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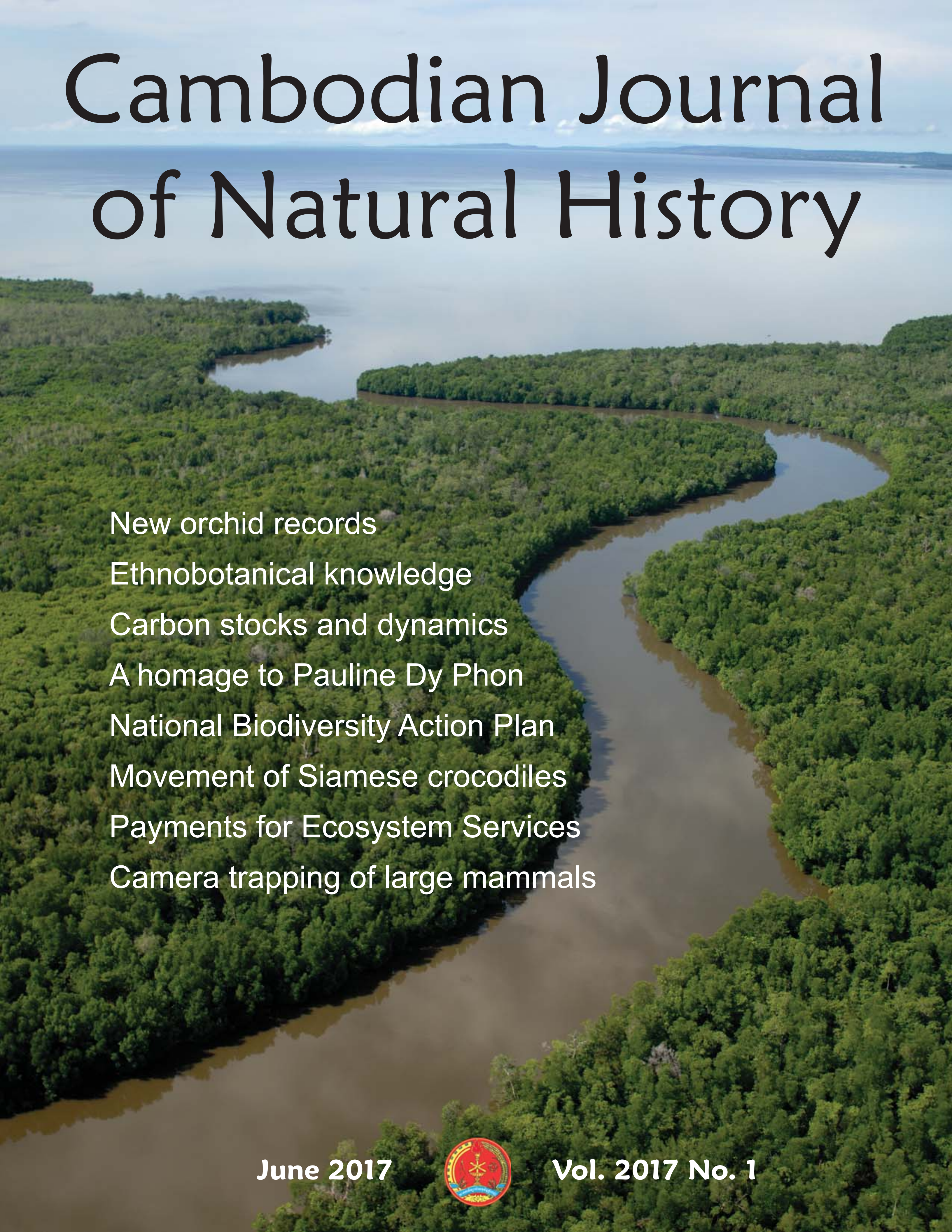

New orchid records

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A homage to Pauline Dy Phon

National Biodiversity Action Plan

Movement of Siamese crocodiles

Payments for Ecosystem Services

Camera trapping of large mammals

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Cover image: Mangrove in Peam Krasaop Wildlife Sanctuary, Koh Kong Province (© Jeremy Holden/Global Wildlife Conservation). The carbon stock of peat soils in mangrove forests at the sanctuary is explored by Taing *et al.* in this issue (pages 55–62).

Editorial — The future of Payments for Ecosystem Services in Cambodia

Virginia SIMPSON & Nicholas J. SOUTER*

Conservation International, Greater Mekong Program, 4th Floor, Building E1, Phnom Penh Center, Sothearos Boulevard, Tonle Bassac, Phnom Penh, 12000, Cambodia.

* Corresponding author. Email nicholas.souter@alumni.adelaide.edu.au

In 2016 Cambodia's protected area system increased significantly in size. The establishment of five new protected areas (Souter *et al.*, 2016) and the declaration of an additional 1,427,940 ha of 'biodiversity conservation corridors' (RGC, 2017) increased Cambodia's coverage of terrestrial protected areas to 42% of its land surface, up from 26% in 2014 (World Bank, 2017). This places Cambodia in the top 4% of nations worldwide in terms of the percentage of land under protection (World Bank, 2017). However, providing adequate oversight is proving difficult, with Cambodia experiencing high rates of both forest and biodiversity loss (Souter *et al.*, 2016).

Financing protected area management is a formidable task for the already under-resourced Ministry of Environment (MoE). Current levels of financial support from government and development partners are significantly below that needed (Souter *et al.*, 2016). There are very few policies or regulations that enable collection of revenues from forests, protected or otherwise, and the revenues that are collected are remitted to the national treasury, rather than directed back into natural resource management. Private sector engagement in sustainable forest management is also very low. Consequently, Cambodia relies heavily on support from development partners, especially bilateral and multilateral donors and large NGOs, to fund protected area management. However, as continued investment by donors and NGOs is not sustainable (Souter *et al.*, 2016), there is increasing pressure for Cambodia to devise independent, long term strategies for funding the management of its natural resources.

Payments for ecosystem services (PES) offer a promising source of revenue which could be directly tied to conservation and management of Cambodia's protected areas. PES is a financial model through which people who benefit from an ecosystem service (like water), provide financial recompense to people whose lands or activities provide that service (such as forest-dwelling communities). Cambodia's urgent need for sustainable finance is not the only priority that PES could help the country to address: poverty reduction, species conservation and boosting the agricultural sector are amongst the others. The people contributing to the maintenance of Cambodia's forest ecosystems or threatened species are often among the nation's poorest and have limited income sources. A PES programme could offer a new, continuous source of revenue and provide an alternative to non-renewable income sources such as unsustainable logging or mining.

Forest ecosystems provide four major ecosystem services (Pagiola, 2008) to which PES could be applied in Cambodia: greenhouse gas mitigation, hydrological services, biodiversity conservation, and scenic vistas for recreation and tourism. PES has previously been used or assessed for some of these purposes in Cambodia. Reducing Emissions from Deforestation and Forest Degradation (REDD+) demonstration sites have been assessed in Mondulkiri, Oddar Meanchey, and Preah Vihear (Cambodia REDD+, 2017) with the aim of generating revenue through reducing greenhouse gas emissions and sequestering carbon. Carbon credits have been sold to protect the Keo Seima Wildlife Sanctuary (Wildlife Conservation Society, 2017). The Wildlife Conservation Society's Ibis Rice programme, bird nest protection, and ecotourism programme have all improved biodiversity conservation (Clements & Milner-Gulland, 2015). Conservation International's conservation agreement programme in the Central Cardamom Mountains has reduced deforestation (Chervier & Costedoat, 2017). Also, the hydrological services provided by the forest catchment of the Stung Atay hydro-power dam have been assessed (Fauna & Flora International, 2014).

There is considerable scope to build upon these efforts and expand the scope and coverage of PES in Cambodia. Providing incentives to improve agricultural productivity and add value to Cambodian farms, including maintaining and increasing forest cover could result in medium- and long-term gains, including increasing the production of traditional (timber) and non-traditional (carbon, firewood, water and biodiversity) goods and services. The growth of Cambodia's agricultural sector (the largest contributor to the national economy) has lagged behind that of the industrial and service sectors. This indicates a real potential for PES to improve agriculture's contribution to GDP, which the government hopes to maintain at 7–8% per annum.

PES could also help the government reach water security goals. The Rectangular Strategy for Growth, Employment, Equity and Efficiency Phase III recognizes the critical role of freshwater ecosystems for ensuring food security as well as sustaining economic activities such as hydroelectricity production and servicing a burgeoning tourism sector. Ongoing water provision through incentivized forest conservation and restoration will be critical for social security, for traditional and emerging economic activities, and for human health.

A well-designed national PES scheme could also facilitate the government's efforts to meeting its international commitments under the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, and the Sustainable Development Goals.

Under the direction of Minister Say Samal, the MoE is drafting a national policy on PES, and a workplan to undertake the studies required to develop a national PES scheme. So far, two PES pilot sites have been identified for further investigation—Kbal Chhay in Sihanoukville, and Phnom Kulen in Siem Reap—both critical watersheds for important tourist destinations, and both supplying water to large beverage companies. In developing its policy, the Royal Government of Cambodia has been examining the highly successful use of PES in the small Central American nation of Costa Rica.

Costa Rica's PES programme is funded by a gas tax, a water tax, protected area entry fees and payments from hydropower operators (Pagiola, 2008). It is credited with contributing to the country's economic success. In only 25 years Costa Rica has tripled its GDP, doubled its forest cover, and won acclaim as an ecotourism destination (Guerry *et al.*, 2015). From 1986 to 2012, national forest cover increased from 21% to 52% (JICA, 2016), and Costa Rica has pledged to become the first carbon neutral country by 2021.

In September 2016, a Cambodian government delegation, sponsored by Conservation International, led by Minister Say Samal and comprising senior officials from MoE, the Ministry of Economics and Finance and the Ministry of Agriculture, Forestry, and Fisheries, visited Costa Rica to examine its PES approach. The visit was hosted by the former Costa Rican Environment Minister, Carlos Manuel Rodriguez, who shared the Costa Rican experience with the Cambodian delegation. On receiving a report of the trip Prime Minister Hun Sen responded with an official order to set Cambodia's PES development in motion.

Cambodia's adoption of PES also needs to be informed by the experience of neighbouring Vietnam. The Government of Vietnam implemented a pilot policy framework on Payments for Forest Ecosystem Services in 2008 which aims to strengthen forest conservation, improve local livelihoods and generate external revenue for nature conservation. The policy focuses on water supply and regulation, soil conservation and landscape conservation for tourism (To *et al.*, 2012). Buyers of ecosystem services in Vietnam include the government, and hydropower, water supply, and tourism companies (To *et al.*, 2012; Surhardiman *et al.*, 2013).

However, PES schemes in Vietnam have been compromised by insecure land tenure, high transaction and opportunity costs, benefit-capture by local elites and lack of a market structure and other regional PES schemes (To *et al.*, 2012; Surhardiman *et al.*, 2013). Lack of monitoring has also made it difficult to determine whether these PES schemes have succeeded in protecting forests. Indeed, it is believed that two of the main drivers of forest degradation in Vietnam—uneven land tenure and lack of community participation in forest protection—cannot be solved by PES as it is currently practiced (McElwee, 2012). These are all problems which, unless carefully managed, could undermine PES in Cambodia.

Conservation International is continuing to support the Royal Government of Cambodia's PES programme, and the Costa Rican government has extended an invitation to develop a bilateral memorandum of understanding with Cambodia to formalize ongoing technical assistance. The road to a national scale PES scheme will be long and difficult—Costa Rica's success took 25 years to realize—and there are lessons from neighbouring Vietnam that need to be learned. PES will only be one tool in the range of approaches needed to secure Cambodia's natural capital. But if, in the long term, we can implement market-based incentives that result in forest and waterway conservation, and a healthy, prospering rural population, the journey will be well worth it.

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Short Communication

New records of Orchidaceae from Cambodia IV

André SCHUITEMAN[1,*], Rudolf JENNY[2], KHOU Eang Hourt[3], NAY Sikhoeun[4] & ATT Sreynak[4]

[1] Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3AB, United Kingdom.

[2] Moosweg 9, 3112 Allmendingen, Switzerland.

[3] Department of Environment, Forest and Water, National Authority for the Protection and the Development for the Cultural and Natural Site of the Preah Vihear Temple, Eco-village, Sra-Aem Commune, Choam Ksant District, Preah Vihear Province, Cambodia.

[4] Department of Wildlife & Biodiversity, Forestry Administration, Ministry of Agriculture Forestry and Fisheries, 40 Preah Norodom Boulevard, Phnom Penh, Cambodia.

* Corresponding author. Email a.schuiteman@kew.org

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The previous article in this series on new orchid records from Cambodia is Schuiteman *et al.* (2016). We here report on eight new records, including the following three new generic records: *Ania*, *Cylindrolobus*, and *Hetaeria*. All were found by the authors, together with Mr Neang Thy, during field trips to western and southern Cambodia in November 2016. Two species (*Cylindrolobus biflorus* and *Hetaeria oblongifolia*) were not seen in flower in the field but flowered in cultivation at the Royal Botanic Gardens, Kew, from collected living specimens, while a third, *Tropidia angulosa*, was observed only as sterile specimens.

In the interests of conservation we do not provide exact localities. Global distribution data follow Govaerts *et al.* (2017), unless indicated otherwise. Vouchers of all specimens mentioned are kept in the Kew Spirit Collection.

Species recorded

***Ania penangiana* (Hook.f.) Summerh. (voucher specimen: Schuiteman *et al.* 16-111; Figs 1 & 2)**

This terrestrial orchid was found in flower on Mt Bokor on 27 November 2016, growing in shallow humus in rocky places under trees in open forest near a waterfall at 910 m above sea level (asl). Only few specimens were seen. This is a widespread, but not common, species that has been recorded from all neighbouring countries of Cambodia, and is distributed from Northeast India to New Guinea.

***Cylindrolobus biflorus* (Griff.) Rauschert (voucher specimen: Schuiteman *et al.* 16-90; Figs 3 & 4)**

Formerly known as *Eria biflora* Griff., this appears to be a relatively common species on Mt Bokor, growing on branches of small, almost shrub-like trees in open, heath-like vegetation at 1,060 m asl. The short-lived flowers were photographed in cultivation at Kew. The species is, like the previous one, widespread, occurring from NE India, through Myanmar and Indochina to Sumatra, Java and Borneo.

***Dendrobium metrium* Kraenzl. (voucher specimen: Schuiteman *et al.* 16-124; Figs 5 & 6)**

Whereas almost all species of *Dendrobium* are epiphytes, *D. metrium* is one of very few terrestrial species. On Mt Bokor, where we found it in flower on 27 November 2016, only a few specimens were seen, growing on the ground in open, scrub-like forest on rocky outcrops with e.g., *Rhododendron moulmainense* Hook.f., at 980 m asl. The plants have an unusual growth habit in that new growths are often formed from the distal part of the stems, producing a somewhat scrambling habit. Seidenfaden (1992) included *D. metrium* (under the synonym *D. sociale* J.J.Sm.) in the section *Pedilonum*, but the papillose-

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Fig. 1 *Ania penangiana* (Hook.f.) Summerh., in situ. Voucher specimen: Schuiteman *et al.* 16-111.

Fig. 2 *Ania penangiana* (Hook.f.) Summerh., flower. Voucher specimen: Schuiteman *et al.* 16-111.

Fig. 3 *Cylindrolobus biflorus* (Griff.) Rauschert, in situ. Voucher specimen: Schuiteman *et al.* 16-90.

Fig. 5 *Dendrobium metrium* Kraenzl., in situ. Voucher specimen: Schuiteman *et al.* 16-124.

Fig. 4 *Cylindrolobus biflorus* (Griff.) Rauschert, flowering stem. Voucher specimen: Schuiteman *et al.* 16-90.

Fig. 6 *Dendrobium metrium* Kraenzl., flower. Voucher specimen: Schuiteman *et al.* 16-124.

Fig. 8 *Eulophia graminea* Lindl., flower. Voucher specimen: Schuiteman *et al.* 16-57.

Fig. 7 *Eulophia graminea* Lindl., in situ. Voucher specimen: Schuiteman *et al.* 16-57.

Fig. 9 *Habenaria hosseusii* Schltr., in situ. Voucher specimen: Schuiteman *et al.* 16-0.

Fig. 10 *Habenaria hosseusii* Schltr., flower. Voucher specimen: Schuiteman *et al.* 16-0.

Fig. 11 *Hetaeria oblongifolia* Blume, flowers. Voucher specimen: Kew cult. 2016-2586.

Fig. 12 *Hetaeria oblongifolia* Blume, in situ. Voucher specimen: Kew cult. 2016-2586.

Fig. 13 *Phaius indochinensis* Seidenf. & Ormerod, flowers. Voucher specimen: Schuiteman *et al.* 16-51.

Fig. 14 *Phaius indochinensis* Seidenf. & Ormerod, in situ. Voucher specimen: Schuiteman *et al.* 16-51.

Fig. 15 *Tropidia angulosa (Lindl.)* Blume, in situ.

pubescent adaxial surface of the lip is more typical of the section *Dendrobium*, to which it may well belong. So far, this species has not been included in any phylogenetic analyses. It was previously recorded from Thailand, Vietnam, Peninsular Malaysia, and Sumatra, but in spite of its relatively wide distribution it appears to be a rare species (Averyanov, 2012).

***Eulophia graminea* Lindl. (voucher specimen: Schuiteman *et al.* 16-57; Figs 7 & 8)**

In general, this is a common, even somewhat weedy species of open, disturbed places, although it also occurs in closed forest (Pedersen *et al.*, 2014). Outside its natural range it is naturalized in Australia, South Africa and USA (Pemberton *et al.*, 2008). We found this species in humid, old-growth, evergreen forest in Pursat Province near Pramaoy, at 350 m asl. Only a single specimen was seen in flower, on 24 November 2016. It occurs over much of tropical Asia, from Pakistan to China, as well as Sumatra, Java, Borneo and the Philippines. *Eulophia graminea* was already listed as occurring in Cambodia by Govaerts *et al.* (2017), but it was not recorded from Cambodia by Seidenfaden (1992). As we have not seen a reference to an exact locality for Cambodia, the present record may be the first from a known locality in this country.

***Habenaria hosseusii* Schltr. (voucher specimen: Schuiteman *et al.* 16-0; Figs 9 & 10)**

Dozens of flowering specimens of this long-spurred orchid were found on 20 November 2016 on an eroded limestone hill near Takream Village in Battambang Province, at 150 m asl. Two other species of *Habenaria* were also observed in flower there: *H. lindleyana* Steud. and *H. dentata* (Sw.) Schltr. The vegetation was an open, secondary forest of young trees without epiphytes, and there were signs of burning. The present species differs in minute details from *H. dentirostrata* Tang & F.T.Wang, which has already been recorded from Cambodia (Leti *et al.*, 2013), and the two species may in fact be conspecific (Kurzweil, 2009). *Habenaria hosseusii* has been recorded from Thailand and Laos.

***Hetaeria oblongifolia* Blume (voucher specimen: Kew cult. 2016-2586; Figs 11 & 12)**

The flowers of this inconspicuous terrestrial orchid are only about 3.5 mm long. As in all species of the genus *Hetaeria*, they are not resupinated, which means that the lip is held uppermost; in most other orchids, the lip is held lowermost. Like *Eulophia graminea* mentioned above, this species was found in humid, old-growth, evergreen forest in Pursat Province near Pramaoy, at 350 m asl. It is widespread throughout tropical and subtropical Asia, from Sri Lanka to Japan, and south-eastwards to Australia and New Caledonia.

***Phaius indochinensis* Seidenf. & Ormerod (voucher specimen: Schuiteman *et al.* 16-51; Figs 13 & 14)**

This is undoubtedly the showiest orchid reported in the present paper, with flowers 6–8 cm across. It proved to be common in humid evergreen montane forest in Pursat Province, about 24 km SW of Pramoy, at 870 m asl, growing in leaf litter in dense shade. Only two or three specimens out of hundreds were seen in flower on 23 November 2016. It often grew together with *Plocoglottis bokorensis* Seidenf., which is superficially similar in appearance when not in flower. However, the latter has distinct, ovoid pseudobulbs at the base of the slender stems, whereas the stems of *P. indochinensis* are uniformly terete. *Phaius indochinensis* is also known from Laos (Schuiteman *et al.*, 2008), Thailand and Vietnam, and has been misidentified as *P. indigofer* Hassk. (Seidenfaden, 1992, as "*indigoferus*"), a species that probably does not occur in Thailand and Indochina.

***Tropidia angulosa* (Lindl.) Blume (not vouchered; Fig. 15)**

Several specimens, long past flowering, were discovered not far from a population of *Hetaeria oblongifolia*, mentioned above. A few living specimens that we collected for cultivation did not survive for more than a few weeks, with the stems rapidly turning black. It has been our experience that, unlike most orchids, *Tropidia* does not respond well to being bare-rooted. Consequently, it is difficult to bring the species into cultivation from wild-collected material. The present species, with its two broad, almost opposite leaves and short terminal raceme, has been reported from all of Cambodia's neighbouring countries, and there can be little doubt that the plant we photographed is indeed *T. angulosa*. A good photograph of a flowering specimen can be found in Seidenfaden (1992) and Averyanov (2008). The species is widely distributed from Northeast India to South Japan, and south to Java, Bali and the Philippines. It is common in Vietnam in "all kinds of lowland and submontane forests on any soils. 0–1,600 m" (Averyanov, 2008).

Conclusions

Fieldwork in almost any area in Cambodia where there is still natural vegetation left reveals new orchid records. At the same time, suitable habitats are still being destroyed, and there can be little doubt that species have already been lost before they could be recorded. Most of the limestone hills that we visited in Battambang Province showed signs of heavy disturbance, with little if any of the original forest cover left. We can only suspect that sensitive and endemic species may have disappeared from these hills, which are entirely surrounded by cultivated land. We will probably never know.

Acknowledgements

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Short Communication

Gastrodia exilis (Orchidaceae), a newly recorded mycoheterotrophic genus and species in Cambodia

SUETSUGU Kenji[1,*], HSU Tian-Chuan[2], TAGANE Shuichiro[3], CHHANG Phourin[4] & YAHARA Tetsukazu[3]

[1] Department of Biology, Graduate School of Science, Kobe University, 1-1 Rokkodai, Nada, Kobe, 657-8501, Japan.

[2] Herbarium of Taiwan Forestry Research Institute, No. 53, Nanhai Road, Taipei 100, Taiwan.

[3] Center for Asian Conservation Ecology, Kyushu University, 744 Motooka, Fukuoka, 819-0395, Japan.

[4] Institute of Forest and Wildlife Research and Development, Forestry Administration, 40 Preah Norodom Boulevard, Phnom Penh, Cambodia.

* Corresponding author. Email kenji.suetsugu@gmail.com

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The genus *Gastrodia* (Orchidaceae) comprises approximately 90 species of mycoheterotrophic orchids distributed throughout the temperate and tropical regions of Asia, Oceania, Madagascar and Africa (Govaerts *et al.*, 2016; Hsu *et al.*, 2016). Within Indochina, *Gastrodia* has been recorded from Thailand and Vietnam but not yet from Cambodia and Laos (Schuiteman & de Vogel, 2000; Suddee & Harwood 2009; Averyanov, 2011; Suddee, 2014; Schuiteman *et al.*, 2015). The genus is characterised by fleshy tubers, the absence of leaves, as well as the fusion of its sepals and petals, and the presence of two mealy pollinia that lack caudicles.

As is the case in most other mycoheterotrophic species, most *Gastrodia* species occur in small populations and appear above the soil surface only during their brief reproductive period (Suetsugu, 2016). Therefore, the diversity and distribution patterns of *Gastrodia* species are easily underestimated. Our recent botanical surveys have resulted in the discovery of many new species and distribution records for this genus (e.g., Suetsugu, 2012, 2013, 2014, 2015, 2016; Hsu & Kuo, 2010, 2011; Hsu *et al.*, 2012, 2016). We document the occurrence of *Gastrodia exilis* here as a newly recorded genus and species for Cambodia. The following description is based on our Cambodian material.

***Gastrodia exilis* Hook.f., *The Flora of British India*, 6, 123 (1890)**

Gastrodia siamensis Rolfe ex Downie, *Bulletin of Miscellaneous Information*, 1925, 416 (1925); *Gastrodia hayatae* Tuyama, *Journal of Japanese Botany*, 17, 580 (1941).

Terrestrial, mycoheterotrophic herb. Rhizome tuberous, fusiform or cylindrical, 7–12 mm long, 3–5 mm in diameter. Inflorescence erect, white to pale brown, glabrous, 14–17 cm long, 1.5 mm in diameter, with 4–6 nodes, with tubular, membranous sheaths. Bracts up to 3 mm long, 1.5 mm wide. Pedicel and ovary up to 10 mm long. Flowers 2–4, 7–9 mm long, white, tubular, slightly turned upwards, resupinate. Sepals and petals connate, forming a five-lobed perianth tube. Sepals ca. 7 mm long, connate basally 3/4–4/5 their length with petals, lateral ones connate basally 2/3–3/4 with each other; free tips of sepals ovate-triangular, ca. 2 mm long, 2 mm wide, apex obtuse, margins slightly undulate; free tip of petals ovate-triangular, ca. 1.5 mm long, 1.5 mm wide, apex obtuse, margins slightly undulate. Lip 4–4.5 mm long, 1.5–2.0 mm wide, hypochile with two globose calli; epichile ovate-elliptic, base contracted, disc 5-ridged with two parallel erect longitudinal keels extending toward apex in the distal half, margin slightly undulate. Column straight, semi-cylindrical, 4–4.5 mm long, white;

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Fig. 1 Flowering and fruiting plant of *Gastrodia exilis* in Bokor National Park. A) Flowering plant, B) Flowers, C) Immature fruit.

lateral wings narrow, the edges parallel to column, acute; rostellum absent. Anther hemispherical, pollinia 2.

Specimen examined: Cambodia, Kampot Province, Bokor National Park, evergreen forest around sphagnum bog, 10°39′9.06″N, 104°03′38.68″E, alt. 935 m, 17 October 2012, Tagane S., Fuse K., Choeung HN 4275 (deposited in the Forestry Administration herbarium in Cambodia).

Distribution: Cambodia (new record), India, Thailand and Sumatra.

Habitat and ecology: Fewer than 10 individuals were found in a small population in the wet understorey of tropical lower montane forest on the plateau of Bokor National Park. The site is close to the collection locality of *Aphyllorchis pallida* Blume and dominant trees were reported by Tagane *et al.* (2015). The flowering time is in early to mid-October.

