, *Coquillettidia crassipes*, *C. bitaeniorhynchus*, *C. brevipalpis*, *C. gelidus*, *C. nigropunctatus*, *C. quinquefasciatus*, *C. tritaeniorhynchus*, *C. vishnui* និង *Mansonia Indiana*។ មូសទាំង១២ប្រភេទនេះអាចចម្លងជំងឺឆ្លងថ្មីនាពេលអនាគត។

Abstract

Vector-borne pathogens are a major cause of disease in humans and domestic animals and both have expanded geographically due to modern transportation and globalization. At least 135 arboviruses cause human disease which are maintained in transmission cycles between vertebrate hosts and blood-sucking arthropods such as mosquitoes, sandflies, midges and ticks. To complete a transmission cycle, a given virus must produce a sufficiently high level of viremia in its vertebrate host for a susceptible arthropod to become infected when taking a blood meal. In Cambodia, 269 mosquito species in 25 genera are known to be of medical importance and the risk of the emergence of zoonotic diseases is particularly high in tropical forest regions because these important biodiversity hotspots are undergoing major land-use changes. This study employed two types of traps (BG-Sentinel and homemade CDC light traps) to sample mosquitoes at sites representing an ecological gradient from forest to urban areas across five provinces in Cambodia (Pursat, Pailin, Preah Vihear, Kampong Thom and Sihanoukville). This resulted in the identification of 88 species of mosquito belonging to 16 genera. Four species represented 81% of all mosquitoes collected: *Culex vishnui*, *C. quinquefasciatus*, *Anopheles peditaeniatus* and *Aedes albopictus*. Twelve of the 88 species recorded are potential bridge vectors (species that connect animal reservoirs to new vertebrate hosts, including humans) that occur from forests to urban areas in each province: *A. albopictus*, *A. vexans*, *Armigeres subalbatus*, *Coquillettidia crassipes*, *C. bitaeniorhynchus*, *C. brevipalpis*, *C. gelidus*, *C. nigropunctatus*, *C. quinquefasciatus*, *C. tritaeniorhynchus*, *C. vishnui* and *Mansonia indiana*. As potential bridge vectors, these species may be able to transmit new infectious diseases in future.

Instructions for Authors

Purpose and Scope

The *Cambodian Journal of Natural History* (ISSN 2226–969X) is an open access, peer-review journal published biannually by the Centre for Biodiversity Conservation at the Royal University of Phnom Penh. The Centre for Biodiversity Conservation is a non-profit making unit, dedicated to training Cambodian biologists and the study and conservation of Cambodia's biodiversity.

The *Cambodian Journal of Natural History* publishes original work by:

- Cambodian or foreign scientists on any aspect of Cambodian natural history, including fauna, flora, habitats, management policy and use of natural resources.
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The Journal especially welcomes material that enhances understanding of conservation needs and has the potential to improve conservation management in Cambodia. The primary language of the Journal is English. For full papers, however, authors are encouraged to provide a Khmer translation of their abstract.

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The Journal's readers include conservation professionals, academics, government departments, non-governmental organisations, students and interested members of the public, both in Cambodia and overseas. In addition to printed copies distributed in Cambodia, the Journal is freely available online from: http://www.fauna-flora.org/publications/cambodian-journal-of-natural-history/ or http://rupp.edu.kh/cjnh

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The following types of manucripts are accepted:

- Full papers (2,000–7,000 words, excluding references)
- Short communications (300–2,000 words, excluding references)
- News (<300 words)
- Letters to the editor (<650 words)

Full Papers and Short Communications

Full Papers (2,000–7,000 words, excluding references) and Short Communications (300–2,000 words, excluding references) are welcomed on topics relevant to the Journal's focus, including:

- Research on the status, ecology or behaviour of wild species.
- Research on the status or ecology of habitats.
- Checklists of species, whether nationally or for a specific area.
- Discoveries of new species records or range extensions.
- Reviews of conservation policy and legislation in Cambodia.
- Conservation management plans for species, habitats or areas.
- The nature and results of conservation initiatives, including case studies.
- Research on the sustainable use of wild species.

The Journal does not normally accept formal descriptions of new species, new subspecies or other new taxa. If you wish to submit original taxonomic descriptions, please contact the editors in advance.

News

Concise reports (<300 words) on news of general interest to the study and management of Cambodia's biodiversity. News items may include, for example:

- Announcements of new initiatives; for example, the launch of new projects, conferences or funding opportunities.
- Summaries of important news from an authoritative published source; for example, a new research technique, or a recent development in conservation.

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Informative contributions (<650 words), usually in response to material published in the Journal.

Recent Literature

Copies or links to recent (<18 months) scientific publications concerning Cambodian biodiversity and the management of natural resources. These may include journal papers, project technical reports, conference posters and student theses.

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Manuscripts are accepted on a rolling basis each year and should be submitted by email to the editors (**Editor.CJNH@gmail.com, Editor.CJNH@rupp.edu.kh).** In the covering email, the lead (corresponding) author should provide the names and contact details of at least three suitably qualified reviewers (whom the editors may or may not contact at their discretion) and confirm that:

- The submitted manuscript has not been published elsewhere,
- All of the authors have read the submitted manuscript and agreed to its submission, and
- All research was conducted with the necessary approval and permit from the appropriate authorities.

Authors are welcome to contact the editors at any time if questions arise before or after submitting a manuscript.

Preparation of Manuscripts

Authors should consult previous issues of the journal for general style, and early-career authors are encouraged to consider guidance provided by:

Fisher, M. (2012) Editorial—To shed light on dark corners. *Cambodian Journal of Natural History*, **2012**, 1–2.

Daltry, J.C., Fisher, M. & Furey, N.M. (2012) Editorial – How to write a winning paper. *Cambodian Journal of Natural History*, **2012**, 97–100.

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