Conservation status: While *Gastrodia exilis* has not been assessed by the *IUCN Red List of Threatened Species* (IUCN, 2016), this species has been reported from only a few scattered localities in India, Thailand, and Sumatra (Hooker, 1890; Downie, 1925; Tuyama, 1941; Seidenfaden, 1978; Joseph *et al.*, 1980; Kumar & Kumar, 2001; Suddee, 2004). In addition, in Cambodia the species is only known from Mt Bokor (see also Note 2 below), where the aforementioned specimen was collected. Given that mycoheterotrophic plants are highly dependent on the activities of both the fungi and the trees that sustain them (e.g., Suetsugu *et al.*, 2014), they are particularly sensitive to environmental disturbance. Because deforestation for resort development is rapidly expanding very near to the locality of this species on Mt Bokor, urgent attention is needed to conserve the Cambodian population. This is also in the interest of many other rare plants growing nearby, such as *Nepenthes bokorensis* Mey and *Dipodium paludosum* (Griff.) Rchb.f.

Notes: 1) Compared with published descriptions and illustrations (Hooker, 1890; Downie, 1925; Tuyama, 1941; Seidenfaden, 1978, Joseph *et al.*, 1980; Kumar & Kumar, 2001; Pedersen *et al.*, 2004), the Cambodian plants we observed were smaller than those from previously reported localities (e.g., India and Thailand), producing shorter rhizomes (0.7–1.2 cm vs. 1.0–5.5 cm), shorter inflorescences (14–17 cm vs. 15.5–112 cm) and smaller number of flowers per inflorescence (2–4 vs. 3–25). However, there are no significant differences in the morphology of the lip and column, which are the most important characters used to classify *Gastrodia* species. Furthermore, given that plant size can be dramatically affected by the availability of nutrients, it would not be surprising to observe variability in plant size among different populations reflecting their different nutritional resources, such as the activity of their mycorrhizal fungi. Therefore, we consider that the differences most likely represent an example of intraspecific variation. The overlap in the size range of plants between the Cambodian and previously reported populations supports this assumption. 2) On 27 November 2016, Dr André Schuiteman and co-workers found another population of *G. exilis* nearby (in evergreen forest near Popokvil Waterfall): this consisted of at least a dozen plants, most growing close together, but some about 100 m away from the others. Most were in fruit, but one specimen still had flowers (voucher specimen: Schuiteman *et al.* 16-120A, spirit mat. K; Schuiteman, pers. comm.).

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Short Communication

Revision of Cambodia's National Biodiversity Strategy & Action Plan to integrate conservation and sustainable use of biological resources into national decision making

Matthew P. MALTBY[1,*], CHAN Somaly[2] & Jady SMITH[3]

[1] Forestry & Natural Resource Management Unit, Winrock International, 2121 Crystal Drive, Suite 500, Arlington, Virginia 22202, USA.

[2] National Council for Sustainable Development, Ministry of Environment, Morodok Techo Building (Lot 503), Tonle Bassac, Chamkarmorn, Phnom Penh, Cambodia.

[3] Live & Learn Environmental Education, Ross House, 4th Floor, 247–251 Flinders Lane, Melbourne Victoria 3000, Australia.

* Corresponding author. Email mmaltby82@gmail.com

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Cambodia became a signatory and acceded to the United Nations Convention on Biological Diversity (CBD) in 1995 (CBD, 2017a), under which the country is obligated to develop and adopt a National Biodiversity Strategy & Action Plan (NBSAP). An NBSAP is the principal means of implementation of the CBD at a national level (CBD, 2017b). It reflects how Cambodia intends to fulfil the objectives of the CBD in light of its specific national circumstances, and sets out a sequence of steps to meet these goals. The present NBSAP for Cambodia includes the following vision for biodiversity: "Equitable economic prosperity and improved quality of life through sustainable use, protection and management of biological resources"; and a mission statement, namely "To use, protect and manage biodiversity for sustainable development in Cambodia" (MoE, 2016a).

The first NBSAP for Cambodia appeared in 2002 (MoE, 2002). Since then, knowledge of the country's natural history has expanded significantly. A combination of applied research, new species discoveries and far-ranging biodiversity conservation programmes have yielded a wealth of new information on the country's flora and fauna, and great progress has been made in developing national capacity and human resources for biodiversity conservation.

On 5th February 2016, The Royal Government of Cambodia approved the country's updated NBSAP (Fig. 1). To meet the complex and often changing challenges facing biodiversity and ecosystem conservation, the essence of a NBSAP is to create a policy requirement that integrates consideration of conservation and sustainable use of biological resources into national decision-making across all sectors of the national economy and policy-making framework.

In parallel to the NBSAP, the National Biodiversity Status Report (MoE, 2016b) was also updated for the first time since 2001. The status report provides a snapshot of the current status of biodiversity in Cambodia, and inventory lists of all species known in major groups (including 162 mammals, 601 birds, 173 reptiles, 72 amphibians, 1,357 fish, 3,113 plants and 671 invertebrates), plant and animal genetic resources, and ecosystem diversity. Verified species lists are now held by the Department of Biodiversity of the National Council for Sustainable Development (Ministry of Environment), and details are available through the National Clearing House Mechanism website (MoE, 2017b). The clearing house mechanism provides information services to facilitate implementation of the NBSAP, which in turn supports

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implementation of the global Strategic Plan for Biodiversity 2011–2020 (CBD, 2017b).

The newly updated NBSAP reflects how Cambodia intends to fulfil the three objectives of the CBD in light of its specific national circumstances and governmental reform, and identifies steps to meet these goals. The purpose of this article is to inform a wider audience of the significance and importance of Cambodia's NBSAP and to briefly outline the key thematic objectives which Cambodia aims to meet over the coming years.

Purpose of the NBSAP

The CBD is a binding agreement that obligates countries to ensure they are conserving biodiversity, which includes having effective national biodiversity planning. Cambodia's new NBSAP also constitutes a direct contribution to Aichi Biodiversity Target 17 under the CBD, which states that by 2015 each Party should have developed, adopted as a policy instrument, and commenced implementing an effective, participatory and updated NBSAP. Indeed, Cambodia was one of the few 150+ signatories to the convention to update its NBSAP prior to the 21st Conference of Parties in Paris, 2015.

Following extensive inter-ministerial meetings, national and sub-national consultations and technical review by national and international experts, the updated NBSAP now includes plans for the conservation and sustainable use of Cambodia's biological diversity. These plans are integrated with relevant sectoral and cross-sectoral programmes, related national policies and also provide significant contributions to national sustainable development goals.

Relevance to biodiversity stakeholders

The NBSAP provides a framework for action at all levels to ensure the productivity, diversity and integrity of natural systems and, as a result, Cambodia's ability as a nation to develop sustainably. It promotes the conservation of biodiversity and ecosystems, the sustainable use of biological resources and describes national contributions to international efforts to implement the CBD, including 20 Aichi Biodiversity Targets.

The NBSAP lists priority actions to be undertaken by the various ministries, departments and agencies during the implementation phase. A series of strategic objectives and priority actions are presented under 24 themes, including: Protection of Natural Resources (Protected areas, Threatened species, *Ex situ* Conservation); Animal

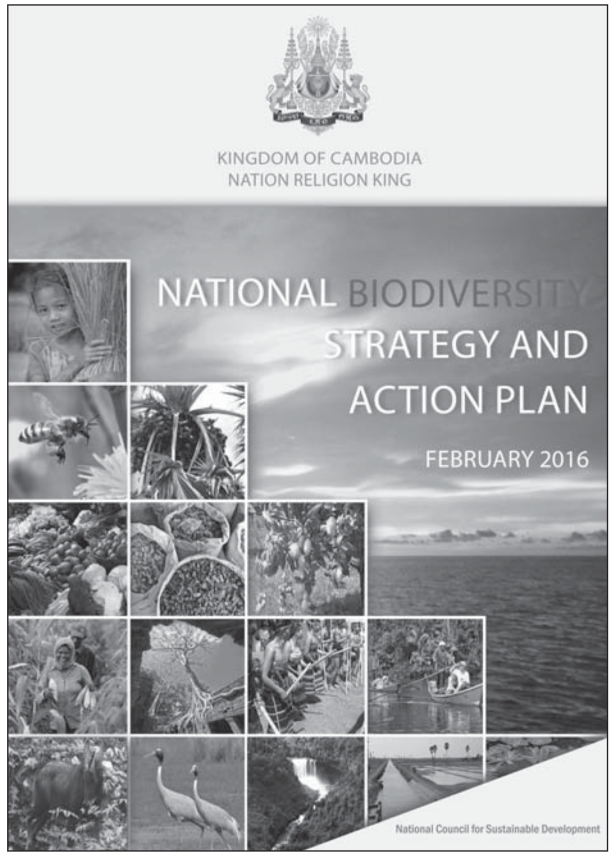

Fig. 1 Cambodia's updated National Biodiversity Strategy and Action Plan.

Wildlife Resources; Freshwater Fisheries and Aquaculture; Coastal and Marine Resources; Forest and Wild Plant Resources; Agriculture and Animal Production; Energy Resources; Mineral Resources; Industry, Technology and Services (Manufacturing, Biotechnology and Biosafety, Tourism); Environmental Security; Land Use Planning; Water Resources; Climate Change and Biodiversity; Community Participation; Awareness, Education, Research Coordination and Development; Legislation and Institutional Structures; and Quality of Life and Poverty Reduction (MoE, 2016a).

Priority actions adopted by the government are grouped into three broad categories: i) Actions promoting awareness and building the capacity of government staff and local communities; ii) Actions promoting community-based natural resource management; and, iii) Actions aimed at clarifying ministerial jurisdictions, reducing responsibility overlap and promoting inter-ministerial coordination and collaboration in a sustainable development perspective (MoE, 2016a).

Monitoring and evaluation

Implementation of the NBSAP is an ongoing, continuous and cyclical process. Proposed mechanisms for implementation are identified in the NBSAP, such as coordination of national and international elements of the strategy through a permanent Inter-ministerial Biodiversity Steering Committee (IBSC) and National Secretariat for Biodiversity. However, as with any policy initiative, rigorous monitoring and evaluation must accompany implementation to measure progress towards overall goals. Long-term success will be determined by the degree to which all parts of society adopt the NBSAP vision and principles and contribute to achieving its goals.

The IBSC is charged with monitoring, evaluation and reporting of progress towards NBSAP targets. Reporting can take place annually and also as a part of national reports to the CBD, the next of which is due in 2018. While 20 biodiversity targets have been adopted, baseline information still needs to be collected to allow accurate reporting and with this in mind, the IBSC will focus its efforts on: i) Developing a strategy for obtaining information from various NGOs and government departments; ii) Strengthening technical skills of nationals on management, collection and processing of data; and, iii) Ensuring complementarity of NBSAP monitoring and evaluation efforts with other national monitoring activities to avoid duplication of effort.

Ultimately, conservation of biodiversity and sustainable use of biological resources will require the support and participation of individual citizens, local communities, urban and regional governments, conservation groups, business and industry, and educational and research institutions. In addition to regular reporting requirements and biennial revision of the NBSAP, an actions and indicators matrix has been developed to support evaluation of effectiveness and can be found in Appendix I of the full document.

Looking forward

The strategic objectives (indicators) and associated priority actions under each NBSAP theme serve as a valuable planning tool and guide for conservation practitioners, policymakers and stakeholders alike. Indeed, the NBSAP provides a national mandate for the establishment of numerous new priority initiatives, as well as continuation and enhancement of many existing long-term conservation activities.

It should remain a priority of the Royal Government of Cambodia, development partners and NGOs to revise the NBSAP periodically, ideally every two years, to ensure that biodiversity data are current and that action plans remain appropriate as threats and challenges to biodiversity protection evolve over time. In particular, the recent environmental reforms in 2016, such as the proclamation of numerous new protected areas, should be a priority to include in future NBSAPs. The complete text of Cambodia's NBSAP can be found online at https://www.cbd.int/doc/world/kh/kh-nbsap-v2-en.pdf.

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The flora of the Bokor Plateau, southeastern Cambodia: a homage to Pauline Dy Phon

Philip W. RUNDEL[1,*] & David J. MIDDLETON[2]

[1] Department of Ecology and Evolutionary Biology, University of California, Los Angeles, California 90095, USA.
[2] Singapore Botanic Gardens, National Parks Board, 1 Cluny Road, Singapore 259569, Singapore.

* Corresponding author. Email rundel@biology.ucla.edu

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មូលន័យសង្ខេប

ខ្ពង់រាបបូកគោស្ថិតនៅភាគអាគ្នេយ៍នៃប្រទេសកម្ពុជា ជាទីជម្រករបស់ប្រភេទរុក្ខជាតិកម្រនិងសហាគមន៍រុក្ខជាតិសំខាន់ៗនៃព្រៃគ្រិន និងព្រៃល្វតរហ័ស ព្រមទាំងមានរុក្ខជាតិសម្បូរបែប។ ពង្រីកបន្ថែមលើការងាររបស់ Pauline Dy Phon ដែលមានអាយុកាលជាងពាក់កណ្តាលសតវត្សកន្លងមកហើយ យើងបានធ្វើបច្ចុប្បន្នភាពលើរុក្ខជាតិមានសរសៃនាំនៅតំបន់ខ្ពង់រាបនេះ។ បញ្ជីកំណត់ត្រារុក្ខជាតិរបស់យើងមាន៣៥៩ប្រភេទ ដែល២២ប្រភេទជាប្រភេទដែលមានតែក្នុងតំបន់បូកគោប៉ុណ្ណោះ។

Abstract

The Bokor Plateau in southeastern Cambodia is home to rare and significant plant communities of stunted forest and heathland, as well as a rich flora. Expanding on the pioneering work of Pauline Dy Phon more than half a century ago, we update the current knowledge of the vascular plant flora of the plateau. Our checklist includes 359 species, with 22 of these endemic to Bokor.

Keywords

Bokor Plateau, Cambodia, stunted forest, heathland, Preah Monivong National Park, endemic species.

Introduction

Bokor National Park (officially known as Preah Monivong National Park) in southeastern Cambodia represents a biodiversity hotspot with a rich plant diversity and a high level of endemism. Within this park the sandstone massif of the Elephant Mountains rises very steeply from a narrow coastal plain along the Gulf of Thailand to an elevation of 1,080 m (Fig. 1). The combination of the steep south-facing slopes of the range and close proximity of the ocean produces unusually wet conditions on the southwestern slopes and upper plateau. Tall species-rich wet forests are present on the lower and middle elevation slopes at Bokor. However, as with tropical montane forests in many other areas of the world, the shallow soils and water-logged depressions at higher elevations on the gently sloping Bokor Plateau exhibit dwarf forests with relatively low sclerophyllous evergreen trees (Dy Phon, 1970; Rundel *et al.*, 2016). A complex interaction of high winds, saturated soils, impeded root respiration, physiological drought, high soil leaching with low nutrient availability, limited rooting volume of shallow soils, reduced solar insolation, and high humidity combine to produce these low forests (Grubb, 1971; 1977; Weaver *et al.*, 1973).

Much of what we know about the plant ecology and flora of Bokor National Park broadly, and the Bokor Plateau more specifically, comes from the remarkable work conducted by Pauline Dy Phon which was carried

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out in the context of her PhD studies at the University of Toulouse in the late 1950s. This detailed study (Dy Phon, 1970) has long formed the basis for understanding the rich plant diversity of global significance in Bokor National Park. Her work has been the stimulus for our studies and for others as well, and we are pleased to dedicate this article to Pauline Dy Phon (see box).

The Bokor Plateau

Despite its seasonal pattern, rainfall on the Bokor Plateau reaches very high levels. Records at 950 m elevation at the southern end of the plateau had a mean annual rainfall of 5,309 mm (Tixier, 1979), while the Val d'Emeraude on the southeast margin of the plateau was reported to receive a mean of 5,384 mm (Dy Phon, 1970). The distribution of this rain peaks sharply in July and August, dropping to a mean of 50 mm or less in January and February at both stations. The Val d'Emeraude experiences rain virtually every day from May through October, but on only 12 days on average in March (Dy Phon, 1970). During the dry season mornings are semi-sunny with scattered clouds moving overhead, while heavier overcast and brief periods of intense showers can occur in the afternoon. Mean monthly temperatures are relatively constant throughout the year, varying only from a low of 19.2°C in July and August to a high of 21.5°C in April (Dy Phon, 1970).

The sandstone substrate of the plateau of the Elephant Mountains weathers into an acidic coarse white sand with a pH of 4.6. Soil profiles of the sphagnum bog as described by Dy Phon (1970) consist of upper sandy A horizons 90 cm in thickness with declining organic matter and increasing saturation with depth. Even in forested areas of the plateau there is often a B horizon at 90–105 cm consisting of an indurated layer of white sand, with yellowish sandstone parent material below this level. As a result there are mosaics present of seasonally water-logged soils.

The wet forests encountered at middle elevations below the plateau on Bokor were termed forest s*ubmontagnardee a fagacées et cibotium* by Dy Phon (1970). These replace the lower wet evergreen forests at elevations of 500–800 or higher. In many ways these are comparable to the hill evergreen forests described in Thailand with a dominant role of Fagaceae and Podocarpaceae in the canopy and the relative absence of Dipterocarpaceae (Rundel *et al.*, 1999). This community changes at about 920 m with the transition from montane wet forest to the Bokor Plateau with its associated edaphic and climatic conditions.

Our study has focused on the gently sloping and weathered Bokor Plateau itself. Here a distinct community of stunted forest (Fig. 2) appears, termed *forêt sempervirente basse de montagne* by Dy Phon (1970). This transition between forest types can be seen near Popokvil Waterfall at about 920 m with mosaics of taller wet forest and lower stunted forest (Fig. 3). The dwarfing of what are commonly tall trees at lower elevations results from a complex interaction of soil depth, elevation, wind exposure, and distance from the coast. This community, which we have called stunted forest, commonly has a matrix that reaches no more than 4 m, while the canopy dominant *Dacrydium elatum* (Roxb.) Wall. ex Hook. with *Dacrycarpus imbricatus* (Blume) de Laub., *Tristaniopsis merguensis* (Griff.) Peter G.Wilson & J.T.Waterh., and *Vaccinium viscifolium* King & Gamble can reach greater heights. The gradient of height for *D. elatum* across the plateau illustrates the effect of environment on stature. Trees near Popkvil Waterfall are 14–16 m in height, but mean height drops to 8–10 m moving across the plateau, and finally only 4–6 m to the south near the developed area (Rundel *et al.*, 2016). Despite changes in commuity structure, tree diversity and density remain relatively unchanged across this gradient (Zhang *et al.*, 2016).

Lianas are common in taller forest stands, including the notable presence of spiny rattans. In addition, there is a moderate diversity of epiphytic and lithophyllic orchids and ferns present. However as soil and wind conditions produce a lower forest canopy, the lianas largely disappear and *Pandanus cupribasalis* H.St.John and *Pinanga sylvestris* (Lour.) Hodel appear in the semi-open understorey.

As soils become shallower and winds increase moving from Popokvil south across the plateau toward the coastal escarpment, the stunted forest is replaced by an irregular cover of sclerophyllous shrubland with a typical height of 1–2 m. Dy Phon (1970) termed this *la lande de myrtacées et vacciniacées*, which we have translated as sclerophyllous heathland. As Dy Phon's name suggests, this community is dominated by species of Myrtaceae and Ericaceae. The former include *Rhodamnia dumetorum* (DC.) Merr. & L.M.Perry, *Rhodomyrtus tomentosa* (Aiton) Hassk., and *Syzygium antisepticum* (Blume) Merr. & L.M.Perry together with *Vaccinium bracteatum* Thunb., *V. viscifolium* King & Gamble, and *Rhododendron moulmainense* Hook. Epiphytes are rare. Open rocky areas that are waterlogged for major portions of the year have a scattered cover of herbaceous perennial such as *Hedyotis rosmarinifolia* (Pit.) Craib and *Polygonum chinense* in a matrix of the graminoids *Carex indica* L., *Fimbrystylis eragrostis* (Nees) Hance, and *Dapsilanthus disjunctus* (Mast.) B.G.Briggs & L.A.S.Johnson.

Localized bog communities (Fig. 4) on the plateau are dominated by a diverse community of low-growing herbaceous perennials 20–30 cm in height. Scattered through this matrix are small islands of shrub establishment where soils have built up to allow better drainage. Four graminoid species provide the major part of the matrix cover (Rundel *et al.*, 2003). These are *Eremochloa eriopoda* C.E.Hubb. (Poaceae), *Eriocaulon ubonense* Lecomte (Eriocaulaceae), and *Dapsilanthus disjunctus* and *Centrolepis cambodiana* Hance (Restionaceae). Small shrub islands scattered across the bog are dominated by single or multiple species reaching to no more than 30–50 cm in height and low mounds 0.5–2.0 m across. Rings of *Sphagnum* spp. are commonly present around the edges of these shrub islands at the edge of the canopy. Tixier (1979) identified these as *S. beccarii* Hampe. and *S. cuspidatum* Ehr. ex Hoffm. Low shrubs forming these islands include *Hedyotis rosmarinifolia* (Rubiaceae), *Ploiarium alternifolium* (Vahl) Melch. (Bonnetiaceae), *Calophyllum calaba* L. var. *cuneatum* (Symington ex M.R.Henderson & Wyatt-Smith) P.F.Stevens (Calophyllaceae), *Ilex wallichii* Hook.f. (Aquifoliaceae), *Syzygium antisepticum* (Myrtaceae), and *Hygrophila ringens* (L.) R.Br. ex Spreng. (Acanthaceae). Species of *Cladonia* and other macrolichens and microbial crusts of cyanobacteria cementing areas of open soil are also present.

History of Bokor Development

The decision by the French colonial government to establish a tourist resort in the uplands of the Elephant Mountains in southeastern Cambodia was made in 1917. The

Pauline Dy Phon, 1933–2010

Pauline Dy Phon made major contributions to our understanding of Cambodian plant ecology, systematics and economic botany, but the significance of her work has not been broadly or appropriately recognized. Although a plant taxonomist and biogeographer by training, her career demonstrated broad interests beyond these fields to include pioneering work on the economic and medicinal uses of Cambodian plants and their cultural significance.

Pauline was born in Cambodia in 1933 to a successful Catholic family. The nation gained independence from France as a constitutional monarchy in 1953, at a time of uncertain political future for the former French colony. With strong family support, Pauline was encouraged to follow her interests and left the country to study in France, obtaining her bachelor's degree in 1959 at the Faculty of Natural Sciences in Paris. She returned to Cambodia to accept a high school teaching position at the Lycée Sisowath in Phnom Penh.

Ambitious though to expand her background in botany, she traveled again to France for graduate work. She obtained her doctorate at the University of Toulouse in 1969, working with Jules Émile Vidal, returning to teach at the Faculty of Sciences in Phnom Penh. It was under her graduate programme that she completed her remarkable work on the vegetation of southeastern Cambodia, which was published in 1970. It was in this era that she also wrote *Guide botanique de la ville de Phnom Penh* (1972) with M.A. Martin, a work republished in 2009. She was recognized by her peers at this time with an appointment by the Cambodian government as chair of the National Commission on Science and Culture.

Pauline's teaching and research career in Phnom Penh was sharply interrupted by the takeover of the country by the Khmer Rouge in April 1975. There followed four difficult years of genocidal government policies that virtually emptied the city of Phnom Penh. Her only written account of the Khmer Rouge period, published in 1982, was a study of "plants in the Khmer diet in normal times and in times of famine".

The Vietnamese invasion in 1979 forced out the Khmer Rouge government but there followed a challenging period of Vietnamese occupation. It was at this time that Pauline sought refuge in France, accepting a position at the Laboratory of Botany at the Natural History Museum in Paris in 1980. This was the beginning of two decades of work in Paris where her research contributed significantly to identifying and classifying the poorly known flora of Cambodia and other countries in Indochina. It was at this time that she completed and published her classic trilingual *Dictionary of Plants Used in Cambodia* (Édition Olympic, Phnom-Penh, 915 pp.).

After the Khmer Rouge period, Pauline returned for the first time to Cambodia in 1994. She died at her home in Paris on 21 May, 2010.

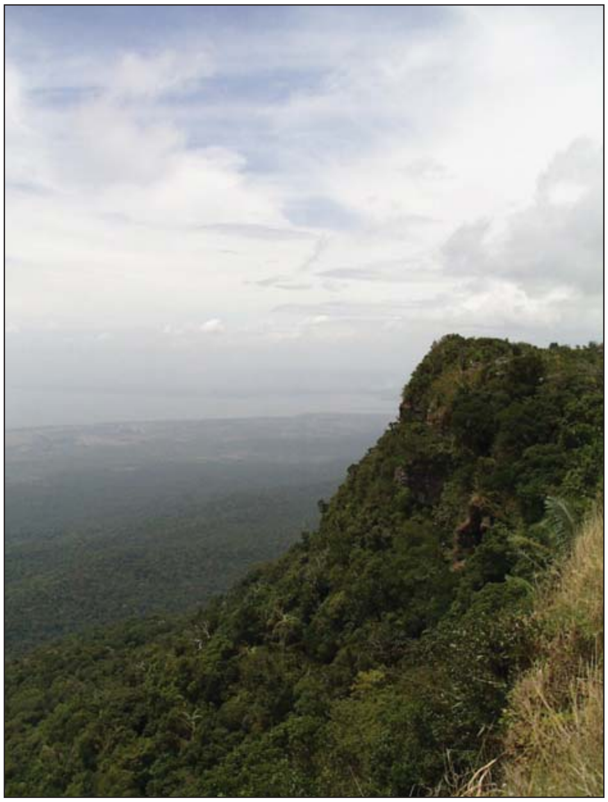

Fig. 1 South-facing escarpment of the Bokor Plateau looking out to the Gulf of Thailand with Phu Quoc Island (Vietnam) in the distance, March 2001 (© Rasoul Sharifi).

Fig. 3 Transition area near Popokvil Waterfall from montane wet evergreen forest to stunted forest on the Bokor Plateau with Dr Kansri Boonpragob of Ramkhamhaeng University, Bangkok, March 2001 (© Rasoul Sharifi).

Fig. 2 Stunted forest of the Bokor Plateau with emergent trees of *Dacrydium elatum,* March 2001 (© Philip Rundel).

Fig. 4 Sphagnum bog and wetland in areas of poor drainage on the Bokor Plateau, March 2001 (© Rasoul Sharifi).

Bokor Plateau was selected, largely for the French elite, for a variety of reasons including its proximity to coastal cities, the cooler upland climate above 1,000 m elevation, the spectacular panorama of the Gulf of Thailand and Phu Quoc Island from the plateau, and the presence of the picturesque Popokvil Waterfall.

A steep, winding road to the plateau was completed in 1921, and the construction of buildings on the plateau began the following year. These included a Catholic church (1922), a Buddhist temple (1924), and finally the luxurious Bokor Hotel Palace at the edge of the escarpment in 1925. The opening of the hotel was associated with the development of associated infrastructure to supply water and electricity and a school and hospital, altogether covering an area of about 5 km^2 (Kowlalcyzk, 2009). The tourist resort was short-lived, however, as the casino was closed in 1940 with the Japanese occupation of Indochina. The end of World War II brought little change to Bokor as an extended war of liberation began throughout the region. Vandalism and gang activity had taken over during the war when some of the buildings were utilized as a military hospital and sanitarium for wounded soldiers.

Two decades passed before an independent Cambodia renovated the hotel and casino in 1959, with Bokor quickly becoming the leading tourist attraction in the country. This golden era for the resort lasted only until 1972 when regional wars made its continued operation untenable. With the coming to power of the Khmer Rouge in 1975, all tourism ceased and Bokor was essentially abandoned. The resort facilities were heavily damaged in 1979 during fighting between Khmer Rouge soldiers and the advancing Vietnamese army who captured the area in 1982.

With the establishment of Bokor National Park in 1993, Cambodian forest rangers established a presence in the park and a small trickle of tourism returned and grew slowly. As political stability returned to Cambodia, there was renewed interest in developing the Bokor Plateau again. In January 2008, the Sokimex Group, a large corporate entity, announced that they had obtained a 99-year lease on 5 km^2 of the plateau for an international tourist development. A new access road up the mountain was soon completed and the large Thansur Bokor Highland Resort and casino constructed with 418 rooms. These developments greatly increased the ease of access and scientific work at Bokor, with increased visits by botanical collectors. In these early stages of resort development, planning is ongoing for extensive expanded facilities including golf courses, individual villas, and agricultural operations, with a proposed total expenditure of US$1 billion (see http://www.sokimex.com/our-business/casino/thansur-bokor-highland-resort).

Conservation

Despite a diverse and ecologically significant flora existing on the Bokor Plateau, conservation needs have not been given serious attention under strong pressures for development. Despite the massive scope of the project, forest and animal protection groups were quiet about the development's potential impact before its opening (Phnom Penh Post, 2012). The scale of ongoing construction can be readily seen in comparing Google Earth images of the plateau before and under current development. Much of the area between the new Thansur Bokor Highland Resort and Popokvil Waterfall has been graded into a network of access roads for housing and infrastructure development. These projects have already impacted the natural communities on the plateau, leading to a strong need to incorporate conservation planning and education into the development process.

The Bokor Plateau includes scattered small sphagnum bogs among its ecological communities, a rare habitat in mainland Southeast Asia (Rundel *et al.*, 2003). The plateau is also home to at least 22 endemic plant species known only from Bokor National Park: *Schefflera cambodiana* Yahara & Tagane, *Argostemma fasciculata* Sridith & Larsen, *Impatiens bokorensis* S.H.Cho & B.Y.Kim, *Garcinia bokorensis* H.Toyama & Yahara, *Diospyros elephasii* Lecomte, *Elaeocarpus bokorensis* Tagane, *Croton phourinii* H.Toyama & Tagane, *Lithocarpus eriobotryifolius* Yahara, *Gentiana ting-nung-hoae* Halda, *Cinnamomum bokorense* Tagane & Yahara, *Lindera bokorensis* Yahara & Tagane, *Machilus bokorensis* Yahara & Tagane, *Neolitsea bokorensis* Yahara & Tagane, *Memecylon bokorense* Tagane, *Sonerila bokorense* S.H.Cho and Y.D.Kim, *Syzygium bokorense* W.K.Soh & J.Parn., *Nepenthes bokorensis* Mey, *Cleyera bokorensis* Nagam. & Tagane, *Phyllanthus bokorensis* Tagane, *Helicia elephanti* Sleumer, *Wikstroemia bokorensis* E.Oguri & Tagane, and *Globba bokorensis* Nob.Tanaka & Tagane.

The Bokor Plateau and its associated development offers significant educational opportunities for Cambodian students at all levels to better appreciate the conservation and sustainability of biodiversity of the country. We hope that there will be broad interest in expanding existing programmes and developing new opportunities for environmental education at Bokor.

The Checklist

Our checklist includes taxa mentioned by Dy Phon (1970) as present on the plateau, our own collections, Sridith &

Larsen (2004), Averyanov *et al.* (2013, 2016), Nuraliev *et al.* (2015), Cho *et al.* (2015, 2017), Schuitemen *et al.* (2016), and reports by Tagane *et al.* (2017) for taxa occurring at or above 920 m. This is the elevation of Popokvil Waterfall. Excluded are non-native plant taxa previously or currently used for landscaping around the developed areas on the plateau. Also excluded are several collections present in the Muséum National d'Histoire Naturelle in Paris for species that are not otherwise accounted for in the collections cited below or in the works of Dy Phon (1970) and Tagane (2017) and for which no altitude data are given. Although some are clearly collections from the plateau area and already accounted for in the list below, many are just as equally clearly taxa of lower altitudes. Although it is possible that the collections include taxa of higher elevations, better data are needed to justify their inclusion in a list accounting only for plants growing above 920 m. Our checklist is comprised of 359 species with 29 ferns and lycophytes, 4 gymnosperms, and 326 angiosperms. The largest family in this checklist is the Rubiaceae with 30 species, followed by the Orchidaceae (28 species), Lauraceae (20 species), and Myrtaceae (13 species). For this flora, 22 species are believed to be endemic to Bokor, as indicated in the text below, highlighting the biodiversity significance of the Bokor Plateau. We hope that our article will serve to stimulate new research that can add to or correct this checklist.

The inclusion of taxa within families follows the Pteridophyte Phylogeny Group (PPG I, 2016) for ferns and lycophytes and the Angiosperm Phylogeny Group (APG IV, 2016) for angiosperms. For ferns and lycophytes, the generic delimitations also follow PPG I (2016), except in *Cyathea* pending clarification of the current placement of the Southeast Asian taxa. For angiosperms, the generic delimitation follows the recent literature for each group of plants most of which is summarised by Stevens (2017). If the spelling or authorship of a taxon name was given incorrectly by an earlier author, we correct it here without comment. What we term stunted forest in the list below is equivalent to what Dy Phon termed *forêt sempervirente basse de montagne*. We have translated her *lande a myrtacées et á vacciniacées* as heathland.

Our work is the outcome of field excursions in 1999 and 2001. The cited Middleton and Monyrak specimens are deposited in the herbarium of the Arnold Arboretum at Harvard University Herbaria (A) and in the Herbarium of the Ministry of the Environment in Phnom Penh. Duplicates of many collections can also be found in the herbarium of the Muséum National d'Histoire Naturelle in Paris (P), which also houses some of the original collections by Dy Phon. Shuichiro Tagane from Kyushu University in Japan and his research group conducted extensive surveys of the flora of the southern slope of Bokor National Park in a series of collecting trips from December 2011 to December 2013. This work, which covered the gradient from the coast to the plateau area, recorded 747 species in 105 families including 24 new species (Tagane *et al.*, 2017). The first set of their collections is deposited in the Kyushu University herbarium in Fukuoka (FU) with a second set in the herbarium of the Forest Administration of Cambodia. Partial sets of collections were distributed to the Forest Herbarium Bangkok (BKF), the Kyoto University Museum (KYO), Royal Botanic Gardens, Kew (K), Naturalis Biodiversity Center (L) and Muséum National d'Histoire Naturelle (P). More recently there have been large collections made by Nguyen Van Du and by Su Kung Wu, with records in TROPICOS database.

LYCOPHYTES

Lycopodiaceae

Huperzia serrata (Thunb. ex Murray) Trevis. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970) as *Lycopodium serratum* Thunb. ex Murray.

Palhinhaea cernua (L.) Vasc. & Franco — Herbaceous perennial in stunted forest and open wetlands. Included by Dy Phon (1970) and Rundel *et al.* (2003) as *Lycopodium cernuum* L.

Phlegmariurus squarrosus (G.Forst.) Á.Löve & D.Löve. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970) as *Lycopodium squarrosum* G.Forst.

Selaginellaceae

Selaginella sp. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

FERNS

Aspleniaceae

Asplenium nidus L. — Uncommon epiphyte in stunted forest. Noted in our work but not collected.

Cyatheaceae

Cyathea gigantea (Wall. ex Hook.) Holttum — Tree fern in understorey of stunted forest. Reported as rare by Dy Phon (1970) under the misapplied name *Cyathea glabra* (Blume) Copel.

Cyathea podophylla (Hook.) Copel. — Tree fern in understorey of stunted forest. Reported by Dy Phon (1970).

Davalliaceae

Davallia repens (L.f.) Kuhn — Lithophytic fern on rocks in exposed area beside track on way to Popokvil Waterfall, Middleton and Monyrak 652. Also reported by Dy Phon (1970) as *Humata repens* (L.f.) Diels.

Davallia solida (G.Forst.) Sw. — Epiphytic fern in stunted forest. Reported by Dy Phon (1970).

Dennstaedtiaceae

Pteridium aquilinum (L.) Kuhn — Terrestrial fern widespread in open grassy areas across the plateau. Noted as common in our work and also noted by Dy Phon (1970)

Pteridium esculentum (G.Forst.) Cockayne — Terrestrial fern at margin of stunted forest. Reported by Dy Phon (1970).

Dicksoniaceae

Cibotium barometz (L.) J.Sm. — Tree fern in understorey of stunted forest. Reported by Dy Phon (1970).

Gleicheniaceae

Dicranopteris linearis (Burm.f.) Underw. — Trailing or scrambling fern common along stunted forest margin. Observed but not collected by us and reported by Dy Phon (1970).

Diplopterygium norrisii (Mett. ex Kuhn) Nakai — Climbing fern at margin of stunted forest. Reported by Dy Phon (1970) as *Gleichenia norrisii* Mett.

Lindsaeaceae

Lindsaea ensifolia Sw. — Terrestrial fern in stunted forest. Reported by Dy Phon (1970) as *Schizoloma ensifolium* (Sw.) J.Sm.

Lygodiaceae

Lygodium flexuosum (L.) Sw. — Herbaceous climbing fern. Reported by Dy Phon (1970) from heathland areas.

Nephrolepidaceae

Nephrolepis brownii (Desv.) Hovenkamp & Miyam. — Terrestrial fern on sandy soil in scrubland near top of plateau, Middleton and Monyrak 600.

Nephrolepis hirsutula (G.Forst.) C.Presl — Epiphytic fern in stunted forest. Reported by Dy Phon (1970).

Oleandraceae

Oleandra musifolia (Blume) C.Presl — Large terrestrial fern in understorey of stunted forest. Reported by Dy Phon (1970).

Oleandra neriiformis Cav. — Terrestrial fern in stunted forest on sandy soil beside stream on way from road to Popokvil Waterfall at 934 m, Middleton and Monyrak 617. Also reported by Dy Phon (1970).

Polypodiaceae

Aglaomorpha coronans (Wall. ex Mett.) Copel. — Epiphytic or terrestrial fern in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 583.

Aglaomorpha rigidula (Sw.) Hovenkamp & S.Linds. — Terrestrial or epiphytic fern in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 608.

Microsorum scolopendria (Burm.f.) Copel. — Epiphytic or lithophytic fern in areas of stunted forest. Reported by Dy Phon (1970) as *Phymatodes scolopendria* (Burm.f.) Ching.

Oreogrammitis dorsipila (Christ) Parris — Lithophytic fern on shaded rocks beside Popokvil Waterfall at 920 m, Middleton and Monyrak 618.

Pyrrosia lingua (Thunb.) Farw. var. *heteractis* (Mett. ex Kuhn) Hovenkamp — Terrestrial fern in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 582. Reported by Dy Phon (1970) as *Pyrrosia eberhardtii* (Christ) Ching. Although terrestrial on the Bokor plateau this species is usually epiphytic.

Selliguea triloba (Houtt.) M.G.Price — Epiphytic or lithophytic fern in areas of stunted forest. Reported by Dy Phon (1970) as *Phymatodes triphylla* (Jacq.) C.Chr. & Tardieu.

Pteridaceae

Pityrogramma calomelanos (L.) Link — Delicate lithophytic fern. Sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 584.

Taenitis blechnoides (Willd.) Sw. — Terrestrial fern in stunted forest. Reported by Dy Phon (1970).

Thelypteridaceae

Cyclosorus interruptus (Willd.) H.Ito — Short erect fern on mossy rock in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 586.

GYMNOSPERMS

Gnetaceae

Gnetum latifolium Blume — Woody climber, occasional at higher elevations around 1,014 m (Tagane *et al.*, 2017).

Podocarpaceae

Dacrycarpus imbricatus (Blume) de Laub. — Tree, common in moist evergreen forest on the plateau. Noted in our work and by Dy Phon (1970) and Tagane *et al.* (2017).

Dacrydium elatum Wall. ex Hook. — Dominant canopy tree over much of the stunted forest on the plateau. Noted by Dy Phon (1970) and Tagane *et al.* (2017). Discussed in Rundel *et al.* (2016) and Tagane *et al.* (2017)

Podocarpus pilgeri Foxw. — Sclerophyllous shrub to small tree in stunted forest among rocks on sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 613.

ANGIOSPERMS

Acanthaceae

Hygrophila ringens (L.) R.Br. ex Spreng. — Small shrub to tiny herb in seasonally inundated vegetation on sandy soil beside track near Popokvil Waterfall and near field station at 936—1,059 m, Middleton and Monyrak 638, 674. Also listed by Rundel *et al.* (2003) as *Hygrophila angustifolia* R.Br.

Justicia ventricosa Wall. ex Hook.f. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Phlogacanthus geoffrayi Benoist — Shrub at margin of moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Strobilanthes aff. *lilacina* C.B.Clarke — Woody subshrub in heathland and stunted forest areas. Reported by Dy Phon (1970).

Thunbergia grandiflora Roxb. — Open ground beside path to Popokvil Waterfall, scrambling over shrub at 1,034 m, Middleton and Monyrak 626.

Adoxaceae

Viburnum sambucinum Reinw. ex Blume — Small tree in scrubby vegetation and stunted forest on sandy soil near summit on roadside towards research centre at 936 m, Middleton and Monyrak 634. Also reported as common by Tagane *et al.* (2017).

Altingiaceae

Liquidambar siamensis (Craib) Ickert-Bond & J.Wen — Tree in stunted forest. Reported by Tagane et al. (2017). Reported as *Altingia siamensis* Craib by Dy Phon (1970) and treated as a synonym of *Altingia excelsa* Noronha (= *Liquidambar excelsa* (Noronha) Oken) in the *Flora of Thailand*.

Anacardiaceae

Toxicodendron succedaneum (L.) Kuntze — Small tree, common in moist evergreen forest on the plateau (Tagane *et al.*, 2017).

Annonaceae

Uvaria hamiltonii Hook.f. & Thomson — Woody climber, occasional on the plateau (Tagane *et al.*, 2017).

Apiaceae

Centella asiatica (L.) Urb. — Herbaceous creeper. Reported by Dy Phon (1970) from heathland areas.

Apocynaceae

Alyxia reinwardtii Blume — Woody climber, occasional in moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Chilocarpus denudatus Blume — Woody climber, common in moist evergreen forest at higher elevations around 941 m (Tagane *et al.*, 2017).

Hoya multiflora Blume — Epiphytic or lithophytic herb scattered at higher elevations around 925 m (Tagane *et al.*, 2017).

Tabernaemontana bufalina Lour. — Small shrub, occasional in evergreen forest at higher elevations around 1,014 m (Tagane *et al.*, 2017).

Tabernaemontana pauciflora Blume — Small shrub, occasional in evergreen stunted forest at higher elevations around 1,014 m (Tagane *et al.*, 2017).

Tylophora ovata (Lindl.) Hook. ex Steud. — Climber in moist evergreen forest on the upper elevation of the plateau at 1,043 m (Tagane *et al.*, 2017).

Urceola micrantha (Wall. ex G.Don) Mabb. — Woody climber, common in evergreen forests, around 1,014–1,043 m (Tagane *et al.*, 2017).

Aquifoliaceae

Ilex annamensis Tardieu — Shrub in understorey of stunted forest. Reported by Dy Phon (1970).

Ilex cymosa Blume — Tree, common in evergreen forest at higher elevations at 970 m (Tagane *et al.*, 2017).

Ilex excavata Pierre — Tree, fairly common in moist evergreen forest on the top of the plateau at 970–1,043 m (Tagane *et al.*, 2017).

Ilex triflora Blume — Small tree, occasional in moist evergreen forest, common along streamside at 960–1,014 m (Tagane *et al.*, 2017)

Ilex viridis Champ. ex Benth. — Subshrub in heathland areas. Reported by Dy Phon (1970) as *Ilex triflora* Blume var. *viridis* (Champ. ex Benth.) Loes.

Ilex wallichii Hook.f. — Shrub in dry sandy soil on open roadside beside inundated area on track towards Popokvil Waterfall at 936 m, Middleton and Monyrak 627. Also reported by Tagane *et al.* (2017) as a shrub to a tree and locally common in moist evergreen forest and open bog on the plateau at 1,005–1,043 m.

N.B. *Ilex* is a genus that deserves more study at Bokor. In addition to the species above, Tagane *et al.* (2017) report two additional unnamed taxa.

Araceae

Pothos chinensis (Raf.) Merr. — Herbaceous climber in stunted forest. Reported by Dy Phon (1970) as *Pothos cathcartii* Schott.

Scindapsus hederaceus Miq. — Herbaceous climber in stunted forest. Reported by Dy Phon (1970) as *Scindapsus polanei* Gagnep.

Araliaceae

Dendropanax lancifolius (Ridl.) Ridl. — Small tree, occasional in moist evergreen forests on the plateau at 935–1,043 m (Tagane *et al.*, 2017).

Dendropanax maingayi King — Shrub to small tree, common in dense evergreen forest at higher elevations at 962–1,014 m (Tagane *et al.*, 2017).

Polyscias diversifolia (Blume) Lowry & G.M.Plunkett — Small tree, common in moist evergreen forest on the plateau at 970–1,014 m (Tagane *et al.*, 2017).

Schefflera cambodiana Yahara & Tagane — Tree, occasional in moist evergreen forest at higher elevations, especially common by the stream below Popokvil Waterfall at 970 m (Tagane *et al.*, 2017). Endemic to Bokor.

Schefflera pueckleri (K.Koch) Frodin — Tree in stunted forest. Reported as *Tupidanthus calyptratus* Hook. & Thomson by Dy Phon (1970).

Schefflera schizophylla (Hance) Frodin — Tree in stunted forest on sandy soil beside track on way to Popokvil Waterfall at 1,000 m, Middleton and Monyrak 651. Reported by Dy Phon (1970) as *Schefflera incisa* R.Vig.

Schefflera subintegra (Craib) C.B.Shang — Tree in thin soil on rocky ground beside Popokvil Waterfall at 920 m, Middleton and Monyrak 620. Also reported by Tagane *et al.* (2017) from moist evergreen forest at 1,014 m.

Arecaceae

Areca triandra Roxb. ex Buch.-Ham. — Erect palm, occasional in higher elevation (Tagane *et al.*, 2017).

Calamus bousigonii Becc. — Climbing palm in stunted forest. Reported by Dy Phon (1970). Also reported by Tagane *et al.* (2017) as locally common on the plateau at 1,014 m, as well as lower elevations.

Calamus palustris Griff. — Climbing palm common at middle to high elevations (Tagane *et al.*, 2017).

Calamus rudentum Lour. — Spiny climbing palm in stunted forest. Reported by Dy Phon (1970).

Daemonorops jenkinsiana (Griff.) Mart. — Climbing palm in stunted forest. Reported by Dy Phon (1970) as *Daemonorops pierreana* Becc. Also reported by Tagane *et al.* (2017) as occasional in evergreen forest and damp sites in middle and higher elevations, to 928 m.

Pinanga sylvestris (Lour.) Hodel — Erect palm, growing in open areas of the understorey in stunted evergreen forest, often abundant with *Pandanus cupribasalis* H.St. John. Reported by Dy Phon (1970) as *Pinanga cochinchensis* Blume. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest at higher elevations, around 935–1,043 m.

Plectocomia elongata Mart. ex Blume — Stout, climbing palm, somewhat common at higher elevations, around 1,014 m (Tagane *et al.*, 2017).

Plectocomia pierreana Becc. Climbing palm in stunted forest. Reported by Dy Phon (1970) as *Plectocomia cambodiana* Gagnep. ex Humbert. Also reported by Tagane *et al.* (2017) as somewhat common at higher elevations, around 930–1,014 m.

Asphodelaceae

Dianella ensifolia (L.) DC. — Herbaceous perennial in stunted forest understorey. Reported by Dy Phon (1970).

Asparagaceae

Dracaena elliptica Thunb. & Dalm. — Shrub, common in moist evergreen forest on the plateau, and also found in middle elevation. Reported by Dy Phon (1970) and Tagane *et al.* (2017) as *Dracaena gracilis* (Baker) Hook.f., an illegitimate name.

Dracaena reflexa Lam. var. *angustifolia* Baker — Trailing shrub, reported by Dy Phon (1970) from the understorey of stunted evergreen forest.

Chlorophytum orchidastrum Lindl. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Cordyline fruticosa (L.) A.Chev. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Asteraceae

Ageratina adenophora (Spreng.) R.M.King & H.Rob. — Herbaceous perennial on roadsides in heathland area. Reported by Dy Phon (1970) as *Eupatorium adenophora*. Naturalized non-native.

Camchaya kampotensis Gagnep. — Herbaceous perennial in wetland and stunted forest areas. Reported by Dy Phon (1970).

Gynura divaricata (L.) DC. — Herbaceous perennial in heathland area. Reported by Dy Phon (1970) as *Gynura auriculata*.

Elephantopus scaber L. — Herbaceous perennial in heathland area. Reported by Dy Phon (1970)).

Spilanthes iabadicensis A.H.Moore — Herbaceous perennial in heathland area. Reported by Dy Phon (1970) as equal to *S. acmella* (L.) L. *Spilanthes iabadicensis* is placed in synonymy of *Acmella uliginosa* (Sw.) Cass. in the *Flora of Thailand*.

Balanophoraceae

Balanophora fungosa J.R.Forst. & G.Forst. subsp. *indica* (Arn.) B.Hansen. — Herbaceous root parasite in stunted forest. Reported by Dy Phon (1970) as *Balanophora gracilis* Tiegh. and *B. sphaerica* (Tiegh.) Lecomte.

Balsaminaceae

Impatiens angustisepala Tardieu — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Impatiens bokorensis S.H.Cho & B.Y.Kim — Herbaceous perennial known only from the type locality on the Bokor plateau at 1,050 m (Cho *et al.*, 2017). Endemic to Bokor.

Impatiens muelleri Tardieu — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970). The type material of this species from Bokor has been variously labelled with other names in the genus but we continue to recognize it pending a definitive revision of the species.

Impatiens velaxata Hook.f. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

N.B. The genus *Impatiens* is in need of revision for the region.

Bonnetiaceae

Ploiarium alternifolium (Vahl) Melch. — Shrub in seasonally inundated area on sandy soil near top of plateau at 944 m, Middleton and Monyrak 591. Also reported by Tagane *et al.* (2017) as common in open sunny bogs at 926 m. Listed by Rundel *et al.* (2003).

Burmanniaceae

Burmannia disticha L. — Herb in seasonally inundated area on sandy soil near top of plateau at 944 m, Middleton and Monyrak 590. Also listed by Rundel *et al.* (2003).

Calophyllaceae

Calophyllum calaba L. var. *cuneatum* (Symington ex M.R.Hend. & Wyatt-Sm.) P.F.Stevens — Shrub in sclerophyllous stunted forest on rocky sandy soil near field station, near top of plateau at 1,042 m, Middleton and Monyrak 656. Also reported by Tagane *et al.* (2017) as a shrub or tree, common in open sunny bog on the plateau and included by Rundel *et al.* (2003). Dy Phon (1970) reports this as *Calophyllum saigonense* Pierre var. *nanum* Gagnep.

Calophyllum dryobalanoides Pierre — Shrub or tree, rare in moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Calophyllum tetrapterum Miq. — Shrub or tree, common in evergreen forest at higher elevations at 933 m (Tagane *et al.*, 2017).

Cannabaceae

Gironniera subaequalis Planch. — Small tree in thin soil on rocky ground beside Popokvil Waterfall at 920 m, Middleton and Monyrak 621.

Caprifoliaceae

Lonicera cambodiana Pierre ex P.Danguy — Climber, locally common in moist evergreen forest and its margins on the plateau at 1,011–1,043 m (Tagane *et al.*, 2017).

Celastraceae

Euonymus indicus B.Heyne ex Wall. — Shrub on sandy soil in scrubland near the top of the plateau at 1,056 m, Middleton and Monyrak 598. Reported by Tagane *et al.* (2017) as *Euonymus javanicus* Blume var. *talungensis* Pierre and said to be common in moist evergreen forest on the plateau at 1,014 m.

Microtropis discolor (Wall.) Wall. ex Meisn. — Small tree, occasional in evergreen forest, often found in humid sites near streams at 1,014 m (Tagane *et al.*, 2017).

Clusiaceae

Garcinia bokorensis H.Toyama & Yahara — Tree, common in moist evergreen forest on and near the top of the plateau at 935–1,041 m (Tagane *et al.*, 2017). Endemic to Bokor.

Garcinia celebica L. — Tree, occasionally at middle elevations but reaching 928 m (Tagane *et al.*, 2017)

Garcinia hanburyi Hook.f. — Tree in forest from the foot to the top of Mt Bokor. Reported by Dy Phon (1970) and Tagane *et al.* (2017).

Garcinia merguensis Wight — Tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 644, 646. Tagane *et al.* (2017) report that it is widely found from the foot to the top in Mt Bokor.

N.B. The genus *Garcinia* would be appropriate for more detailed study as Tagane *et al.* (2017) list two unidentified species, one from the plateau.

Convolvulaceae

Argyreia longipes (Gagnep.) Traiperm & Staples — Climber, common in moist evergreen forest at higher elevations around 1,014 m (Tagane *et al.*, 2017).

Argyreia scortechinii (Prain) Prain ex Hoogland — Climber in dwarf forest on sandy soil beside track on way to Popokvil Waterfall at 1,000 m, Middleton and Monyrak 647.

Cyperaceae

Carex indica L. — Clump forming sedge in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 581. Reported by Dy Phon (1970).

Fimbristylis dichotoma (L.) Vahl — Clump forming sedge in boggy vegetation indicating seasonal waterlogging on sandy soil beside track towards Popokvil Waterfall at 936 m, Middleton and Monyrak 654. Also listed by Rundel *et al.* (2003).

Fimbristylis eragrostis (Nees & Meyen) Hance — Reported by Dy Phon (1970) as *Fimbristylis lepidota* E.G.Camus from bogs as well as dry places.

Scleria ciliaris Nees — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Scleria harlandii Hance — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Scleria terrestris (L.) Fassett — Clump forming sedge in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 603.

Daphniphyllaceae

Daphniphyllum beddomei Craib — Tree, occasional in moist evergreen forests at higher elevations at 970–1,014 m (Tagane *et al.*, 2017). This species is included as a synonym of *Daphniphyllum paxianum* Rosenthal in the *Flora of China* but is recognized as distinct in the *Flora of Thailand*.

Daphniphyllum sp. — Dy Phon (1970) reported a species she called *Daphniphyllum roxburghii* H. Br. for which we can find no record, either of a specimen or publication. There is an illegitimate name *Daphniphyllum roxburghii* Baill. ex Rosenthal, now treated as *D. oldhamii* (Hemsl.) Rosenthal from Japan, Korea and China, but there is no evidence this species occurs in Cambodia. We are unsure of the identity of this species.

N.B. The genus *Daphniphyllum* deserves more study at Bokor. Tagane *et al.* (2017) list two additional species in middle elevation forests.

Droseraceae

Drosera burmannii Vahl — Small insectivorous herb in seasonally inundated area on sandy soil at 944 m, Middleton and Monyrak 588. Also listed by Rundel *et al.* (2003).

Drosera peltata Thunb. — Small insectivorous herb. Not seen by us but reported by Dy Phon (1970) from areas of seasonal wetlands.

Ebenaceae

Diospyros elephasii Lecomte — Small tree, common in moist evergreen forest on the top plateau. 962–1,043 m (Tagane *et al.*, 2017). Endemic to Bokor.

Diospyros venosa Wall. ex A.DC. — Tree in stunted forest. Reported by Dy Phon (1970). Tagane *et al.* (2017) used this name for a taxon at middle elevations below the plateau.

Elaeocarpaceae

Elaeocarpus bokorensis Tagane — Tree, common on the plateau from 800–1,000 m. (Tagane *et al.,* 2015). Endemic to Bokor.

Elaeocarpus dubius Aug.DC. — Tree, common in evergreen forest and its margin and roadside at 450–900(<1,000) m (rare on the plateau) (Tagane *et al.*, 2017).

Elaeocarpus griffithii (Wight) A.Gray — Tree, rare in moist evergreen forest on the plateau around 928 m (Tagane *et al.*, 2017).

Elaeocarpus lanceifolius Roxb. — Tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau around 1,055 m, Middleton and Monyrak 670.

Elaeocarpus thorelii Pierre — Small tree, rare, at higher elevation, around 970 m (Tagane *et al.*, 2017).

N.B. The genus *Elaeocarpus* deserves more study at Bokor to evaluate records. Tagane *et al.* (2017) list two unidentified taxa collected on the plateau. There are other species at middle elevations.

Ericaceae

Lyonia ovalifolia (Wall.) Drude — Tree in stunted forest. Reported by Dy Phon (1970) as *Pieris ovalifolia*. Also reported as rare in open bog on the plateau at 926 m by Tagane *et al.* (2017).

Rhododendron moulmainense Hook. — Shrub in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau around 1,047 m, Middleton and Monyrak 662. Tagane *et al.* (2017) identify this as *Rhododendron klossii* Ridl.

Vaccinium bracteatum Thunb. — Shrub or treelet in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau around 1,044 m, Middleton and Monyrak 659. Also reported by Tagane *et al.* (2017). Reported by Dy Phon (1970) as *Vaccinium cambodianum* Dop.

Vaccinium viscifolium King & Gamble — Small tree in thin soil on rocky ground by Popokvil Waterfall and near field station at the top of the plateau, 920–1,046 m, Middleton and Monyrak 622, 661. Also reported by Tagane *et al.* (2017) as occasional in moist evergreen forest on the plateau.

Eriocaulaceae

Eriocaulon ubonense Lecomte f. *kradungense* (Satake) A.Prajaksood & J.Parn. — Small herb in boggy vegetation indicating seasonal waterlogging on sandy soil beside track towards Popokvil Waterfall at 936 m, Middleton and Monyrak 628. Included as *Eriocaulon* cf. *henryanum* Ruhland in Rundel *et al.* (2003).

Escalloniaceae

Polyosma integrifolia Blume — Tree, occasional in evergreen forest at higher elevations around 944 m (Tagane *et al.*, 2017).

Euphorbiaceae

Croton phourinii H.Toyama & Tagane — Shrub, locally common in moist evergreen forest on the plateau at 930 m (Tagane *et al.*, 2017). Dy Phon (1970) reported a *Croton* sp. in the understorey of stunted forest. Endemic to Bokor although its distinction from *Croton phaenodon* Airy Shaw was questioned by an anonymous reviewer.

Gymnanthes remota (Steenis) Esser — Small tree, occasional in moist evergreen forest at higher elevations around 960–1,014 m (Tagane *et al.*, 2017).

Macaranga andamanica Kurz — Small tree, common in moist evergreen forest on the plateau, especially frequent along streams at higher elevations, around 975–1,014 m (Tagane *et al.*, 2017).

Fabaceae

Codariocalyx gyroides (Roxb. ex Link) Hassk. — Shrub, occasional at semi-shaded forest margin on the plateau at 960 m (Tagane *et al.*, 2017).

Ormosia fordiana Oliv. — Tree in thin soil on rocky ground beside Popokvil Waterfall at 920 m, Middleton and Monyrak 624. Tagane *et al.* (2017) report an unidentified *Ormosia* on the plateau at 933 m.

Fagaceae

Castanopsis acuminatissima (Blume) A.DC — Tree, common at higher elevations around 970 m (Tagane *et al.*, 2017).

Castanopsis cambodiana A.Chev. ex Hickel & A.Camus — Tree, occasional in moist evergreen forest on the plateau at 935 m (Tagane *et al.*, 2017).

Lithocarpus elegans (Blume) Hatus. ex Soepadmo — Tree, rare in moist evergreen forest on the plateau at 1,000 m (Tagane *et al.*, 2017).

Lithocarpus elephantum (Hance) A.Camus — Tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 585. Also reported by Tagane *et al.* (2017) from moist evergreen forest at higher elevations, around 1,014–1,043 m.

Lithocarpus eriobotryifolius Yahara — Tree, occasional in moist evergreen forest at higher elevations around 930 m (Tagane *et al.*, 2017). Endemic to Bokor.

Lithocarpus farinulentus (Hance) A.Camus — Tree in stunted forest. Reported by Dy Phon (1970).

Lithocarpus leiophyllus A.Camus — Tree in sclerophyllous stunted forest on rocky sandy soil beside track towards Popokvil and near field station, at the top of the plateau at 1,043 m, Middleton and Monyrak 658. Also reported by Tagane *et al.* (2017) as fairly common and one of the dominant species in moist evergreen forest on the plateau.

Quercus augustinii Skan — Tree, occasional at higher elevations around 970 m (Tagane *et al.*, 2017).

Quercus langbianensis Hickel & A.Camus — Tree in stunted forest on the top plateau. Reported by Dy Phon (1970) and Tagane *et al.* (2017) as *Quercus cambodiensis* Hickel & A.Camus.

Quercus sp. — Tree, rare in evergreen forest at 970 m. Reported by Tagane *et al.*(2017).

N.B. The Fagaceae would appear to be in need of more detailed study at Bokor and throughout Indochina.

Flagellariaceae

Flagellaria indica L. — Woody climber in stunted forest. Reported by Dy Phon (1970).

Gentianaceae

Fagraea auriculata Jack — Tree, common in humid evergreen forest on the top plateau around 1,014 m. Reported y Dy Phon (1970) and Tagane *et al.* (2017).

Fagraea ceilanica Thunb. — Scandent tree, occasionally epiphyte, common in middle to high elevations around 1,014 m (Tagane *et al.*, 2017).

Gentiana greenwayae Merr. — Herbaceous perennial in heathland and stunted forest areas. Reported by Dy Phon (1970). Sometimes treated as *Gentiana praticola* subsp. *greenwayae* (Merr.) Halda.

Gentiana ting-nung-hoae Halda — Herbaceous perennial in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 607. Also listed by Rundel *et al.* (2003). *Gentiana bokorensis* Hul is a synonym of this species. It has also been treated as a subspecies of *Gentiana nudicaulis* Kurz. Endemic to Bokor.

Hanguanaceae

Hanguana cf. *malayana* (Jack) Merr. — Herb on sandy soil in stunted forest beside track on way to Popokvil Waterfall at 1,000 m, Middleton and Monyrak 604.

N.B. The genus *Hanguana* was, until recently, considered to be monotypic. Recent research in Malaysia and Singapore has led to the description of many new species and the conclusion that *Hanguana malayana* itself is likely quite narrowly distributed. It is quite possible that the Bokor plant is an undescribed species.

Juglandaceae

Engelhardia roxburghiana Lindl. ex Wall. — Tall tree found from low to high elevations (Tagane *et al.*, 2017).

Juncaceae

Juncus prismatocarpus R.Br. — Herbaceous perennial. Reported by Dy Phon (1970) from wetland areas with scattered subshrubs.

Lamiaceae

Anisochilus cambodianus Murata — Woody herb, rarely found on open sunny rocks on the plateau at 1,014 m (Tagane *et al.*, 2017).

Clerodendrum smitinandii Moldenke — Small tree, fairly common along forest edge and roadside around 970 m (Tagane *et al.*, 2017).

Premna interrupta Wall. ex Schauer — Scandent shrub, often epiphytic on tree trunks, occasional at higher elevations around 935 m (Tagane *et al.*, 2017).

Lauraceae

Beilschmiedia gammieana King ex Hook.f. — Tree, rare, at 1,014 m (Tagane *et al.*, 2017).

Beilschmiedia penangiana Gamble — Small tree, common in moist evergreen forest at higher elevations around 970–1,043 m (Tagane *et al.*, 2017).

Cassytha filiformis L. — Herbaceous scrambling parasite in stunted forest. Reported by Dy Phon (1970).

Cinnamomum bokorense Tagane & Yahara — Tree, occasional at middle elevations and reaching 935 m (Tagane *et al.*, 2017). Endemic to Bokor.

Cinnamomum curvifolium (Lour.) Nees — Tree, somewhat common in evergreen forest in middle and higher elevations around 970 m (Tagane *et al.*, 2017).

Cinnamomum dimorphandrum Yahara & Tagane — Small tree, somewhat common in moist evergreen forest at higher elevations, 941–1,043 m (Tagane *et al.*, 2017).

Cinnamomum iners Reinw. ex Blume — Treelet in heathland areas. Reported by Dy Phon (1970).

Cinnamomum litseifolium Thwaites — Tree in stunted forest. Reported by Dy Phon (1970).

Lindera bokorensis Yahara & Tagane — Small tree, rare, at 970 m (Tagane *et al.*, 2017). Endemic to Bokor.

Litsea cambodiana Lecomte — Tree in stunted forest. Reported by Dy Phon (1970). Tagane *et al.* (2017), however, describes this as a middle elevation tree not present on the plateau.

Litsea martabanica (Kurz) Hook.f. — Small tree, common in middle elevation evergreen forests and a single collection from 970 m (Tagane *et al.*, 2017).

Litsea monopetala (Roxb.) Pers. — Tree locally common in moist evergreen forest on the plateau around 928 m (Tagane *et al.*, 2017).

Litsea verticillata Hance — Small tree, somewhat common in evergreen forest at higher elevations around 1,014 m (Tagane *et al.*, 2017).

Litsea vang Lecomte — Tree in stunted forest. Reported by Dy Phon (1970).

Machilus bokorensis Yahara & Tagane — Small tree, common in moist evergreen and stunted forest on the top plateau on sandy soil at 936–1,056 m. Middleton and Monyrak 597, 629, 643. Also reported by Tagane *et al.* (2017). Reported by Dy Phon (1970) as *Machilus odoratissima* Nees. Endemic to Bokor.

Neolitsea aff. *alongensis* Lecomte — Tree in stunted forest. Reported by Dy Phon (1970).

Neolitsea bokorensis Yahara & Tagane, ined. — Small tree, common in moist evergreen forest on the plateau around 1,011–1,043 m (Tagane *et al.*, 2017). Presumably endemic to Bokor.

Neolitsea cambodiana Lecomte var. *cambodiana* — Small tree, locally common at higher elevations around 1,014–1,043 m (Tagane *et al.*, 2017).

Neolitsea cambodiana Lecomte var. *glabra* C.K.Allen — Tree in stunted forest. Reported by Dy Phon (1970).

Neolitsea zeylanica (Nees & T.Nees) Merr. — Sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 611. Tagane *et al.* (2017) restricts this name to a low elevation tree species.

N.B. The Lauraceae is a diverse family on both the plateau and lower elevations at Bokor. The Lauraceae of Cambodia, like the rest of Southeast Asia, is poorly known and in need of greater study.

Lentibulariaceae

Utricularia bifida L. — Tiny herb in boggy vegetation indicating seasonal waterlogging on sandy soil at 936 m, Middleton and Monyrak 641. Also listed by Rundel *et al.* (2003).

Utricularia caerulea L. — Small herb in boggy vegetation indicating seasonal waterlogging on sandy soil at 936 m, Middleton and Monyrak 640.

Utricularia delphinioides Thorel ex Pellegr. — Wet grassland. Reported by Dy Phon (1970).

N.B. In addition to the above species, blogs by F.S. Mey in 2011 report four additional species — *Utricularia minutissima* Vahl, *U. odorata* Pellegr., *U. striatula* Sm., and *U. uliginosa* Wight.

Loganiaceae

Mitrasacme pygmaea R.Br. — Small herb growing in cracks in disintegrating road beside sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,058 m, Middleton and Monyrak 673.

Loranthaceae

Barathranthus axanthus (Korth.) Miq. — Small parasitic shrub, scattered in evergreen forest at stunted and high elevation, around 940 m (Tagane *et al.*, 2017).

Macrosolen cochinchinensis (Lour.) Tiegh. — Semi-woody epiphytic parasite in stunted forest. Reported by Dy Phon (1970). Reported by Tagane *et al.* (2017) as occasional in hill evergreen forest at 800–1,000 m.

Lythraceae

Ammannia baccifera L. — Herbaceous perennial in wetland areas. Reported by Dy Phon (1970).

Magnoliaceae

Magnolia duperreana Pierre — Tree in stunted forest. Reported by Dy Phon (1970) as *Kmeria duperreana*. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest on the plateau around 939–1,014 m.

Magnolia liliifera (L.) Baill. — Small tree, common in moist evergreen forest on the plateau, around 1,014–1,043 m (Tagane *et al.*, 2017).

Magnolia sp. — A treelet in stunted forest on sandy soil beside a stream on way from road to Popokvil Waterfall at 934 m, Middleton and Monyrak 616.

Malvaceae

Pavonia rigida (Wall. ex Mast.) Hochr. — Herbaceous creeper. Reported by Dy Phon (1970) from heathland area as synonymous with *Urena rigida* Wall. Both genera may now be synonyms of *Hibiscus*.

Sterculia parviflora Roxb. ex G.Don — Tree, occasional in evergreen forest from middle to high elevations, around 1,014 m (Tagane *et al.*, 2017).

Melastomataceae

Medinilla rubicunda (Jack) Blume — Small tree, often epiphytic on tree trunks and rocks, somewhat common in moist evergreen forest on the plateau, around 1,014 m (Tagane *et al.*, 2017).

Melastoma malabathricum L. subsp. *normale* (D.Don) Karst. Mey. — Shrub in sclerophyllous stunted forest on rocky sandy soil near field station, near top of plateau at 1,049 m, Middleton and Monyrak 664. Reported by Dy Phon (1970) as *Melastoma normale*.

Melastoma pellegrinianum (H.Boissieu) Karst.Mey. — Shrub to small tree, common in disturbed semi-evergreen forest in lowland and open sunny bogs on the plateau, around 1,014 m (Tagane *et al.*, 2017).

Melastoma saigonense (Kuntze) Merr. — Wet grassland. Reported by Dy Phon (1970) as *Melastoma villosum* Sims which is a later homonym of *M. villosum* Aublet.

Melastoma sanguineum Sims — Woody shrub in heathland areas. Reported by Dy Phon (1970). Tagane *et al.* (2017) report this species only from disturbed forest margins at low and middle elevation.

Memecylon bokorense Tagane — Shrub to small tree, occasional in understorey of moist evergreen forest at higher elevations, especially common around Popokvil Waterfall (Tagane *et al.*, 2017). Endemic to Bokor.

Memecylon lilacinum Zoll. & Moritzi — Shrub in montane forests collected at 928 m (Tagane *et al.*, 2017).

Sonerila bokorense S.H.Cho and Y.D.Kim — Herbaceous perennial in stunted forest at 950–1,050 m. Endemic to Bokor and described by Cho *et al.* (2015).

N.B. Tagane *et al.* (2017) describes one unidentified species of *Memecylon* from 970 m on the plateau. More work on the Melastomataceae would help resolve species limits, with many taxa present at middle elevations.

Meliaceae

Aglaia spectabilis (Miq.) S.S.Jain & Bennet — Tree, occasional at higher elevations, around 970 m (Tagane *et al.*, 2017).

Dysoxylum cauliflorum Hiern — Tree, common in evergreen forest at all elevations, in particular along a stream at 970 m (Tagane *et al.*, 2017).

Dysoxylum sp. — Tall tree, occasional in primary forest at all elevations (Tagane *et al.*, 2017).

Toona ciliata M.Roem. — Tree, rare at higher elevations, around 970 m (Tagane *et al.*, 2017).

Menispermaceae

Hypserpa nitida Miers — Climber, occasional in moist evergreen forest on the plateau at 1,014–1,043 m (Tagane *et al.*, 2017).

Moraceae

Ficus consociata Blume — Small tree, often found near streams at higher elevations, around 970 m (Tagane *et al.*, 2017).

Ficus heteropleura Blume — Hemi-epiphytic shrub or tree, common in moist evergreen forest on the plateau, around 962–1,014 m (Tagane *et al.*, 2017).

Ficus ischnopoda Miq. — Subshrub in stunted forest. Reported by Dy Phon (1970). Tagane *et al.* (2017) records this species from open rapidly flowing streams at middle elevations but not the plateau.

Ficus sumatrana (Miq) Miq. — Tree in stunted forest. Reported by Dy Phon (1970).

Ficus sundaica Blume — Small tree, common in moist evergreen forest on the plateau, and also found in the lowlands (Tagane *et al.*, 2017).

Streblus indicus (Bureau) Corner — Small tree in stunted forest. Reported by Dy Phon (1970). Tagane *et al.* (2017) report it as a scandent or erect tree, common in moist evergreen forest, especially abundant along lower streamside of Popokvil Waterfall below 930 m.

Myristicaceae

Horsfieldia amygdalina (Wall.) Warb. — Tree, common in lowland, occasional in middle elevation, and rare on the plateau, around 970–1,014 m (Tagane *et al.*, 2017).

Myrtaceae

Decaspermum montanum Ridl. — Small tree, somewhat common in dense evergreen forest on the plateau, around 970–1,043 m (Tagane *et al.*, 2017).

Melaleuca leucadendra (L.) L. — Tree in boggy areas with saturated soils. Reported by Dy Phon (1970).

Rhodamnia dumetorum (DC.) Merr. & L.M.Perry — Shrub in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 657. Also reported by Tagane *et al.* (2017) as locally common in somewhat disturbed areas in both lower and higher elevations.

Rhodomyrtus tomentosa (Aiton) Hassk. — Shrub to small tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,048 m, Middleton and Monyrak 663. Also reported by Tagane *et al.* (2017) as occasional in disturbed areas in both lower and higher elevations.

Syzygium antisepticum (Blume) Merr. & L.M.Perry — Prostrate shrub to small tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,054 m, Middleton and Monyrak 669. Also reported by Tagane *et al.* (2017) as fairly common in evergreen forest at higher elevations and open sunny bog on the plateau. In the latter environment, this species grows as a dwarf shrub, 40 cm tall, having smaller and thicker leaves (Tagane *et al.*, 2017). Included as *Syzygium zeylanicum* (L.) DC. by Rundel *et al.* (2003).

Syzygium attenuatum (Miq.) Merr. & L.M.Perry — Small tree, occasional in dense evergreen forest at higher elevations, around 1,014–1,043 m (Tagane *et al.*, 2017).

Syzygium bokorense W.K.Soh & J.Parn. — Shrub on sandy soil in high rainfall area on way to Popokvil Waterfall at 936 m, Middleton and Monyrak 610, 630. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest and its margins on the plateau, around 1,014 m. Endemic to Bokor.

Syzygium claviflorum (Roxb.) Wall ex Steud. — Shrub to small tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,045 m, Middleton and Monyrak 660. Also reported by Tagane *et al.* (2017) as common in open bogs on the plateau, around 938–1,043 m.

Syzygium formosum (Wall.) Masam. — Small tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,056 m, Middleton and Monyrak 671. Also reported by Tagane *et al.* (2017) as fairly common along rapid streams and in swamp forests on the plateau.

Syzygium hancei Merr. & L.M.Perry — Small tree in thin soil on rocky ground beside Popokvil Waterfall at 920 m, Middleton and Monyrak 623. Tagane *et al.* (2017) treated this species as *Syzygium mekongense* (Gagnep.) Merr. & L.M.Perry.

Syzygium jambos (L.) Alston var. *sylvaticum* (Gagnep.) Merr. & L.M.Perry — Tree, somewhat common in middle and higher elevations, around 970 m (Tagane *et al.*, 2017).

Syzygium lineatum (DC.) Merr. & L.M.Perry — Tree in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 605. Also reported by Tagane *et al.* (2017) as somewhat commonly found in evergreen forest from low to high elevations on the plateau, around 1,014 m.

Tristaniopsis merguensis (Griff.) Peter G.Wilson & J.T.Waterh. — Common tree in stunted forest. Reported by Dy Phon (1970). Also reported by Tagane *et al.* (2017).

N.B. The genus *Syzygium* is a diverse group at Bokor, and questions remain about the species present on the plateau. Soh and Parnell (2015) recently revised the species for Indochina.

Nepenthaceae

Nepenthes bokorensis Mey — Herb in seasonally inundated area on sandy soil at around 944 m, Middleton and Monyrak 587, 589, 592, 602. Reported by Dy Phon (1970) as *Nepenthes thorelii* Lecomte. Listed as *Nepenthes kampotiana* Lecomte in Rundel *et al.* (2003). Endemic to Bokor.

Nyssaceae

Nyssa javanica (Blume) Wangerin — Tall tree in moist evergreen montane forests and reaching 928 m (Tagane *et al.*, 2017).

Ochnaceae

Campylospermum serratum (Gaertn.) Bittrich & M.C.E. Amaral — Shrub or treelet in scrubland or stunted forest in sandy soil near top of plateau at 936–1,056 m, Middleton and Monyrak 596, 612, 636. Also reported by Tagane *et al.* (2017) under the name *Gomphia serrata* (Gaertn.) Kanis as common in evergreen forest on the plateau.

Oleaceae

Jasminum lanceolaria Roxb. — Climber, somewhat common in both lower and higher elevations (Tagane *et al.*, 2017).

Jasminum nobile C.B.Clarke — Woody climber in stunted evergreen sclerophyllous forest along edge of track on plateau at 989–1,042 mm, Middleton and Monyrak 593, 625. Also reported by Tagane *et al.* (2017) as common in edge of evergreen forest on the plateau, around 1,014–1,043 m.

Olea brachiata (Lour.) Merr. — Tree, occasional in evergreen forest and its margins on the plateau around 970–1,043 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Olea maritima* Wall. ex G.Don.

Olea salicifolia Wall. ex G.Don — Small tree, common in moist evergreen forest on the plateau, around 1,014–1,043 m (Tagane *et al.*, 2017).

Orchidaceae

Appendicula hexandra (J.Koenig) J.J.Sm. — Epiphytic orchid in stunted forest. Listed by Averyanov *et al.* (2013). Reported by Dy Phon (1970) as *Appendicula koenigii* Hook.f.

Bulbophyllum lobbii Lindl. — Lithophytic epiphyte in areas of stunted forest. Reported by Dy Phon (1970).

Bulbophyllum physocoryphum Seidenf. — Epiphytic orchid in evergreen forest on the plateau at 1,000 m. Reported by Averyanov *et al.* (2013).

Bulbophyllum retusiusculum Rchb.f. — Epiphytic orchid in evergreen forest on the plateau. Reported by Averyanov *et al.* (2013).

Bulbophyllum tenuifolium (Blume) Lindl. — Epiphytic orchid in evergreen forest on the plateau and common along streams. Reported by Averyanov *et al.* (2013).

Calanthe cardioglossa Schltr. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970) and collected by Averyanov *et al.* (2012).

Calanthe lyroglossa Rchb.f. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970) as *Calanthe nephroidea* Gagnep.

Calanthe spathoidea — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970). This name does not appear to have ever been published and it is not known to what it refers.

Ceratostylis subulata Blume — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970) as *Ceratostylis teres* (Griff.) Rchb.f.

Cleisostoma birmanicum (Schltr) Gerey — Epiphytic orchid. Stunted forest at 1,000 m (Schuiteman *et al.*, 2016).

Cleisostoma fuerstenbergianum Kraenzl. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970) as *Sarcanthus geoffrayi* Guillaumin.

Coelogyne parishii Hook.f. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970).

Conchidium muscicola (Lindl.) Rauschert — Epiphyte in areas of stunted forest. Reported by Dy Phon (1970) as *Eria muscicola* (Lindl.) Lindl.

Dendrobium revolutum Lindl. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970).

Dendrobium scabrilingue Lindl. — Epiphytic orchid in evergreen forest. Reported by Averyanov *et al.* (2016).

Dendrobium tenellum (Blume) Lindl. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970).

Eria biflora Griff. — Lithophytic or epiphytic orchid in stunted forest. Reported by Dy Phon (1970)

Eria lasiopetala (Willd.) Ormerod — Lithophytic or epiphytic orchid in stunted forest. Reported by Dy Phon (1970) as *Eria albidotomentosa* (Blume) Lindl.

Eria tenuiflora Ridl. — Epiphytic orchid in cloud forest on the plateau (Averyanov *et al.*, 2013).

Liparis acuminata Hook.f. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970).

Mycaranthes floribunda (D.Don) S.C.Chen & J.J.Wood. — Lithophytic or epiphytic orchid in stunted forest. Reported by Dy Phon (1970) as *Eria paniculata* Lindl.

Oberonia falcata King & Pantl. — Epiphytic orchid in evergreen montane forest at 940 m (Schuiteman *et al.*, 2016.

Papilionanthe pedunculata (Kerr) Garay. — Terrestrial orchid climber in stunted forest. Reported by Dy Phon (1970) as *Aerides pedunculata* Kerr.

Pholidota articulata Lindl. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970).

Plocoglottis bokorensis (Gagnep.) Seidenf. — Terrestrial herbaceous perennial. Submontane forests of Bokor. Reported by Nuraliev (2014) without elevation, but collected at 1,300 m at Khao Yai, Thailand.

Spathoglottis pubescens Lindl. — Terrestrial orchid in wetland areas and stunted forest. Reported by Dy Phon (1970).

Stichorkis gibbosa (Finet) J.J.Wood — Epiphytic orchid in evergreen montane forest at 940 m (Schuiteman *et al.* 2016).

Trichotosia velutina (Lodd. ex Lindl.) Kraenzl. — Epiphytic orchid in stunted forest. Reported by Dy Phon (1970) as *Eria velutina* Lodd. ex Lindl.

N.B. Averanov *et al.* (2013) collected a number of orchid species from Bokor without elevation data.

Pandanaceae

Pandanus capusii Martelli — Subshrub up to 80 cm. Stunted forest and heathland areas. Reported by Dy Phon (1970).

Pandanus cupribasalis H.St.John — Understorey of open forest stands, especially near Popokvil Waterfall. Typically 2–3 m in the lower forest stands but as tall as 8 m in wet forest at lower elevations (Stone, 1971).

Pentaphylacaceae

Anneslea fragrans Wall. — Tree, occasional on the top plateau, and rare in the lowland, around 1,011–1,043 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Anneslea* sp.

Cleyera bokorensis Nagam. & Tagane, ined. — Rheophytic shrub to small tree, common along streams at higher elevations, around 991–1,043 m (Tagane *et al.*, 2017). Endemic to Bokor.

Eurya nitida Korth. var. *nitida* — Shrub in sclerophyllous stunted forest near field station, near top of plateau at 1,050 m, Middleton and Monyrak 665. This appears to be what Dy Phon (1970) reports as *Eurya japonica* Thunb. Tagane *et al.* (2017) report only *Eurya trichocarpa* Korth. from upper middle elevations and not the plateau.

Ternstroemia gymnanthera (Wight & Arn) Bedd. — Small tree, occasional in moist evergreen forest on the plateau, around 928–1,043 m (Tagane *et al.*, 2017).

Phyllanthaceae

Antidesma montanum Blume var. *montanum* — Small tree in dwarf forest on sandy soil beside track on way to Popokvil Waterfall at 1,000 m, Middleton and Monyrak 650. Also reported as *Antidesma montanum* by Tagane *et al.* (2017) as fairly common in moist evergreen forest on the plateau, around 930–1,014 m.

Aporosa yunnanensis (Pax & K.Hofm.) F.P.Metcalf — Tree, rare in evergreen forest at higher elevations, around 970 m (Tagane *et al.*, 2017).

Glochidion lanceolarium (Roxb.) Voigt — Tree 3–4 m tall. Stunted forest. Reported by Dy Phon (1970). Tagane *et al.* (2017) record this species only at low elevation.

Glochidion hypoleucum (MIq.) Boerl. — Tree in stunted forest. Reported by Dy Phon (1970) as *Glochidion glaucifolium* Müll.Arg.

Glochidion rubrum Blume — Small tree, occasional in edge of evergreen forest, around 930–1,014 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970).

Phyllanthus bokorensis Tagane — Small tree, common at streamside, especially along lower stream of Popokvil Waterfall, and in open areas on the plateau, around 1,014 m (Tagane *et al.*, 2017). Endemic to Bokor.

Phyllanthus kampotensis Beille — Shrub in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 645.

Phyllanthus roseus (Craib & Hutch.) Beille — Small tree, occasional in understorey of moist evergreen forest and its margin on the plateau at 1,014 m (Tagane *et al.*, 2017).

N.B. Both *Glochidion* and *Phyllanthus* require more careful study.

Pittosporaceae

Pittosporum balansae A.DC. — Shrub in understorey of stunted forest. Reported by Dy Phon (1970) as *Pittosporacus balansae*, possibly a typological error.

Pittosporum pauciflorum Hook. & Arn — Small tree, common in moist evergreen forest on the plateau, around 975–1,043 m (Tagane *et al.*, 2017).

N.B. More study may determine that these two taxa are the same.

Poaceae

Bambusa sp. — Edge of shrub stands in heathland area. Reported by Dy Phon (1970).

Eremochloa eriopoda C.E.Hubb. — Common grass in bog areas and seasonally waterlogged soils. Listed by Rundel *et al.* (2003).

Imperata cylindrica (L.) P.Beauv. — Forest edge and roadside. Reported by Dy Phon (1970).

Panicum sp. — Roadside. Reported by Dy Phon (1970). Also listed by Rundel *et al.* (2003).

Phragmites aff. *karka* (Retz.) Trin. ex Steud. — Common in disturbed areas at forest edge and roadside. Reported by Dy Phon (1970).

Polygalaceae

Polygala arillata Buch.-Ham. ex D.Don — Shrub, locally common around moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Polygala tonkinensis Chodat — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Salomonia longiciliata Kurz — Boggy vegetation indicating seasonal waterlogging on sandy soil beside track towards Popokvil Waterfall at 936 m, Middleton and Monyrak 639.

Xanthophyllum ellipticum Korth. ex Miq. — Small tree, scattered in moist evergreen forest and its vicinity on the plateau at 930 m (Tagane *et al.*, 2017).

Polygonaceae

Polygonum chinense L. — Herbaceous perennial. Reported by Dy Phon (1970) as common in heathland areas.

Primulaceae

Ardisia crenata Sims subsp. *crassinervosa* (E.Walker) C.M.Hu & Vidal — Treelet in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 642. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest and its vicinity on the plateau around 1,014 m.

Ardisia quinquegona Blume var. *quinquegona* — Small tree, occasional in evergreen forest from middle to high elevations, around 970–1,043 m (Tagane *et al.*, 2017).

Ardisia sanguinolenta Blume — Small tree, widely and commonly found from middle to high elevations (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Ardisia colorata* Roxb.

Ardisia smaragdina Pit. — Shrub on sandy soil in scrubland near top of plateau at 1,056 m, Middleton and Monyrak 595. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest on the plateau, around 1,014–1,043 m.

Labisia pumila (Blume) Fern.-Vill. — Shrub, occasional in moist evergreen forest, often occurs near streams, around 941 m (Tagane *et al.*, 2017).

Maesa ramentacea (Roxb.) A.DC. — Shrub in understorey of stunted forest. Reported by Dy Phon (1970). Tagane *et al.* (2017) report this species from middle elevations.

Rapanea neriifolia (Siebold & Zucc.) Mez var. *macrocarpa* (Pit.) C.M.Hu — Tree, occasional in moist evergreen forest on the plateau, around 1,005–1,043 m (Tagane *et al.*, 2017).

Proteaceae

Helicia elephanti Sleumer — Shrub in stunted forest on the plateau. Reported by Dy Phon (1970). Also reported by Tagane *et al.* (2017) as a small tree, occasional along streams at higher elevations and particularly abundant along the lower stream of Popokvil Waterfall. Endemic to Bokor.

Helicia vestita W.W.Sm. — Tree, somewhat common in hill evergreen forest at 800–940 m (Tagane *et al.*, 2017).

Restionaceae

Centrolepis cambodiana Hance — Tufted herb on sandy soil in stunted forest beside inundated area on way to Popokvil Waterfall at 936 m, Middleton and Monyrak 632. Also listed by Rundel *et al.* (2003).

Dapsilanthus disjunctus (Mast.) B.G.Briggs & L.A.S.Johnson — Clump forming herb in boggy vegetation in seasonally inundated area beside track towards Popokvil Waterfall at 936 m, Middleton and Monyrak 655. Included as *Leptocarpus disjunctus* Mast. in Rundel *et al.* (2003).

Rhamnaceae

Frangula crenata (Siebold & Zucc.) Miq. — Shrub to small tree, common in open bog and its surroundings on the plateau, at 926 m (Tagane *et al.*, 2017).

Rosaceae

Prunus grisea (Blume ex Müll.Berol.) Kalkman var. *tomentosa* (Koord. & Valeton) Kalkman — Small tree, fairly common in moist evergreen forest on the plateau, and along the stream at higher elevations, 930–1,043 m (Tagane *et al.*, 2017).

Rhaphiolepis indica (L.) Lindl. — Small tree in thin soil on rocky ground beside Popokvil Waterfall at 920 m, Middleton and Monyrak 619. Also reported by Tagane *et al.* (2017) as fairly common in moist evergreen forest on the plateau, and along the stream at higher elevations, around 933–1,043 m.

Rhaphiolepis mekongensis (Cardot) Tagane & H.Toyama — Tree, common in moist evergreen forest on the plateau.

Rubus rugosus Sm. — Woody creeper. Reported by Dy Phon (1970) from heathland areas.

Rubus rosaefolius S.Vidal — Woody subshrub. Heathland areas. Reported by Dy Phon (1970).

Sorbus corymbifera (Miq.) T.H.Nguyên & Yakovlev — Tree in stunted forest. Reported by Dy Phon (1970) as *Sorbus granulosa* (Bertol.) Rehder. Also reported by Tagane *et al.* (2017) as occasional in moist evergreen forest on the plateau, around 988–1,014 m.

Rubiaceae

Argostemma fasciculata Sridith & Larsen — Perennial herb, in mixed shrubby sclerophyllous montane forest rich in epiphytes (Sridith & Larsen, 2004). Endemic to Bokor.

Canthium cambodianum Pit. — Small tree, rare in moist evergreen forest on the plateau, around 970–1,014 m (Tagane *et al.*, 2017).

Chassalia curviflora (Wall.) Thwaites — Treelet in heathland areas. Reported by Dy Phon (1970). Also reported by Tagane *et al.* (2017) as a shrub, commonly and widely found in the understorey of evergreen forest from middle to high elevations.

Coelospermum truncatum (Wall.) Baill. ex K.Schum. — Woody climber, somewhat common at higher elevations, at forest edge along roadside, around 1,014 m (Tagane *et al.*, 2017).

Gaertnera sralensis (Pierre ex Pit.) Kerr — Shrub in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,053 m, Middleton and Monyrak 668. Also reported by Tagane *et al.* (2017) as fairly common in understorey of moist evergreen forest at higher elevations, around 1,014–1,043 m.

Gynochthodes sublanceolata Miq. — Climber, occasional in moist evergreen forest at higher elevations, around 970 m (Tagane *et al.*, 2017).

Hedyotis rosmarinifolia (Pit.) Craib — Herb with woody base in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,065 m, Middleton and Monyrak 580. Also listed by Rundel *et al.* (2003).

Hedyotis scandens Roxb. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Ixora brunonis Wall. ex G.Don subsp. *kratensis* (Craib) Chamch. — Shrub, somewhat common in understorey of moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Ixora villosa Roxb. var. *chevalieri* Pit. — Shrub in stunted evergreen sclerophyllous forest along edge of track on plateau at 989 m, Middleton and Monyrak 594.

Lasianthus cambodianus Pit. — Shrub, occasional in moist evergreen forest at higher elevations, around 935 m (Tagane *et al.*, 2017).

Lasianthus chinensis (Champ.) Benth. — Shrub, occasional in moist evergreen forest and its vicinity, around 960–1,014 m (Tagane *et al.*, 2017).

Lasianthus chrysoneurus (Korth.) Miq. — Shrub in understorey of stunted forest. Reported by Dy Phon (1970) as *Lasianthus hoaensis* Pierre ex Pit. Tagane *et al.* (2017) record this only at upper middle elevations.

Lasianthus curtisii King & Gamble. — Shrub occasional at higher elevations around 928 m (Tagane *et al.*, 2017).

Lasianthus fordii Hance. — Shrub, common in understorey of evergreen forest at higher elevations, around 962 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Lasianthus kamputensis* Pierre ex Pit.

Lasianthus giganteus Naiki — Treelet in moist evergreen forest, locally abundant near Popokvil sphagnum bog at 960 m (Tagane *et al.*, 2017).

Lasianthus hirsutus (Roxb.) Merr. — Shrub, commonly and widely found from stunted to high elevations, around 970–1,014 m (Tagane *et al.*, 2017).

Lasianthus inodorus Blume — Shrub, occasional at higher elevations, around 935 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Lasianthus poilanei* Pit.

Lasianthus sp. — Shrub, occasional at higher elevations, around 941–970 m. Reported as "*Lasianthus* sp. 3" by Tagane *et al.* (2017).

Mussaenda cambodiana Pierre ex Pit. — Climber, common at the margin of evergreen forest in middle to high elevations, around 930–1,043 m (Tagane *et al.*, 2017). Probably the same as Middleton and Monyrak 672 from sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,057 m.

Oldenlandia tenelliflora (Blume) Kuntze — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970) as *Borreria stricta* (L.f.) K.Schum.

Ophiorrhiza sanguinea Blume — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970)

Pavetta graciliflora Wall. ex Ridl. — Shrub to small tree, common in moist evergreen forest and its margin at higher elevations, around 940–1,014 m (Tagane *et al.*, 2017).

Prismatomeris tetrandra (Roxb.) K.Schum. subsp. *tetrandra* — Small tree, somewhat common and widely found in evergreen forest, around 970 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Prismatomeris albidiflora* Thwaites.

Psychotria asiatica L. — Shrub, occasional in evergreen forest and its vicinity at higher elevations, around 960 m (Tagane *et al.*, 2017).

Psychotria sarmentosa Blume var. *membranacea* (Pit.) P.H.Hô — Climber, scattered in moist evergreen forest at higher elevations, around 1,014 m (Tagane *et al.*, 2017).

Psychotria serpens L. — Climber, occasional in moist evergreen forest at higher elevations, around 974–1,043 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970).

Psychotria sp. — Treelet in stunted forest on sandy soil beside track on way to Popokvil Waterfall at 1,000 m, Middleton and Monyrak 653.

Psydrax sp. — Climber, occasional in moist evergreen forest at higher elevations, around 1,014 m (Tagane *et al.*, 2017).

Tarenna quocensis Pit. — Shrub to small tree, occasionally found in middle to high elevations (Tagane *et al.*, 2017).

N.B. The Rubiaceae is a particularly large and difficult family. Further study is necessary to ensure the same species concepts are used by each author.

Rutaceae

Acronychia pedunculata (L.) Miq. — Shrub or treelet in sclerophyllous stunted forest on rocky sandy soil near field station, at the top of the plateau at 1,042 m, Middleton and Monyrak 609, 667. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest at higher elevations, around 1,014–1,043 m .

Melicope lunu-ankenda (Gaertn.) T.G.Hartley — Tree, locally common in moist evergreen forest on the plateau at 928 m (Tagane *et al.*, 2017). This appears to be what was reported by Dy Phon (1970) as *Euodia triphylla* (Lam.) DC., although Tagane *et al.* (2017) also report another species, *Melicope pteleifolia* (Champ. ex Benth.) T.G.Hartley, in the upper montane forest.

Salicaceae

Casearia grewiifolia Vent. var. *grewiifolia* — Small tree, rare in moist evergreen forest and its margin on the plateau at 970 m (Tagane *et al.*, 2017).

Homalium cochinchinensis (Lour.) Druce — Small tree, locally common in moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Santalaceae

Dendrotrophe varians (Blume) Miq. — Woody climbing root parasite in moist evergreen forest at higher elevations, around 1,014 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) from heathland areas.

Sapindaceae

Guioa diplopetala (Hassk.) Radlk. — Treelet on sandy soil in high rainfall area in stunted forest beside inundated area on way to Popokvil Waterfall at 936 m, Middleton and Monyrak 631. Also reported by Tagane *et al.* (2017) as common in moist evergreen forest on the plateau at 1,014 m.

Mischocarpus pentapetalus (Roxb.) Radlk. — Tree, commonly found in middle to high elevations, around 970–1,043 m (Tagane *et al.*, 2017).

Mischocarpus sundaicus Blume — Tree, occasional at higher elevations, around 935 m (Tagane *et al.*, 2017).

Nephelium hypoleucum Kurz — Tree in stunted forest on sandy soil beside track on way to Popokvil Waterfall at 1,000 m, Middleton and Monyrak 649. Also reported by Tagane *et al.* (2017) as common in evergreen forest at 970 m.

Schisandraceae

Illicium cambodianum Hance — Small tree, common in moist evergreen forest at higher elevations, around 935–1,043 m (Tagane *et al.*, 2017).

Illicium griffithii Hook.f. & Thomson — Treelet to 1.5 m in heathland areas. Reported by Dy Phon (1970). This may be the same as *Illicium tenuifolium* (Ridl.) A.C.Sm., a locally common shrub in moist evergreen forest in upper middle elevations reported by Tagane *et al.* (2017).

Schoepfiaceae

Schoepfia fragrans Wall. — Small tree, scattered in moist evergreen forest on the plateau, around 1,014–1,043 m (Tagane *et al.*, 2017).

Smilacaceae

Heterosmilax paniculata Gagnep. — Climber, common in evergreen forest from middle to high elevations (Tagane *et al.*, 2017).

Smilax cambodiana Gagnep. — Semi-woody climber. Reported by Dy Phon (1970) from stunted forest areas.

Smilax corbularia Kunth subsp. *corbularia* — Climber, common in moist evergreen forest on the plateau, around 941–1,043 m (Tagane *et al.*, 2017).

Smilax davidiana A.DC. — Climber on sandy soil in scrubland near the top of the plateau at 1,056 m, Middleton and Monyrak 601.

Smilax glabra Roxb. — Climber, common in moist evergreen forest at higher elevations, around 991–1,014 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) from heathland areas.

Smilax inversa T.Koyama — Climber, rare in moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017).

Smilax lanceifolia Roxb. — Climber, common in moist evergreen forest and its vicinity on the plateau, around 975–1,014 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) from heathland areas.

N.B. The genus *Smilax* is diverse at Bokor and deserving of more detailed study. Tagane *et al.* (2017) report four undescribed species, including two that occur on the plateau.

Stemonuraceae

Gomphandra cambodiana Pierre ex Gagnep. — Tree, occasional in evergreen forest at higher elevations, around 935 m (Tagane *et al.*, 2017).

Symplocaceae

Symplocos caudata Wall. ex G.Don — Small tree, occasional in moist evergreen forest at middle and high elevations, 975–1,014 m (Tagane *et al.*, 2017).

Symplocos theifolia D.Don — Small tree, occasional in evergreen forest from middle to high elevations (Tagane *et al.*, 2017). This species was reported as *Symplocos lucida* (Thunb.) Siebold & Zucc. by Nooteboom & Vidal (1977) but that is an illegitimate name.

Theaceae

Schima wallichii (DC.) Korth. — Shrub to small tree in stunted forest on sandy soil near summit on roadside towards research centre, 936–1,060 m, Middleton and Monyrak 633, 648. 675. Tagane *et al.* (2017) and Dy Phon (1970) treat this as *Schima crenata* Korth., a name considered to be a synonym in the Flora of Thailand.

Thymeleaceae

Eriosolena composita (L.f.) Tiegh. — Shrub or tree, occasional in edge of moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017). Reported by Dy Phon (1970) as *Daphne composita* (L.f.) Gilg.

Wikstroemia bokorensis E.Oguri & Tagane, ined. — Shrub, rare in edge of moist evergreen forest on the plateau at 1,014 m (Tagane *et al.*, 2017). Presumably endemic to Bokor.

Wikstroemia longifolia Lecomte — Shrub, occasional in edge of moist evergreen forest on the plateau, 963–1,014 m (Tagane *et al.*, 2017).

Verbenaceae

Lantana camara L. — Stunted woody subshrub along roadsides in heathland area. Reported by Dy Phon (1970). Naturalized non-native.

Vitaceae

Cayratia japonica (Thunb.) Gagnep. var. *mollis* (Wall. ex M.A.Lawson) Momiy. — Herbaceous climber, common along edge of evergreen forest in middle elevation at 970 m (Tagane *et al.*, 2017).

Tetrastigma ramentaceum Planch. — Semi-woody climber, somewhat common in moist evergreen forest on the plateau, 970–1,063 m (Tagane *et al.*, 2017). Reported by Dy Phon from heathland and stunted forest areas.

Xyridaceae

Xyris complanata R.Br. — Herbaceous perennial in open wetlands and bogs. Reported by Dy Phon (1970) and Rundel *et al.* (2003).

Zingiberaceae

Alpinia oxyphylla Miq. — Rare herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Amomum repoeense Pierre ex Gagnep. — Herbaceous perennial in stunted forest. Reported by Dy Phon (1970).

Globba bokorensis Nob.Tanaka & Tagane — Herbaceous perennial, occasional in open Sphagnum bog and semi-shaded moist evergreen forests on the plateau, often epiphytic on trunk and rocks (Tanaka *et al.*, 2015). Endemic to Bokor.

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Status and conservation significance of ground-dwelling mammals in the Cardamom Rainforest Landscape, southwestern Cambodia

Thomas N.E. GRAY[1,*], Andrew BILLINGSLEY[2], Brian CRUDGE[3], Jackson L. FRECHETTE[4], Romica GROSU[1], Vanessa HERRANZ-MUÑOZ[5], Jeremy HOLDEN[4], KEO Omaliss[7], KONG Kimsreng[6], David MACDONALD[8], NEANG Thy[6], OU Ratanak[6], PHAN Channa[6,8] & SIM Sovannarun[3,9]

[1] Wildlife Alliance, No. 86, Street 123, Toul Tompong, Chamkarmorn, Phnom Penh, Cambodia.

[2] Conservation International – Greater Mekong Program, 4th floor, Building B1, Phnom Penh Center, Sihanouk Boulevard, Tonle Bassac, Chamkarmorn, Phnom Penh, Cambodia.

[3] Free the Bears Fund Inc., PO Box 723, Phnom Penh, Cambodia.

[4] Fauna & Flora International, No. 19, Street 360, Boeung Keng Kang 1, Phnom Penh, Cambodia.

[5] Bastet Conservation, No. 143, Street 105, Toul Tompong, Chamkarmorn, Phnom Penh, Cambodia.

[6] Ministry of Environment, Morodok Techo Building, Chaktomuk, Daun Penh, Phnom Penh, Cambodia.

[7] Forestry Administration, Ministry of Agriculture Forestry and Fisheries, No. 40, Preah Norodom Boulevard, Phnom Penh, Cambodia.

[8] Wildlife Conservation Research Unit, Department of Zoology, University of Oxford, The Recanati-Kaplan Centre, Tubney House, Tubney, Oxon OX13 5QL, England.

[9] Royal University of Phnom Penh, Confederation of Russia Boulevard, Toul Kork, Phnom Penh, Cambodia.

* Corresponding author. Email gray@wildlifealliance.org

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មូលន័យសង្ខេប

តំបន់ទេសភាពព្រៃរងទឹកភ្លៀងជួរភ្នំក្រវាញមានទំហំ១៧.០០០គម២ ដែលជាតំបន់ការពារទេសភាពស្ថិតនៅភាគនិរតីនៃប្រទេសកម្ពុជា ដែលមានរយៈកម្ពស់ចាប់ពីកម្ពស់នីវ៉ូសមុទ្រ រហូតដល់ជាង ១.៧០០ម។ ទោះបីជា តំបន់ទេសភាពនេះមានតម្លៃផ្នែកអភិរក្សក៏ដោយ ក៏ថ្មីៗនេះមានព័ត៌មានតិចតួចនៅឡើយត្រូវបានបោះពុម្ពស្តីពីស្ថានភាពនិងសារៈសំខាន់នៃការអភិរក្សប៉ូពុយឡាស្យុងថនិកសត្វគោក។ យើងរាយការណ៍លទ្ធផលការសិក្សាដោយម៉ាស៊ីនថតស្វ័យប្រវត្តិចំនួនប្រាំពីរនៅក្នុងប្រាំតំបន់ការពារផ្សេងៗគ្នានៅក្នុងតំបន់ទេសភាពទាំងមូល រវាងឆ្នាំ២០១២និង២០១៦ ដែលមាន ២៥៥ ទីតាំងម៉ាស៊ីនថតស្វ័យប្រវត្តិនិងត្រូវជាជាង៣០.០០០ អន្ទាក់យប់។ យ៉ាងតិចណាស់ថនិកសត្វគោក ៣០ប្រភេទ ពីមាឧមធ្យមទៅធំត្រូវបានកត់ត្រា ក្នុងនោះមានមួយប្រភេទត្រូវបានចុះក្នុងបញ្ជីក្រហមរបស់អង្គការ IUCNជាប្រភេទជិតផុតពូជធ្ងន់ធ្ងរ ពីរប្រភេទជិតផុតពូជ ប្រាំបីប្រភេទងាយរងគ្រោះនិងបីប្រភេទជិតរងគ្រោះជាសកល។ ខ្លាឃ្មុំតូច *Helarctos malayanus* ខ្លាពពក *Neofelis nebulosa* និងឆ្កែព្រៃ *Cuon alpinus* ត្រូវបានកត់ត្រាប្រាំមួយដងឬច្រើនជាងនេះ នៅក្នុងអំឡុងពេលសិក្សាចំនួនប្រាំពីរដង។ ទោះបីជាប៉ូពុយឡាស្យុងនៃប្រភេទទាំងបីនេះនៅទាបជាងសមត្ថភាព

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ទ្រទ្រង់នៃអេកូឡូស៊ីក្នុងតំបន់ក៏ដោយ ក៏ពួកវាមានសារៈសំខាន់ណាស់នៅក្នុងតំបន់ទាំងមូល។ ទោះជាយ៉ាងណាក៏ដោយ គ្មានម៉ាស៊ីនថតស្វ័យប្រវត្តិទីតាំងណាមួយបានកត់ត្រានូវពពួកខ្លា *Panthera* នោះទេ នេះបង្ហាញថាប្រភេទខ្លាធំនិងខ្លារខិនទំនងជាផុតពូជនៅក្នុងតំបន់នេះទៅហើយ។ លើកលែងតែខ្លាពីរប្រភេទនេះចេញ និង ប្រភេទសត្វពាហនៈមានក្រចក (ungulates) ដែលជាអ្នកឯកទេសនៅក្នុងព្រៃរបោះ ប្រភេទថនិកសត្វគោករងការគំរាមកំហែងក្នុងបញ្ជីក្រហមរបស់អង្គការ IUCN និងថនិកសត្វទឹកសាបទំនងជាមានវត្តមានក្នុងតំបន់ទេសភាពព្រៃរងទឹកភ្លៀងជួរភ្នំក្រវាញ ដោយពួកវាត្រូវបានឃើញតាមរយៈម៉ាស៊ីនថតស្វ័យប្រវត្តិនាពេលថ្មីៗនេះ។ ដូច្នេះជួរភ្នំក្រវាញមានសារៈសំខាន់ណាស់សម្រាប់ការអភិរក្សជាសកល។ ផ្ទុយមកវិញ ការប្រមាញ់ជាពិសេសការដាក់អន្ទាក់ព្រមជាមួយនឹងការប្រើសត្វឆ្កែស្រុកជួយប្រមាញ់ក្នុងតំបន់ទេសភាពទំនងជាអាចធ្វើឲ្យមានការប៉ះពាល់យ៉ាងខ្លាំងលើតម្លៃផ្នែកអភិរក្សទាំងពេលបច្ចុប្បន្ននិងអនាគត។ ដើម្បីរក្សាឲ្យគង់វង្សនូវភាពចម្រុះនៃថនិកសត្វសំខាន់ៗបានគឺ តម្រូវឲ្យមានការផ្លាស់ប្តូរឲ្យប្រសើរឡើងនូវការទទួលខុសត្រូវទាំងរដ្ឋាភិបាលនិងសង្គមស៊ីវិលដើម្បីឆ្លើយតបទៅនឹងប្រភពនៃការបរបាញ់នេះ។

Abstract

The Cardamom Rainforest Landscape (CRL) is a 17,000 km^2 protected landscape in southwestern Cambodia spanning an elevation range from sea-level to above 1,700 m. Despite the conservation value of the landscape there is little recent published information on the status and conservation significance of the ground-dwelling mammal populations. We report on seven camera trap studies conducted in five protected areas across the landscape between 2012 and 2016 with 255 trap-stations and >30,000 trap-nights. At least 30 species of medium to large ground-dwelling mammals were detected including one species included on the IUCN Red List as Critically Endangered, two as Endangered, eight as Vulnerable, and three as Near Threatened. Sun bears *Helarctos malayanus*, mainland clouded leopards *Neofelis nebulosa*, and dholes *Cuon alpinus* were detected from six or more of the seven studies. Populations of these three species in the landscape, though below ecological carrying capacity, are regionally significant. However we did not detect any *Panthera* cats, confirming that tigers *P. tigris* and leopards *P. pardus* are likely to have been extirpated. With the exception of these two species, and deciduous dipterocarp forest specialist ungulates, all globally threatened ground-dwelling and freshwater mammals likely to occur in the CRL have been detected in recent camera trapping surveys. The Cardamoms are thus of global conservation significance. However, poaching, particularly snaring, combined with the presence of domestic dogs across the landscape is likely to be impacting current and future conservation value strongly. The persistence of significant mammalian biodiversity requires a paradigm shift in both governmental and civil society responses to the drivers of poaching.

Keywords

Asian elephant, by-catch, camera trap, protected area, snare, small carnivore.

Introduction

The Cardamom Rainforest Landscape (CRL) is a conservation landscape covering >17,000 km^2 of protected areas in the southwestern Cambodian provinces of Koh Kong, Pursat, Kompong Speu, Preah Sihanouk, Battambang, and Kompong Chhnang (Table 1; Fig. 1). The landscape spans a large elevation range from sea level to the peak of Phnom Aural—at >1,700 m Cambodia's highest mountain—and consequently a diversity of habitat types from mangroves and lowland rainforest to limited areas of montane cloud forest. The CRL forms part of a larger conservation landscape in southern and western Cambodia with 12 largely contiguous protected areas, from Bokor National Park to Samlaut Multiple Use Area, covering 20,680 km^2. Since April 2016, the management of all protected areas in the landscapes has been under the General Department of Administration for Nature Conservation and Protection of the Ministry of Environment (MoE) (Souter *et al.*, 2016). A number of international conservation NGOs, including Wildlife Alliance, Fauna & Flora International, and Conservation International, are active in some of the protected areas in the CRL, supporting the MoE with protected area management, law enforcement, biodiversity monitoring, and conservation outreach and community development activities. Nevertheless, despite the presence of conservation activities in the landscape and presumed significance for biodiversity, little has been published on the conservation status of the landscape's mammals since pioneering surveys conducted at the turn of the century (e.g., Boonratana, 1999; Daltry & Momberg, 2000; Daltry & Traeholt, 2003; but see Holden & Neang, 2009; Royan, 2010; Coudrat *et al.*, 2011). The aim of this paper is to provide a compilation of recent (post 2012) camera trapping data from the landscape in order to provide an update on the status, and conservation significance, of the CRL's ground-dwelling mammals.

Methods

We collated data from seven discrete systematic camera trap studies conducted between 2012 and 2016 within five of the protected areas in the CRL (Table 2). Whilst camera trapping occurred in the landscape prior to this, 2012 was chosen as a start date for our analysis because data during the study period (2012–2016) were available to the authors and did not require significant additional analysis. All of the studies deployed at least 10 camera trap stations within clearly defined survey areas of between 10 and 200 km^2. Camera trapping on Phnom Dalai (site A; Fig. 1) was part of a monitoring programme for Asian elephant *Elephas maximus* conducted between 2010 and 2013; however we only use data from this site from between February 2012 and March 2013. Results from a camera trapping study in Peam Krasaop Wildlife Sanctuary between January and May 2015, which detected a number of threatened species, are being published separately (Thaung *et al.*, unpublished data). All of the studies had different objectives (Table 2), used

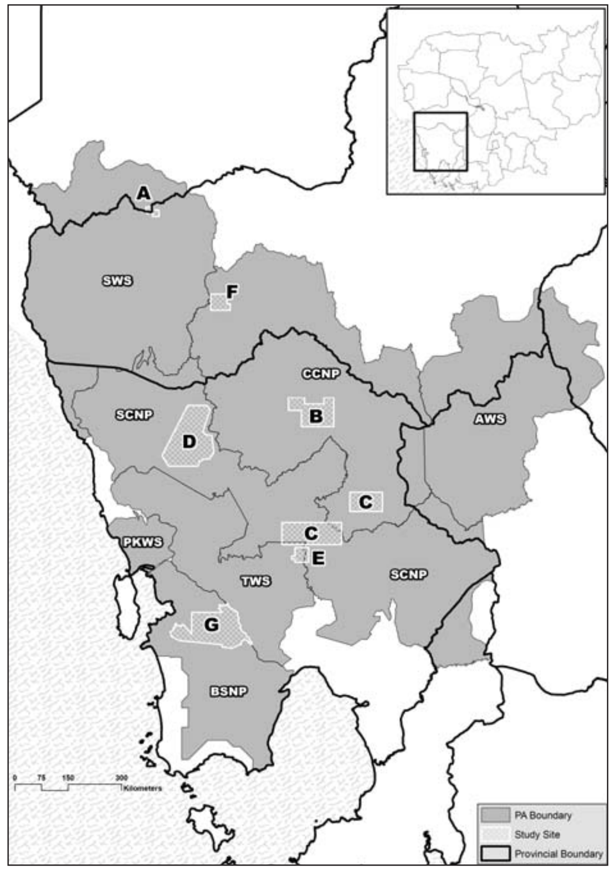

Fig. 1 Protected areas and locations of camera-trap studies within the Cardamom Rainforest Landscape, southwestern Cambodia. Abbreviations are given in Table 1 and individual letters refer to studies detailed in Table 2.

Table 1 Protected areas of the Cardamom Rainforest Landscape, southwestern Cambodia.

Protected Area	Size (km^2)	Elevation range (m a.s.l.)	% deforestation 2000–2015[1]	% Economic Land Concession[2]
Southern Cardamom National Park (SCNP)	4,104	10–980	2.7	0.3
Central Cardamom National Park (CCNP)	4,013	20–1,540	1.2	0
Phnom Samkos Wildlife Sanctuary (SWS)	3,338	10–1,717	8.2	2.3
Phnom Aural Wildlife Sanctuary (AWS)	2,538	60–1,740	8.6	20.2
Botum Sakor National Park (BSNP)	1,472	0–420	15.2	36.9
Tatai Wildlife Sanctuary (TWS)	1,443	10–520	3.1	0.5
Peam Krasop Wildlife Sanctuary (PKWS)	238	0–240	5.7	0

[1] Estimated following Hansen *et al.* (2013).

[2] From datasets held by the Ministry of Agriculture, Forestry and Fisheries and the Ministry of Environment.

Table 2 Camera trap studies in the Cardamom Rainforest Landscape (2012–2016) included in this paper. NP = National Park; WS = Wildlife Sanctuary. Figures for survey area and elevation are approximate.

Study	Protected area	Dates	Locations & trap-nights	Survey area (km^2)	Elevation range (m)	Methodology & target species
A[1]	Phnom Dalai, Phnom Samkos WS	February 2012–March 2013	13 & 3,923	10	540–1,040	Asian elephant-targeted camera trapping with locations chosen to maximise detection of elephants
B[2]	Central Cardamom NP	December 2012–March 2013	81 pairs & 8,152	95	460–1,220	Camera trap grid for clouded leopard capture-mark-recapture with cameras set as pairs in locations to maximise clouded leopard detections.
C[3]	Central Cardamom NP	June 2015–June 2016	31 & 4,599	185	100–820	Approximate grid formation with cameras set at locations to maximise detections of large mammals.
D[4]	Southern Cardamom NP	December 2015–June 2016	67 & 8,236	200	105–620	Random grid with cameras set within 50 m of predetermined random points.
E[5]	Tatai WS	March–May 2016	14 & 969	20	140–440	Approximate grid formation with cameras targeting bears.
F[5]	Central Cardamom NP	March–May 2016	14 & 865	30	540–660	Approximate grid formation with cameras targeting bears.
G[3]	JW Concession, Botum Sakor NP	August–December 2016	35 & 3,425	180	10–380	Approximate grid formation with cameras set along trails (50%) and at random locations (50%).

Organisations leading data collection: [1] Fauna & Flora International; [2] Wildlife Conservation Research Unit; [3] Conservation International; [4] Wildlife Alliance; [5] Free the Bears. All work was done with the support of the Royal Government of Cambodia.

different methodologies, equipment, and survey teams. As such, their results are not directly comparable. Nevertheless they provide a useful summary of the current status of the ground-dwelling large mammal community across the landscape.

For every camera trap study we extracted records of all mammals detected excluding Scandentia (tree-shrews) and Rodentia apart from the two species of Hysticidae (Malayan porcupine *Hystrix brachyura* and Asiatic brush-tailed porcupine *Atherurus macrourus*). All records of primates were retained. Throughout the paper the taxonomy and nomenclature of IUCN (2016) is used. All photographs were verified for identification by three authors (TNEG, VHM, PC) with experience of camera trapping in the region. However, as many regional studies have shown (e.g., Hla Naing *et al.*, 2015), this approach is not foolproof and misidentifications may be present in the dataset. Images in which identifications were not possible (~6% of all encounters with 'mammals') were excluded. The percentage of functioning (>20 nights of usable photographs) camera trap stations in each study from which each species was recorded was then calculated. We subsequently refer to this metric as 'trap-prevalence'. For each camera trap site we also calculated a camera trap encounter rate (i.e. the number of photographic events per 100 trap-nights) for each species.

Results

Between February 2012 and December 2016, the seven studies generated data from 255 camera trap stations deployed for 30,169 trap-nights across approximately 720 km^2 of the CRL (Table 2). At least 30 species of mammal were detected including one listed as Critically Endangered (Sunda pangolin *Manis javanica*), two as Endangered (Asian elephant *Elephas maximus*, dhole *Cuon alpinus*), eight as Vulnerable, and three as Near Threatened (Table 3). Seven species were detected from

Table 3 IUCN status (CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened, LC = Least Concern), trap-prevalence (% of functioning camera traps recorded from) and camera trap encounter rate (number of photographic events per 100 trap-nights) of ground-dwelling mammals across seven camera trap studies in the Cardamom Rainforest Landscape, southwestern Cambodia (2012–2016). Study sites are identified in Table 2.

Species	IUCN status	Study sites						
		A	B	C	D	E	F	G
Northern pig-tailed macaque *Macaca leonina*	VU	100 / 6.4	27 / 0.4	35 / 0.5	38 / 0.7	36 / 1.3	64 / 3.4	51 / 0.7
Nicobar crab-eating macaque *Macaca fascicularis*	LC		1 / <0.1				7 / 0.9	3 / <0.1
Sunda pangolin *Manis javanica*	CR				17 / 0.1			3 / <0.1
Malayan porcupine *Hystrix brachyura*	LC	77 / 2.1	1 / <0.1	16 / 0.2	15 / 0.4	21 / 0.7	7 / 0.3	14 / 0.9
Asiatic brush-tailed porcupine *Atherurus macrourus*	LC		37 / 1.1	35 / 0.6	50 / 1.9	21 / 0.1	7 / 0.1	20 / 1.8
Dhole *Cuon alpinus*	EN	77 / 0.4	32 / 0.5	26 / 0.2	21 / 0.4		14 / 0.5	23 / 0.4
Sun bear *Helarctos malayanus*	VU	38 / 0.2	26 / 0.4	19 / 0.2	29 / 0.3	21 / 0.7	14 / 0.3	11 / 0.3
Asiatic black bear *Ursus thibetanus*	VU	54 / 0.2	1 / <0.1		2 / <0.1			
Yellow-bellied weasel *Mustela kathiah*	LC		4 / <0.1					
Crab-eating mongoose *Herpestes urva*	LC	62 / 1.5	17 / 0.2		6 / <0.1			3 / <0.1
Yellow-throated marten *Martes flavigula*	LC	8 / <0.1	36 / 0.8	6 / 0.1	2 /<0.1		21 / 0.4	
Ferret-badger *Melogale* sp.	LC	8 / <0.1						
Greater hog badger *Arctonyx collaris*	VU	77 / 0.6	4 / <0.1	3 / <0.1	2 / <0.1			34 / 0.9
Binturong *Arctictis binturong*	VU		2 / <0.1					
Common palm civet *Paradoxurus hermaphroditus*	LC	54 / 1.0	47 / 1.3	71 / 0.8	83 / 4.0	50 / 1.2	71 / 4.7	74 / 5.8
Masked palm civet *Paguma larvata*	LC		4 / <0.1					
Spotted linsang *Prionodon pardicolor*	LC		4 / <0.1					
Large Indian Civet *Viverra zibetha*	LC	69 / 2.1	58 / 2.0	13 / 0.1	6 / 0.1		7 / 0.3	
Small Indian civet *Viverricula indica*	LC						7 / 0.1	3 / <0.1
Spotted linsang *Prionodon pardicolor*	LC		4 / <0.1					
Clouded leopard *Neofelis nebulosa*	VU	31 / 0.3	14 / 0.1	3 / <0.1	9 / 0.1		7 / 0.1	9 /<0.1
Asiatic golden cat *Catopuma temminckii*	NT		14 / 0.2		6 /<0.1	7 / 0.1		
Marbled cat *Pardofelis marmorata*	NT		23 / 0.3	3 /<0.1	11 / 0.1		14 / 0.2	
Leopard cat *Prionailurus bengalensis*	LC	38 / 0.3	36 / 0.7	39 / 0.3	35 / 0.9			43 / 0.7
Asian elephant *Elephas maximus*	EN	85 / 1.9		19 / 0.2		29 / 0.7		
Wild pig *Sus scrofa*	LC	100 / 27.6	57 / 1.5	58 / 0.7	39 / 2.7	29 / 1.0	57 / 6.4	37 / 1.4
Lesser Oriental chevrotain *Tragulus kanchil*	LC	23 /<0.1	41 /2.0	65 / 0.6	68 / 5.6	7 / 0.4	43 / 0.8	63 / 3.9
Sambar *Rusa unicolor*	VU		10 / 0.2	10 / 0.1	11 / 0.4	14 / 0.5	7 / 0.2	
Northern red muntjac *Muntiacus muntjak*	LC	100 / 26.9	78 / 3.7	61 / 0.9	58 / 1.8	36 / 1.3	50 / 2.1	49 / 1.6
Chinese serow *Capricornis milneedwardsii*	NT	8 / 0/6	10 / 0.1	3 / <0.1	15 / 0.7			
Gaur *Bos gaurus*	VU	85 / 11.0		6 / <0.1			7 / 0.1	

all studies including northern pig-tailed macaque *Macaca leonina*, sun bear *Helarctos malayanus* (both listed as Vulnerable), lesser Oriental chevrotain *Tragulus kanchil*, and northern red muntjac *Muntaicus vaginalis*. Mean trap prevalence varied from 64% for common palm civet *Paradoxurus hermaphroditus* to <0.5% (i.e. detected from a single camera trap location) for ferret badger *Melogale* sp.

Discussion

Few places in tropical Asia support a near-intact mammal species complement (Wilcove *et al*., 2013) and our camera trap records confirm that the Cardamom Rainforest Landscape (CRL) is one such region. Rhinoceroses (Rhinocerotidae) have been extinct in Cambodia since at least the 1980s and the last record of tiger *Panthera tigris* from the country was in 2007 (Gray *et al*., 2012). Nevertheless we present records of 11 globally threatened species and the CRL remains nationally and regionally significant for large mammal conservation. Although significant portions of the landscape were unprotected prior to the creation of the 4,100 km^2 Southern Cardamom National Park in May 2016, the CRL appears to have avoided the ecological extirpation of many medium to large mammals that has occurred due to hunting in many other protected landscapes in Indochina (Wilcox *et al*., 2014; Harrison *et al*., 2016). Almost all of the studies detected mainland clouded leopards *Neofelis nebulosa* (6 out of 7 studies; Fig. 2), dholes *Cuon alpinus* (6 out of 7; Fig. 2), and sun bears *Helarctos malayanus* (7 out of 7), which demonstrates that habitat quality and prey base remain reasonable within the CRL and that the pervasive snaring, which is impacting much of Southeast Asia (Gray *et al*., 2017), has yet to drive massive declines in the populations of these moderately hunting-sensitive species.

We present camera trapping data in two forms: trap prevalence and encounter rate. However these metrics are unlikely to be directly correlated with species abundance or density. The term 'Relative Abundance Index' (*sensu* O'Brien *et al*., 2003) for camera trap encounter rates is highly misleading and is increasingly regarded as a meaningless measures of species abundance or status (Sollmann *et al*., 2013; Burton *et al*., 2015). We therefore recommend trap-prevalence and encounter rate be used as the terms to report by-catch information from camera trap studies when more robust methodologies to account for non-detection (e.g., Capture Mark Recapture: Gray & Prum, 2012; Occupancy: Gray, 2012; Random Encounter Model: Rowcliffe *et al*., 2008) are not employed. However, both trap-prevalence and encounter rate are likely to be biased. The former is likely a function of the size of the study area and, particularly, the duration of camera trap deployment and the latter by camera trap placement in relation to a species' daily movements amongst a myriad of other factors (Sollmann *et al*., 2013).

Status of selected species

The majority of the CRL comprises hilly evergreen forest and thus would have supported historically lower densities of ungulates and carnivores than the open deciduous dipterocarp forests of the northern and eastern plains (Gray *et al*., 2013). The landscape's largest mammalian predators, tiger and leopard *Panthera pardus*, are likely to have been extirpated. Neither species has ever been recorded by camera trap from the CRL (though tiger was camera trapped from the adjoining Bokor National Park between 2000 and 2004) whilst there are no confirmed 21st century records of leopard from the Cardamom Mountains. Reliable surveys in the early 2000s recorded tiger pug-marks in a small number of locations (Daltry & Momberg, 2000; J. Holden pers. obs.) but there have been no records since 2005.

With the exception of bears, the dhole therefore remains the largest carnivore present in the landscape, as indeed Boonratana (1999) speculated was the case as long ago as the late 1990s. Dholes still appear to be relatively widespread: detected from six of the seven studies but pack size appears low (<5; many photographs show single individuals). However Kawanishi & Sunquist (2008) suggested dholes persist in smaller packs in the evergreen forests of Southeast Asia than in the Indian subcontinent probably due to the low prey biomass and small size of ungulate prey. It is also unclear how effective camera trapping is for estimating group size of species in dense evergreen forest. Nevertheless, videos (e.g., from sites D and G; Fig. 1) often show an individual dhole limping, presumably as a result of snare injuries. It is possible that dhole numbers in the CRL are depressed due to a combination of accidental mortality from snaring, interactions with domestic dogs, and reduced prey densities: threats which impact the species across its Asian range (Kamler *et al*., 2015).

Although clouded leopards (Fig. 2) were detected in six of our studies, trap prevalence (10%) was lower than reported elsewhere in the species' range. For example, Tan *et al*. (2016) detected the species from 233 of 894 camera trap stations (trap-prevalence 26%) across nine sites in Peninsular Malaysia, with approximately 200 trap-nights required per clouded leopard photograph (compared to >750 trap-nights across our studies). This suggests that clouded leopard densities in the Cardamoms are likely to be below estimates from elsewhere in the species' range (e.g., between 2 and 5 individuals per

Fig. 2 Threatened and Near Threatened mammals in the Cardamom Rainforest Landscape. Clockwise from top-left: Asiatic golden cat *Catopuma temminckii* (site B, © WildCRU); Greater hog badger *Arctonyx collaris* (site G, © Wildlife Alliance); Marbled cat *Pardofelis marmorata* (site C, © Conservation International); Dhole *Cuon alpinus* (site G, © Wildlife Alliance); Chinese serow *Capricornis milneedwardsii (*site D, © Wildlife Alliance); Clouded leopard *Neofelis nebulosa* (site D, © Wildlife Alliance).

100 km^2: Borah *et al.*, 2014; Mohamad *et al.*, 2015). Nevertheless the species is absent or very rare across many areas in Indochina (Wilcox *et al.*, 2014) including much of Cambodia (e.g., Gray *et al.*, 2014). Thus, given the size of the landscape, and detections of clouded leopard relatively close to villages and National Road 48 (e.g., <6 km at site G; Fig. 1), the CRL still seems likely to support a regionally significant population of the species.

Asian elephants remain in the landscape with the species detected from three of the seven studies, plus additional ad-hoc camera trapping in the core of Botum Sakor National Park (58 'encounters' from five camera trap stations between December 2013–January 2014: Fauna & Flora International, unpublished data) and Tatai Wildlife Sanctuary (two camera trap locations between December 2014–March 2015: Wildlife Alliance, unpublished data). While Daltry & Traeholt (2003) reported strong local community support for Asian elephant conservation in the CRL, an estimated 38 individuals were poached between 2000 and 2004 (Gray *et al.*, 2016). However we believe poaching of elephant has been extremely limited in the landscape since 2006 and therefore elephant populations may be recovering with evidence of breeding (Gray *et al.*, 2016). Whilst population estimates and demographic data on the landscape's elephant population have yet to be collated or analysed, field data collection for a faecal DNA capture-mark-recapture study was conducted across the core of the landscape during the 2015–2016 dry season by Fauna & Flora International. A population estimate is expected during 2017. The second largest herbivore extant in the landscape, the gaur, was only recorded from three of the seven camera trap studies in the landscape and its population seems likely to be small and potentially fragmented. Sambar *Rusa unicolor* and Chinese serow *Capricornis milneedwardsii* were recorded slightly more widely, particularly in more remote areas, but detection levels were low. Nevertheless the CRL is likely to support the most nationally important populations of these two species, which are rarely detected in camera trap studies elsewhere in Cambodia (e.g., Phan *et al.*, 2010; Gray & Phan, 2012). Sambar are likely to have declined significantly throughout the country as much of Cambodia is suitable for the species (Timmins *et al.*, 2015). In contrast, mountainous habitat for Chinese serow (Fig. 2) is limited in Cambodia and the species is unlikely to have declined as precipitously. Nevertheless, recent camera trap records of serow appear restricted to the Cardamoms and Virachey National Park, where they were detected from 15 of 26 camera traps in 2014–2015 (G. McCann / HabitatID, pers. comm. 2017).

The status of small carnivores in the CRL warrants further research and more detailed analysis. The high trap-occupancy of the globally Vulnerable greater hog badger from Phnom Dalai (site A; Figs 1 & 2) and the JW Concession in Botum Sakor National Park (site G), at opposite ends of the range of elevations we camera trapped, is noteworthy. Only camera trapping in Virachey National Park, northeastern Cambodia (from 500–1,400 m. a.s.l., trap-occupancy 35% from 26 stations: McCann & Pawlowski, 2017) has detected the species as frequently in Cambodia in recent years. Believed to be highly susceptible to snaring (Duckworth *et al.*, 2016), the low number of detections of this species from the other sites is likely to reflect genuine declines driven by hunting. The JW Concession has the highest densities of patrol staff in the CRL (>8 per 100 km^2). Combined with a unique management status (as an Economic Land Concession for ecotourism with Wildlife Alliance providing technical support for law enforcement), and the surrounding forest areas in Botum Sakor National Park receiving only nominal protection, such patrol levels may mean illegal activity, particularly snaring, may be low by regional and even landscape levels. It is possible that these levels of enforcement, instituted in 2014, may have allowed the recovery of hog badger and not slower breeding species (e.g., sambar). Alternatively, the JW Concession may represent prime habitat for the species differing in some respect from the majority of the landscape.

Our higher elevation sites (A and B; Fig. 1) produced a wider variety of small carnivores including the first national record of yellow-bellied weasels *Mustela kathiah* (for more details see Phan *et al.*, 2014) and supporting the finding of Holden & Neang (2009) that masked palm civets *Paguma larvata*, spotted linsangs *Prionodon pardicolor*, and ferret-badgers *Melogale* sp. are present at higher elevations within the Cardamom Mountains. Large-spotted civets *Viverra megaspila* was not detected in any of our studies despite records from other studies in the landscape with considerably less effort. Royan (2010) reported a single camera trap photograph from Botum Sakor National Park in 2005, Timmins & Sechrest (2010) camera trapped two 'in the Andoung Teuk area' in 2008–2009, while the species has also been camera trapped around the Wildlife Release Station, Tatai Wildlife Sanctuary (N. Marx, pers. comm. 2017) and in areas of Central Cardamom National Park (Holden & Neang, 2009; Conservation International, unpublished data). Finally Thaung *et al.* (unpublished data) obtained 22 records from three of their six camera trap stations in and around Peam Krasaop Wildlife Sanctuary in 2015. Many of these sites are closer to villages and thus may experience higher hunting pressure than our study sites, making it appear unlikely that the absence of this species is due to hunting. The lack of large-spotted civet detections from the relatively well protected lowland and largely flat forests of the JW Concession (site G; Fig. 1) is perplexing. Large Indian civets *Viverra zibetha* were detected at more than 50% of camera trap stations in studies A and B (the two highest altitude sites) but only rarely elsewhere with no detections in studies E and G (Fig. 1). In sum, most of the survey areas did not record any *Viverra* at all despite recording a large complement of species conventionally considered to be more hunting sensitive than this genus. The reasons for the observed patterns of *Viverra* civet detections are unclear and may represent complex interactions involving the detectability of these species from large mammal focused camera trapping studies, hunting pressure, and habitat preferences.

The Critically Endangered Sunda pangolin *Manis javanica* was detected from two of the seven camera trap studies, both of which randomly deployed the cameras (sites D and G; Fig. 1). It is possible that detectability of pangolins from conventional large mammal focused camera trapping (in which cameras are often placed on trails, paths, water features etc.) may be very low and this would explain the paucity of records from camera trapping throughout tropical Asia. Sun bears *Helarctos malayanus* were detected from all camera trap studies and thus appears relatively widespread throughout the landscape. In contrast, the Asiatic black bear *Ursus thibetanus*, with only two records (at ~500 m a.s.l. at site D and ~800 m a.s.l. at site B; Fig. 1), was rarely detected away from Phnom Dalai (site A; Fig. 1) where the species was recorded by more than half of camera traps. This relatively high altitude site was the only study where Asiatic black bears were recorded more widely than sun bears.

The northern pig-tailed macaque was the most widely recorded globally threatened species (detected from all studies and on average from 50% of camera trap stations) and the CRL likely supports a large population. In Laos, Vietnam, and Myanmar, the species is predominantly associated with lowland forests below 500 m (Boonratana *et al.*, 2008). However, our study includes multiple records above this elevation in sites A and B (Fig. 1) and the species was found across the full range of elevations camera trapped. Our analysis also supports the assertion of Coudrat *et al.* (2011) that stump-tailed macaque *Macaca arctoides* may not occur in the CRL. All confirmed Cambodian records are from east of the Mekong and it seems possible that previous claims (e.g., Kong & Tan, 2002) and assertions of occurrence in southwestern Cambodia (e.g., Walston, 2001) may have been in error.

Our studies did not detect any otter species but targeted camera trapping in the landscape recorded both hairy-nosed otter *Lutra sumatrana* and smooth-coated otter *Lutrogale perspicillata* between 2006 and 2012 (Heng *et al.*, 2016). As far as we can ascertain there are no records of Eurasian otter *Lutra lutra* from Cambodia and also no reliable (c.f. Daltry & Momberg, 2000) records of Asian small-clawed otter *Aonyx cinereus* west of the Mekong in the country. There has been little camera trapping in remnant areas of deciduous dipterocarp forest or grassland in the CRL. However, Thaung *et al.* (unpublished data) recorded large-spotted civets (see above), hog deers *Hyelaphus* (*porcinus*) *annamiticus*, and Sunda pangolins *Manis javanica* from grassland–*Melaleuca*–mangrove mosaics around Peam Krasaop Wildlife Sanctuary in 2015 (six camera trap stations; 511 trap-nights). More effort in remnant areas of deciduous dipterocarp forest is required, but it seems unlikely that significant, if any, populations of dry forest specialist species (e.g., banteng *Bos javanicus*, Eld's deer *Rucervus eldii*, jungle cat *Felis chaus*, golden jackal *Canis aureus*, small Asian mongoose *Herpestes javanicus* and Burmese hare *Lepus peguensis*) remain in the landscape. The former two species and leopards are thus the only globally threatened terrestrial or freshwater mammals known to have occurred historically in Cambodia west of the Mekong, and still extant in the country, without recent (post 2012) camera trap records from the CRL.

Threats to Cardamom rainforest mammals

As is the case throughout Southeast Asia (Hughes, 2016) the mammal populations of the CRL are threatened by deforestation and hunting. Cambodia experienced the most rapid growth in deforestation rates globally between 2001 and 2014 (Petersen *et al.*, 2015) and approximately 1,150 km^2 of the CRL's protected areas have been lost to Economic Land Concessions for industrial agriculture (Table 1; Davis *et al.*, 2015). This deforestation has disproportionately impacted lowland deciduous dipterocarp forest, particularly in protected areas with limited NGO support for enforcement, and may have also isolated the core of Botum Sakor National Park from the rest of the landscape.

The widespread presence of domestic dogs in accessible areas (e.g., dogs were detected from 15 of 35 camera trap stations in site G; Fig. 1) is also an issue, particularly given the landscape's dhole population. Domestic dogs are a significant threat to wildlife through disease transmission, predation, and non-lethal effects (Silva-Rodríguez & Sieving, 2012; Hughes & Macdonald, 2013). Free-ranging domestic dogs in the landscape require lethal management and protected area management authorities should be given the authority to implement this.

Illegal commercial hunting, particularly snaring, remains the major threat to the CRL's ground-dwelling mammals and is likely to be impacting populations of most such species in the landscape (Gray *et al.*, 2017). For example, more than 109,000 snares were removed from the Southern Cardamom National Park and Tatai Wildlife Sanctuary between 2010 and 2015 (Wildlife Alliance, unpublished data) and law enforcement elsewhere in the landscape, with the notable exception of the JW Concession (see above), is minimal. This needs urgent attention through legislative reform criminalising the possession of materials used to construct snares and greater numbers of, and more efficient, protected area staff and rangers. It is hoped that the Natural Resource and Environmental Code of the MoE will sufficiently strengthen the Protected Area Law to ensure that snaring can be severely punished. Long-term social behaviour change communication, targeting the emotional and functional drivers of wild meat consumption in largely urban centres across Southeast Asia, is also critical. Any move to normalise wild meat consumption through wildlife farming needs to be strongly resisted given the potential for extremely negative impacts on biodiversity (Brooks *et al.*, 2010; Livingstone & Shepherd, 2016).

Despite the extirpation of some of Asia's largest and most charismatic species of large mammal (e.g., two species, presumably, of rhinoceros, leopard, and tiger), our camera trap records show that the CRL remains regionally significant for the conservation of medium to large ground-dwelling mammals. However without urgent strengthening of legislation and law enforcement to reduce levels of snaring, and concurrent allocation of conservation resources to effective results-based protected area management and enforcement (Gray *et al.*, 2016), many of these species may soon disappear from the landscape and the spectre of "empty forests" will be realised.

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The impact of shrimp farming on water quality in Anlung Pring, a protected landscape in Cambodia

YAV Net[1], SENG Kimhout[2,4], NHIM Sophea[3], CHEA Vannara[3], BOU Vorsak[1] & Tomos AVENT[5]

[1] BirdlIfe International–Cambodia Programme, No.2, Street 476, Sangkat Toul Tompong 1, Khan Chamkarmon, PO Box 2686, Phnom Penh, Cambodia.

[2] Forestry Administration, No. 40, Preah Norodom Boulevard, Phsar Kandal 2, Khann Daun Penh, Phnom Penh, Cambodia.

[3] Department of Hydrology and River Works, Ministry of Water Resources and Meteorology, No. 364, Monivong Boulevard, Phsa Demthkov, Chamkamon, Phnom Penh, Cambodia.

[4] Wildfowl & Wetlands Trust, No. 2, Street 476, Toul Tompung 1, Chamkarmon, Phnom Penh, Cambodia.

[5] Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire, GL2 7BT, United Kingdom.

* Corresponding author. Email yavnet2011@gmail.com

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មូលន័យសង្ខេប

តំបន់ដីសើមទឹកភ្លាវផ្តល់ជាទីជម្រកយ៉ាងសំខាន់សម្រាប់សត្វស្លាបទឹក និងប្រភេទជលជាតិផ្សេងៗទៀត ប៉ុន្តែនៅភាគខាងត្បូង នៃប្រទេសកម្ពុជា តំបន់នេះកំពុងទទួលរងនូវការគំរាមកំហែងកាន់តែខ្លាំងឡើងៗ ដោយសារការអភិវឌ្ឍន៍វារីវប្បកម្ម។ តំបន់ទឹកភ្លាវភាគច្រើននៅជុំវិញតំបន់ការពារទេសភាពអន្លង់ព្រីង ដែលមានទីតាំងភូមិសាស្ត្រស្ថិតនៅខេត្តកំពតត្រូវបានកែប្រែទៅជាកសិដ្ឋានចិញ្ចឹមបង្គាដែលផ្តល់នូវក្តីកង្វល់យ៉ាងខ្លាំងថា វានឹងអាចផ្តល់ផលប៉ះពាល់ដល់គុណភាពទឹកនៅក្នុងតំបន់អភិរក្ស។ ដើម្បីធ្វើការស៊ើបអង្កេតតាមដានពីបញ្ហានេះ យើងបានប្រមូលសំណាកទឹកចំនួន ៣ខែ (ខែមករា មីនា និងខែឧសភា ឆ្នាំ២០១៦) ពីប្រាំកន្លែងផ្សេងៗគ្នាទាំងក្នុង និងក្រៅតំបន់ការពារ ហើយធ្វើការវិភាគដើម្បីវាយតម្លៃគុណភាពទឹក និងផលប៉ះពាល់នៃទឹកសំណល់ ដែលត្រូវបានបញ្ចេញពីកសិដ្ឋានចិញ្ចឹមបង្គានៅក្បែរនោះ។ កម្រិតនៃចរន្ត (conductivity) កម្រិតល្អក់ (turbidity) សំណល់រឹងរលាយសរុប (TDS) ស៊ុលផាត (SO_4) អាម៉ូញ៉ូម (NH_4-N) គីមីសាស្ត្រមានតម្រូវការអុកស៊ីសែន (COD) និងជីវសាស្ត្រមានតម្រូវការអុកស៊ីសែន (BOD) មានកម្រិតខ្ពស់ជាងកម្រិតស្តង់ដារនៅតាមកន្លែងប្រមូលសំណាកជាច្រើន ជាពិសេសកន្លែងទាំងនោះស្ថិតនៅក្នុង និងក្បែរកសិដ្ឋានចិញ្ចឹមបង្គា។ ប៉ារ៉ាម៉ែត្របី (សំណល់រឹងរលាយសរុប គីមីសាស្ត្រ និងជីវសាស្ត្រដែលមានតម្រូវការអុកស៊ីសែន) គឺមានកម្រិតខ្ពស់ខ្លាំងនៅក្នុងកសិដ្ឋានចិញ្ចឹមបង្គាដែលត្រូវបានគិតថាជាមូលហេតុនៃការបំពុល។ កន្លែងសំណាកដែលប្រមូលនៅក្នុងតំបន់អភិរក្ស ប៉ុន្តែមានទឹកដាច់ដោយឡែកពីកសិដ្ឋានចិញ្ចឹមបង្គាបង្ហាញថា កម្រិតនៃប៉ារ៉ាម៉ែត្រនីមួយៗភាគច្រើនក្បែរ និងក្នុងកម្រិតស្តង់ដារចំពោះប៉ារ៉ាម៉ែត្រដូចគ្នា។ យើងសំណូមពររកដំណោះស្រាយ ដើម្បីកាត់បន្ថយផលប៉ះពាល់នៃកសិដ្ឋានចិញ្ចឹមបង្គាទៅលើគុណភាពទឹក និងទាមទារឱ្យធ្វើការសិក្សាស្រាវជ្រាវបន្ថែមទៀតអំពីកម្រិតនៃផលប៉ះពាល់លើប្រព័ន្ធអេកូឡូស៊ី។

Abstract

Estuaries provide a critically important habitat for waterbirds and other aquatic species, but in southern Cambodia they are increasingly threatened by aquaculture development. Much of the area around Anlung Pring Protected Landscape in Kampot Province has been converted to shrimp farming and there are concerns that these farms may negatively impact water quality inside the protected area. To investigate this, we collected water samples (in January, March and

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May, 2016) from five discrete locations inside and outside of the reserve and analyzed these to determine the effects of waste water from nearby shrimp farms on local water quality. Levels of conductivity, turbidity, total dissolved solids, sulphate, ammonium, chemical and biological oxygen demand were higher than recommended levels at many sampling points, especially those within and adjacent to the shrimp farms. Three parameters (coliforms, chemical and biological oxygen demand) were substantially higher within the shrimp farms, suggesting that they were the cause of this pollution. Sampling points that were in the reserve, but hydrologically isolated from shrimp farms, showed levels much closer to, and often within, recommended guidelines for the same parameters. We suggest that solutions to minimize the impact of shrimp farms on water quality, and further research on their ecological impact, are required.

Keywords

Water quality, shrimp farming, environmental impact.

Introduction

Estuaries are important ecosystems and provide critical habitat for waterbirds and other aquatic species. They are also excellent areas for aquaculture development (Hossain, 2001; Wouter & Patrick, 2003; Primavera, 2006) and land conversion for shrimp farming is a cause for environmental concern, especially in relation to water quality (Flaherty & Karnjanakesorn, 1995; Graslund & Bengtsson, 2001; Hossain, 2001; Jones *et al.*, 2001; Paezosuna *et al.*, 2003; Islam & Tanaka, 2004; Primavera, 2006; Crab *et al.*, 2007) and the subsequent potential for long-term damage to aquatic food webs (Kennish, 1997).

Many studies have reported significant environment degradation due to shrimp farming (Paezosuna *et al.*, 2003), including increased organic pollution (Bui *et al.*, 2012; Wilbers *et al.*, 2014), creation of favorable habitat for pathogenic microorganisms (Anh *et al.*, 2010), high nutrient waste (Bui *et al.*, 2012), increased phytoplankton productivity (Islam & Tanaka, 2004), removal of nutrients from culture water (Crab *et al.*, 2007), and decline of aquatic ecosystem health (Naylor *et al.*, 2000; Bui *et al.*, 2012). As a consequence, the Thai government has identified areas where shrimp farming is permitted and areas where it is banned (Flaherty *et al.*, 2000). Many shrimp farms have recently been developed along canals in coastal and inland areas in Cambodia and Vietnam (Anh *et al.*, 2010) and it is likely that these have caused dramatic declines in numbers of sarus cranes (*Grus antigone*) visiting Hon Chong in southern Vietnam (van Zalinge *et al.*, 2011). Water quality in Cambodia is protected by a sub-degree on pollution which was issued in 1999 (Royal Government of Cambodia, Sub-decree 27, 1999).

Anlung Pring Protected Landscape (APPL) is one of three protected non-breeding areas of the globally Endangered eastern sarus crane *G. a. sharpii* in Cambodia (Yav *et al.*, 2015). Most wetlands to the south of APPL have been converted to shrimp farming and the landscape has directly abutted one shrimp farm since 2013 (Yav, 2014). Concerns regarding the farms include the impact of water pollution on the wetland ecosystem of the area, especially as changes to water quality may affect growth of *Eleocharis* spp., which are the main food for the cranes (Yav, 2014; Yav *et al.*, 2015). Rigorous understanding of the influence of water waste discharged from shrimp farming is consequently required, especially regarding chemical substances that may affect the ecology of the wetland. This study consequently assessed water quality inside and outside of APPL and investigated the effects of shrimp farms on levels of pollutants entering the site.

Methods

Study site

APPL covers 217 ha in Kampong Trach District of Kampot Province (10°28′40′′N, 104°31′32′′E) in southern Cambodia, approximately one kilometre from the border with Vietnam within the lower Mekong floodplain (Fig. 1). The site is divided into two parts by a road embankment, and the northern part covers 33 ha and southern section 184 ha. As many as 342 sarus cranes foraged in the site in 2013 (Yav, 2014). The cranes mainly feed upon *Eleocharis* tubers and preferentially select areas where these occur (Yav *et al.*, 2015). The area also supports the livelihoods of surrounding communities through the provision of fire wood, wild food, tourism and livestock fodder (van Zalinge *et al.*, 2013)

The area of APPL is low-lying with an elevation range of 0.0–3.5 m above sea level and is next to a small river that experiences tidal influences, even though the site is approximately 20 km from the Gulf of Thailand (Yav *et al.*, 2015). The area around the southern section of APPL is dominated by shrimp farms, some of which are contiguous with the conservation area (Fig. 1). Waste water is regularly discharged from these shrimp farms into a canal which is influenced by tidal movements, allowing waste water to flow into the conservation area (Yav *et al.*, 2015). The eastern, northern and western sections of APPL are mainly surrounded by rice fields and settlements.

Sample collection

Water samples were collected from five discrete areas within APPL during the sarus crane feeding season on 11 January, 11 March and 16 May 2016 (Fig. 1). With the exception of one sampling area in the northern section of the reserve, all other sampling areas were hydrologically linked to the shrimp farms. The five areas comprised: 1) the northern part of the reserve (NPR), which is hydrologically separated from the rest of the reserve by an embankment and receives fresh water from northern uplands during the wet season; 2) canals inside the central section of the reserve (CIR); 3) the southern part of the reserve, which is adjacent to but separated by an embankment from the shrimp farms (SPR); 4) inside the shrimp farms (SF); and finally, 5) canals outside the reserve and adjacent to shrimp farms, which receive water from the farms and tidal flows (COR). Two points at least 200 m apart were sampled in each of the five areas every month, resulting in a total of 30 samples.

Samples were collected by filling containers with water taken from a depth of 30–50 cm (approximately the middle of the water column). Different containers were used to collect water for different analyses. Water for coliform analysis was collected in a 250 ml glass bottle, sterilized at 120°C. Water for biochemical oxygen demand tests was collected in a 1,000 ml glass bottle, filled with no air bubbles remaining. Water for total phosphorus, iron and chemical oxygen demand tests were collected in 500 ml polyethylene bottles and preserved with H_2SO_4. Water for other tests including pH, EC, turbidity, sulphate, ammonium, nitrate as nitrogen and nitrite-nitrogen were collected in 1,000 ml polyethylene bottles with no preservation. All samples were kept in ice boxes at temperatures of 4–6 °C.

Sample tests and data analysis

Samples were tested by the Department of Hydrology and River Works of the Ministry of Water Resources and Meteorology for pH, conductivity, turbidity, salinity, total dissolved solids (TDS), sulphate (SO_4), ammonium (NH_4-N), nitrate as nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), total phosphorus (TP), iron (Fe), coliforms, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and aluminum (Al).

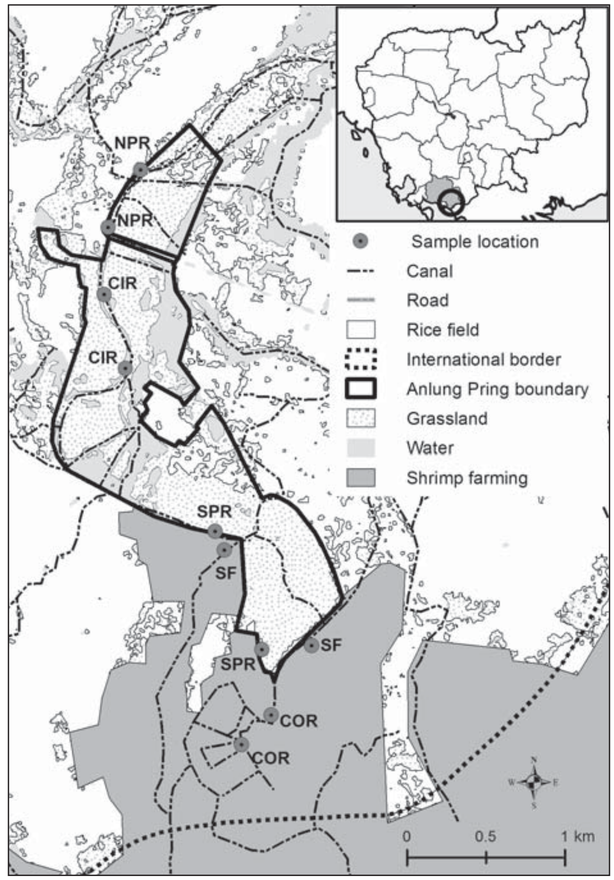

Fig. 1 Locations of water sampling at Anlung Pring Protected Landscape, Kampot Province. SF = shrimp farm, COR = canal outside reserve, SPR = southern part of reserve, CIR = canals inside reserve, NPR = northern part of reserve.

The mean values from the three sampling events at each sample location were calculated. Data normality was tested using one-sample Kolmogorov-Smirnov tests and Shapiro-Wilk tests (Dytham, 2011; Stowell, 2014). A one-way analysis of variance (ANOVA) was used for group comparisons and Tukey HSD tests for pairwise comparisons (Stowell, 2014) if data were normally distributed (p>0.05), whereas Kruskal-Wallis tests and Mann-Whitney U tests were used if data were not normally distributed (p<0.05). The statistical packages SPSS vers. 20 and R vers. 3.3.2 were employed for this purpose.

Results

Significant variation was found among the five areas sampled in terms of pH, conductivity, salinity, TDS, NO_3-N, coliforms, COD and BOD (all values of p<0.01) (Table 1). No significant differences were found between

Table 1 Water quality parameters (Mean ±SE) sampled in and around Anlung Pring Protected Landscape in 2016. Bold font indicates significantly different values, and dashes indicate a parameter was not recorded. SF = shrimp farm, COR = canals outside reserve, SPR = southern part of reserve, CIR = canals inside reserve, NPR = northern part of reserve.

Parameter	Mean ±SE					Advised levels	Associated references
	SF	COR	SPR	CIR	NPR		
pH	8.00 ±0.14	7.02 ±0.09	7.10 ±0.14	6.62 ±0.03	**2.30 ±0.77**	6–9	Anh *et al.* (2010); Bui *et al.* (2012)
Conductivity (mS/cm)	49.85 ±6.78	40.38 ±6.61	40.75 ±3.07	42.97 ±5.08	**10.15 ±6.64**	<0.01	Bartram & Ballance (1996)
Turbidity (NTU)	29.63 ±11.15	133.00 ±40.20	60.97 ±21.10	26.40 ±2.86	19.33 ±7.03	<5	Chapman (1996); WHO (2011)
Salinity (g/l)	32.98 ±4.95	25.48 ±1.93	26.65 ±2.71	27.80 ±3.72	**6.28 ±4.21**	No limit	Boyd & Green (2002)
TDS (g/l)	23.23 ±5.24	21.16 ±1.56	21.18 ±1.89	22.47 ±2.63	**5.18 ±3.38**	<0.6	WHO (1996, 2011)
SO_4 (mg/l)	1,869.28 ±451.45	1,674.00 ±392.69	1,846.20 ±482.44	1,948.87 ±622.77	757.65 ±456.83	100	Chapman (1996)
NH_4-N (mg/l)	0.19 ±0.07	0.16 ±0.02	0.27 ±0.07	0.46 ±0.12	1.95 ±0.68	<0.1	Bui *et al.* (2012)
NO_3-N (mg/l)	0.05 ±0.01	0.07 ±0.02	0.08 ±0.02	0.04 ±0.01	**0.01 ±0.00**	<0.06	Pulatsu *et al.* (2004); Bui *et al.* (2012)
NO_2-N (mg/l)	0.05 ±0.01	0.06 ±0.01	0.06 ±0.01	0.04 ±0.01	0.02 ±0.01	0.1–0.75	Boyd & Green (2002)
TP (mg/l)	0.09 ±0.04	0.15 ±0.04	0.09 ±0.02	0.05 ±0.01	0.05 ±0.02	<0.3	Boyd (2003); Bui *et al.* (2012)
Fe (mg/l)	0.63 ±0.21	0.72 ±0.05	0.88 ±0.13	1.04 ±0.12	1.87 ±0.96	0.03	Ramakrishnaiah *et al.* (2009)
Coliforms (MPN/litre)	**280.00 ±149.55**	**146.67 ±23.90**	78.33 ±26.26	76.67 ±28.60	31.67 ±15.79	<500	Anh *et al.* (2010)
COD (mg/l)	**25.48 ±2.11**	14.65 ±1.37	15.27 ±1.28	17.03 ±1.41	**7.07 ±4.16**	<3	Bui *et al.* (2012); Ly & Larsen (2012)
BOD (mg/l)	**20.72 ±4.88**	7.18 ±1.16	6.27 ±0.66	7.38 ±0.55	**2.33 ±0.86**	<6	Boyd & Green (2002); Bui *et al.* (2012)
Aluminum (mg/l)	0.03 ±0.01	0.03 ±0.00	0.06 ±0.03	0.04 ±0.01	-	0.2	Chapman (1996)

sampling areas in the remaining parameters (turbidity, SO_4, NH_4-N, NO_2-N, TP, Fe, and Al) (all values of $p>0.05$).

Compared to the northern section of the reserve, levels of conductivity, salinity, TDS, and NO_3-N were significantly higher within the shrimp farm and all hydrologically connected areas (all values of $p<0.01$). Levels of coliforms were also significantly higher within shrimp farms and adjacent canals outside the reserve compared to other hydrologically linked areas (southern section of the reserve and central canals) and the northern section of the reserve ($p<0.01$). Compared to all other areas, pH levels were significantly higher within the shrimp farms ($p<0.05$) and significantly lower within the northern section of the reserve ($p<0.01$) (Table 1). The same was true of BOD and COD (all values of $p<0.05$).

Discussion

Our results show significant variation in water quality between the shrimp farms, hydrologically linked areas and a hydrologically unconnected area in APPL. Because the northern section of Anlung Pring is hydrologically isolated from all other areas of the site by a road embankment, water quality in this section is unaffected by discharge from shrimp farms adjacent to the southern section of the reserve. Values for pH were very low in the northern section and fall outside recommended ranges for protecting farming and aquatic ecosystems (Anh *et al.*, 2010; Bui *et al.*, 2012). This may be due to the embankment separating the reserve and allowing chemical fertilizers from rice fields in northerly catchment areas to accumulate in the northern section, creating increased acidification. This is supported by the fact that levels of ammonia nitrogen (NH_4-N) were also much higher in the northern section of the site. Ammonia can acidify the environment through the release of H^+ ions during the biochemical conversion to nitrate (Schuurkes & Mosello, 1988).

Conductivity, TDS, SO_4, NH_4-N, NO_3-N, Fe, COD and BOD were higher than recommended levels for a variety of water uses at most sampling points outside of the hydrologically isolated northern section of Anlung Pring (Lloyd, 1987; Bartram & Ballance, 1996; Chapman, 1996; World Health Organization, 1996, 2011; Boyd & Green, 2002; Ramakrishnaiah *et al.*, 2009; Bui *et al.*, 2012; Ly & Larsen, 2012). In addition, the highest levels of conductivity, TDS, BOD and COD were found in shrimp farms, suggesting that effluent from these may be affecting water quality within the protected landscape. TDS is normally positively correlated with conductivity (Ansari *et al.*, 2015) and indicates the degree of dissolved substances such as metal ions in water (Efe *et al.*, 2005; Ubwa *et al.*, 2013). BOD measures of the amount of oxygen required by bacteria and other microorganisms that stabilize decomposable organic matter (Ubwa *et al.*, 2013). High levels of COD and BOD indicate reductions in water quality (Ubwa *et al.*, 2013; Ansari *et al.*, 2015) by organic compounds (Bui *et al.*, 2012; Ubwa *et al.*, 2013) and reflect high organic and inorganic matter (Boyd & Green, 2002; Bui *et al.*, 2012; Ansari *et al.*, 2015). This has negative impacts on ecosystem health (Anh *et al.*, 2010; Bui *et al.*, 2012) and reduces habitat quality for fish (Nguyen *et al.*, 2006). High levels of both COD and BOD can result from organic waste from abattoirs (Bartram & Ballance, 1996), pellet feed use and discharge from shrimp farming (Anh *et al.*, 2010).

Our analyses indicates that many water quality parameters fall outside of a variety of recommended guidelines at APPL and may therefore be negatively affecting the quality of wetland habitats at the site. In Cambodia, Yang & Guo (2003) suggest that water pollution mostly occurs in transnational waters in the Lower Mekong Basin. Poor water quality affects habitat integrity (Simeonov *et al.*, 2003), fish and aquatic production (Lloyd, 1987), causes acid sulphate soils and algae blooms (Boyd & Green, 2002; Bui *et al.*, 2012), and creates favourable conditions for pathogenic microorganisms (Anh *et al.*, 2010). Though some aspects of Cambodia's environment have remained cleaner compared to some neighbouring countries (Monirith *et al.*, 2000), wetland pollution along the coastline threatens habitat integrity and could have a highly adverse impact on biodiversity (Naylor, 1998). We consequently suggest monitoring of water quality and engagement with shrimp farmers to minimize the impact of their practices on protected areas. The development of structures to prevent polluted waters from entering APPL may also prove necessary, and further research on the ecological impacts of water pollution is required to assess the effectiveness of related conservation interventions.

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Carbon stock of peat soils in mangrove forest in Peam Krasaop Wildlife Sanctuary, Koh Kong Province, southwestern Cambodia

TAING Porchhay, EANG Phallis, TANN Sotha & CHAKRABORTY Irina*

Faculty of Mathematics, Sciences and Engineering, Paññāsāstra University of Cambodia, No. 184, Preah Norodom Blvd (41), Phnom Penh, Cambodia.

* Corresponding author. Email cambodiapeatland@gmail.com

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មូលន័យសង្ខេប

មានការយល់ដឹងតិចតួចណាស់ពីតំបន់ដីមមោក (Peatland) នៅកម្ពុជា។ តំបន់ដីមមោកដែនជម្រកសត្វព្រៃពាមក្រសោបក្នុងខេត្តកោះកុងត្រូវបានរកឃើញក្នុងឆ្នាំ២០១៤ ដែលគ្របដណ្តប់ដី៤៩៧៦ហិចតា (គិតទាំង៣៨ហិចតានៅក្រៅដែនជម្រក) នៃព្រៃកោងកាងតំបន់ឆ្នេរ។ ក្រៅពីមុខងារជាទីជម្រក និងរក្សាគុណភាពទឹក ដីមមោកក៏ជាអាងស្តុកកាបូនដ៏សំខាន់ ហើយដើរតួយ៉ាងសំខាន់ក្នុងការប្រែប្រួលអាកាសធាតុ។ ការកំណត់ពីបរិមាណកាបូនស្តុកក្នុងដីមមោកនៅដែនជម្រកសត្វព្រៃពាមក្រសោបបានផ្តល់ជាចំណេះដឹងដ៏មានតម្លៃដើម្បីឈានដល់ការយល់ដឹងពីលទ្ធភាពផ្ទុកកាបូនក្នុងតំបន់ដីមមោកកម្ពុជា។ យើងបានប៉ាន់ប្រមាណពីបរិមាណកាបូនស្តុកក្នុងតំបន់ដីមមោកក្នុងព្រៃកោងកាងនៃដែនជម្រក។ សំណាកដីមមោកត្រូវបានប្រមូល និងវិភាគ។ ចំណុះកាបូនក្នុងដីមមោកគឺចន្លោះ១៩,៦ ទៅ ២២,៩% និងមានដង់ស៊ីតេមាឌ ០,៣៤៧ក្រ/សម^{៣}។ ផ្អែកលើការសិក្សានេះ និងការសិក្សាពីមុនៗ ជម្រៅជាមធ្យមនៃស្រទាប់ដីមមោកគឺ ១១០សម និងមានមាឌសរុបគឺប្រហែល ៥,៨៣ x ១០^{៧}ម^{៣}។ យើងប៉ាន់ប្រមាណថាមានកាបូនប្រហែល៤,៤៧ x ១០^{៦}មក្រ ដែលស្តុកក្នុងដីមមោកនៃដែនជម្រកសត្វព្រៃពាមក្រសោប។

Abstract

Very little is known about peatlands in Cambodia. The peatland in Peam Krasaop Wildlife Sanctuary (PKWS), Koh Kong Province, was discovered in 2014 and covers 4,976 ha (including 38 ha outside the sanctuary) in a coastal mangrove forest. In addition to their functions as habitats and maintaining water quality, peatlands are significant carbon sinks and therefore play important roles in mitigating climate change. Determining the size of the carbon stock in peat in PKWS is consequently valuable for understanding the sequestration capacity of Cambodian peatlands. We estimated the amount of carbon stock of peat soils in the mangrove forest of the sanctuary. Peat cores were collected and analysed. The carbon content of the peat was between 19.6 and 22.9%, and its bulk density was 0.347 g/cm^3. Based on our work and previous studies, the average depth of the peat layer is 110 cm and the total peat volume is about 5.83 × 107 m^3. We consequently estimate that approximately 4.47 × 10^6 Mg of carbon is stored in the peatlands of PKWS.

Keywords

Bulk density, carbon stock, mangrove, organic carbon content, peat soil, wetlands.

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Introduction

Wetland environments are abundant in Cambodia, covering 30% of the country (Kol, 2003; Mak, 2015). Peatlands, a type of wetland ecosystem characterized by accumulated organic matter (Parish *et al.*, 2008), have not been well studied in Cambodia and mangrove peatlands in particular have been neglected (Donato *et al.*, 2011).

Peat is a soil type dominated by decomposing plant materials, and contains more than 18% and 30% of organic carbon and organic matter respectively (Agus *et al.*, 2011). Peat is formed from decomposing plant materials under saturated conditions (Parish *et al.*, 2008), as dead vegetation layers on top of the soil. Benefits provided by peatlands include climate regulation—in the form of carbon sequestration—and other ecosystem services (Parish *et al.*, 2008). The latter include the roles peatlands play in the hydrological cycle by removing nutrients and sequestering large volumes of water and provision of habitat to diverse animal and plant species.

Peatlands cover around 3% (400×10^6 ha) of the global land area and occur in most areas of the world (Strack, 2008). Most are found in the boreal and temperate zones (3.57×10^8 ha: Page *et al.*, 2010), but tropical and subtropical zones are also important peatland regions, because of the high rates of plant production and high rainfall which reduces rates of decay (Parish *et al.*, 2008). Peatlands cover around 2.5×10^7 ha in Southeast Asia, almost 60% of peatlands within the Tropics. More than 70% of these occur in Indonesia. Malaysia, Brunei, and Thailand also have significant peatland areas, while smaller areas are found in Vietnam, the Philippines, Cambodia, Laos, Myanmar, and Singapore (ASEAN Secretariat, 2014).

The world's peatlands contain a carbon pool of about 550 Gt, which is twice that of above-ground forest biomass (Parish *et al.*, 2008). As a consequence, these play a major role in regulating climate through carbon dioxide storage, but also as a source of methane, another greenhouse gas (GHG). Loss of carbon storage caused by peatland fires or inappropriate management practices can lead to GHG emissions which contribute to climate change. When peat is exposed to oxygen, it oxidizes and releases carbon dioxide into the atmosphere. Climate change also affects the GHG cycle of peatlands by transforming their carbon sinks into sources of carbon emissions due to changes in temperature and rainfall, whereas their carbon content remains constant if they are protected and water levels remain unchanged. For instance, climate change is currently predicted to severely degrade 60% of Canadian peatlands and further contribute to global warming by releasing carbon dioxide and methane into the atmosphere (Tarnocai, 2006).

Degradation of peatlands is commonplace despite their many documented benefits, with human activities having a significant impact. A major cause of peatland degradation is their conversion to agricultural land by draining or burning, with over 12% (3×10^6 ha) of peatlands having being converted in Southeast Asia (ASEAN Secretariat & GEC, 2011). In the absence of disturbance, peatlands continuously accumulate carbon by storing slowly-decaying plant materials in the anaerobic peat layer. Because carbon sequestration in peatlands plays an important role in climate regulation, restoration of peatland is among the most cost-effective ways to mitigate climate change (Bain *et al.*, 2011).

The objective of our study was to estimate the amount of carbon stored in the coastal mangrove peatland in Peam Krasaop Wildlife Sanctuary, Koh Kong Province, southwestern Cambodia.

Methods

Study site

Peam Krasaop Wildlife Sanctuary (PKWS) is a protected area established by Royal Decree in 1993. It includes 23,750 ha of coastal mangrove in Koh Kong Province (Fig. 1), although the sanctuary area is larger (25,897 ha) according to an official map approved in 2003 (An *et al.*, 2009). Part of PKWS lies within the boundary of the Koh Kapik and Associated Islets Ramsar Site, which was designated as a result of supporting a significant mangrove ecosystem (criteria 1), endangered and rare species (criteria 2), and providing a site for feeding, breeding, and nursery grounds for fish and shellfish species (criteria 8) (Srey, 2012). The main tree species at the site are *Lumnitzera racemosa*, *Excoecaria agallocha*, *Rhizophora apiculata*, *R. mucronata*, *Brugueira gymnorrhiza*, *Melaleuca cajuputi*, *Heritiera littoralis*, *Xylocarpus granatum*, *L. littorea*, *Ceriops tagal*, *Avicennia alba*, *Scyphiphora hydrophyllacea*, *Glochidion littorale*, *Phoenix paludosa*, *Nypa fruticans*, *Acrostichum speciosum*, and *Pandanus* sp. (Lo *et al.*, 2014).

In 2014, as part of the ASEAN SEApeat project, activities were undertaken to assess peatlands in Cambodia. Based on satellite images, it was determined that PKWS had a high likelihood of containing peat (Lo *et al.*, 2014). Following interpretation of satellite imagery, on-site assessments were conducted to verify the presence of peat. Our study was conducted in 2016 within the mangrove peatland in PKWS. Prior to fieldwork, peat depth measurements from 22 peat cores and a map of the peatland were obtained from the SEApeat project. The mangrove peat layers ranged from 44–200 cm, with an

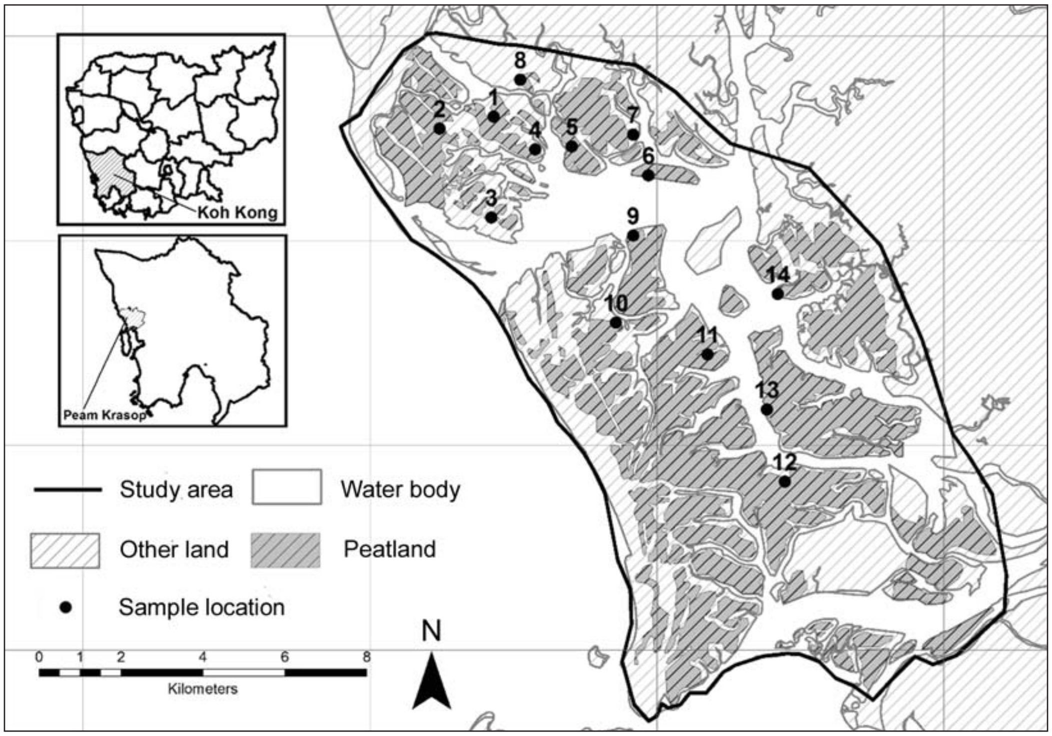

Fig. 1 Location of Peam Krasaop Wildlife Sanctuary and study samples.

average depth of 115 cm, and a total of 4,976 ha of the area were estimated to be peatland (Lo *et al.*, 2014).

Sampling methods

To select sampling locations, maps were created by transferring polygon outlines of areas of peatland identified in PKWS by Lo *et al.* (2014) into ArcGIS software and overlaying these with images from GoogleEarth. Because the characteristics of peat across PKWS were expected to be similar to Lo *et al.* (2014), it was assumed 14 peat cores would be sufficient to estimate its carbon stock. These were collected in PKWS on 23–24 January 2016.

A soil auger (made by Eijkelkamp, the Netherlands) was used to collect the 14 core samples. The volume of the soil auger (half-cylinder) was 1,410 cm^3 (height = 100 cm, radius = 3 cm). The depth of the peat layer was measured in each core. Each core was divided into 25 cm vertical sections. From each vertical core section, 5 cm samples were cut to produce 46 samples, these representing the length of each core at 25 cm intervals. Each of the 46 samples was analysed for bulk density and organic carbon. An additional 14 samples of the top layer of peat (1–25 cm) were collected using a soil ring (height = 4 cm, radius = 2.1 cm, volume = 55.4 cm^3) constructed by the authors from a stainless steel pipe, with a thickness of 1 mm. A GPS was used to record the locations of samples.

Samples were wrapped in aluminium foil, placed in individual plastic bags labelled with their respective locations, and packed into an ice box for transport. These were stored at 4°C for three days prior to analyses for bulk density and organic carbon content.

Bulk density

The volume of the soil sample was calculated from the diameter of the auger and soil ring. Peat sample bulk density (BD) was determined using the gravimetric method (Agus *et al.*, 2011). To determine dry mass, samples were dried at 105°C for six hours and weighed, and this process was repeated up to four times until constant mass was achieved. BD was defined as the dry weight of soil per unit volume. This was calculated as $BD = M_s/V_t$, where BD was bulk density (g/cm^3), M_s was the mass of the dry peat soil (g), and V_t was the volume of the soil sample (cm^3).

Peat depth and area

The depth of the peat layer was defined as the length of peat cores obtained in the field. The area of peatland in PKWS was digitized from the SEApeat project map into

71 polygons using ArcGIS, which was used to calculate the area of each polygon. The locations for our peat depth data were also included in ArcGIS, and the depth of each polygon was estimated as the product of its area and respective peat depth. Because of the limited number of samples, peat depths were assigned to each polygon as follows: 1) If a single core sample had been taken in the polygon, the value for that core was used; 2) If more than one core sample was taken, the mean of these was used; and 3) If no core sample was available for the area, the value of the nearest similar area with a known depth was used. Similarity was determined subjectively, based on vegetation cover and contiguousness.

Organic carbon content

Total organic carbon (TOC) was measured by loss on ignition at 550°C (Agus *et al.*, 2011). Two grams of each sample were dried at 105°C for 15 minutes, then weighed. To obtain a dry mass value (M_{dry}), this process was repeated until mass did not change between drying cycles. The dry samples were then transferred into a combustion oven at 550°C for four hours (Santisteban *et al.*, 2004; the method was modified according to Agus *et al.*, 2011, reducing the combustion time from six hours). The samples were cooled in a desiccator and their mass recorded as ash mass (M_{ash}). TOC was calculated as TOC = (M_{dry} – M_{ash}/ M_{dry}) / 1.724, where TOC was total organic carbon (g/g), M_{ash} was ash mass (g), M_{dry} was dry mass (g) and 1.724 was the conversion factor for organic matter to organic carbon (Agus *et al.*, 2011).

Carbon stock

The total carbon stock of the PKWS peatland was calculated as C_{stock} = A x D x BD x TOC, where C_{stock} was carbon stock (Mg), D was average peat depth (m), BD was average bulk density (Mg/m^3), TOC was organic carbon content (Mg/Mg), and A was the peatland area (m^2) (Weissert *et al.*, 2013).

Results

Bulk density

Bulk density values for core sections obtained from soil ring samples were on average 26% lower than auger samples taken at the same depth, at 0.347 (n=14, SD=0.11) and 0.436 (n=14, SD=0.14) g/cm^3 respectively (Table 1). However, this difference was only significant at p=0.037 due to high variance within the data. The value obtained from the soil ring is used in subsequent calculations because this sampling method is less disruptive than the auger (see Discussion). There was no significant difference between bulk densities and depth (p=0.309) and there was no consistent trend in BD variation with depth, some cores having increased BD at greater depth, some decreased BD, and others similar BD (Fig. 2).

Peat depth and volume

Combining data from Lo *et al*. (2014) with our study, the average depth of the peat layer was estimated as 1.10 m (n=35, SD=0.41) (Fig. 3). The total area of the peatland in PKWS was estimated at 4,938 ha (exluding 38 ha of peatland outside the sanctuary). Using these data, the total volume of peatland within PKWS is estimated to be approximately 5.83×10^7 m^3 (Table 2).

Organic carbon content

Organic matter values for the peat soils in PKWS ranged from 33.8–40.2%. The organic carbon content of peat by depth is shown in Table 2 and averaged 22.2% overall. There were no significant difference in organic carbon content with depth (p>0.05).

Carbon stock

The carbon stock of peatland in PKWS was estimated to be 4.47×10^6 Mg (Table 1). As BD and carbon content did not vary significantly with depth, we conclude that there is no significant difference in carbon stock with depth.

Discussion

Bulk density

The bulk density (BD) of peat in PKWS appears to be typical of mangrove systems. Previous reviews indicate that the BD of mangrove peat in Indo-Pacific oceanic and

Table 1 Bulk density values for core sections from soil ring samples (surface samples only) and auger samples (25 cm subsections of each core).

Sampling depth	*n*	Mean BD (g/cm^3)	SD
Soil ring	14	0.347	0.118
1 to 25 cm	14	0.436	0.149
25 to 50 cm	14	0.398	0.086
50 to 75 cm	9	0.410	0.121
75 to 100 cm	6	0.446	0.085
>100 cm	3	0.338	0.045

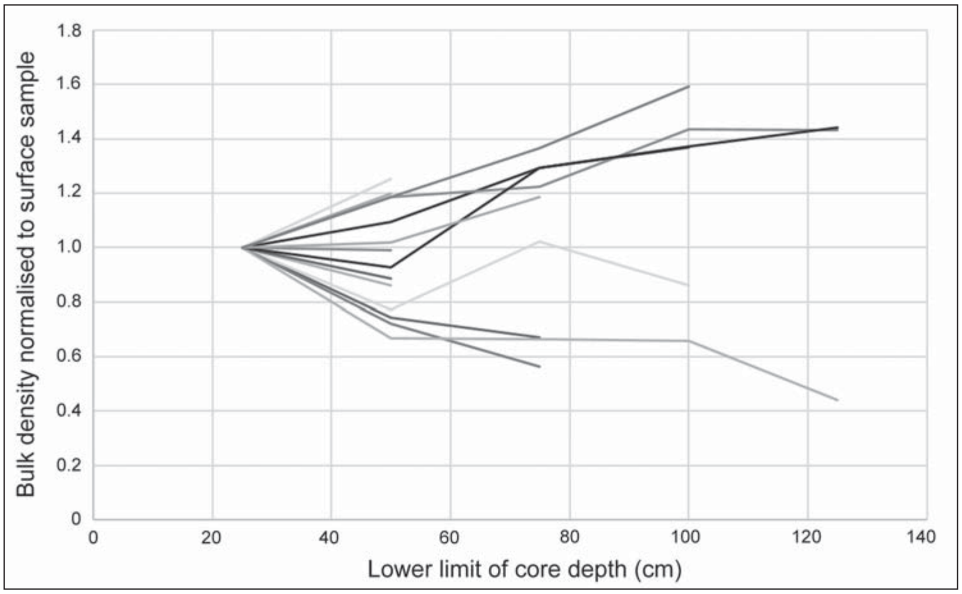

Fig. 2 Normalized bulk density of core sections from Peam Krasaop Wildlife Sanctuary. Each line represents one core.

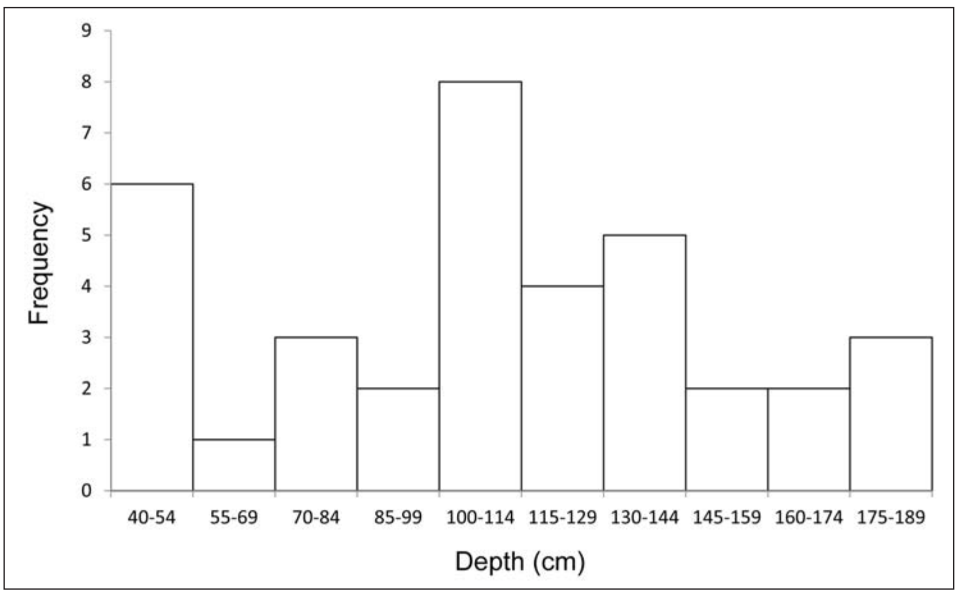

Fig. 3 Frequency of peat layer depths (*n*=36) at 15 cm intervals at Peam Krasaop Wildlife Sanctuary.

Table 2 Carbon stock in different peat layers at Peam Krasaop Wildlife Sanctuary.

Depth (cm)	*n*	Area (m^2)	Volume (m^3)	Bulk density (Mg/m^3)	Organic matter (Mg/Mg)	Carbon content (Mg/Mg)	Carbon stock (Mg)
1 to 25	14	4.94×10^7	1.23×10^7	0.347	0.387	0.224	9.62×10^5
25 to 50	14	4.94×10^7	1.22×10^7	0.347	0.402	0.233	9.89×10^5
50 to 75	9	4.46×10^7	1.11×10^7	0.347	0.372	0.216	8.32×10^5
75 to 100	6	4.42×10^7	1.04×10^7	0.347	0.338	0.196	7.07×10^5
>100 cm	3	4.03×10^7	1.23×10^7	0.347	0.394	0.229	9.76×10^5
	Total		$\mathbf{5.84 \times 10^7}$				$\mathbf{4.47 \times 10^6}$

estuarine systems ranges from 0.35 to 0.55 g/cm^3 (Donato *et al.*, 2011). The BD of peat in U Minh Ha National Park (Vietnam) ranges from 0.19 to 0.26 g/cm^3 with an average of 0.23 g/cm^3 (Quoi, 2010), compared to 0.347 g/cm^3 in PKWS. According to Andriesse (1988), the BD of peat soil ranges from 0.05 g/cm^3 in very fibric (i.e. containing undecomposed plant fibres) soils to around 0.5 g/cm^3 in well-decomposed materials. The high BD of mangrove peat in PKWS thus suggests it mainly comprises well-decomposed material, with only some areas including fibric peat. Based on our observations, the presence of plant roots within the well-decomposed peat of some of our samples came from live mangrove trees growing in the area (Fig. 4).

The BD of samples taken with our soil ring were more accurate than samples taken using the auger, which tends to distort soil cores. Agus *et al.* (2011) recommend using a soil ring to sample peat soil for BD analysis. It was not possible to use a soil ring for deeper layers of peat in PKWS due to the presence of mangrove root structures and overlaying water. Peat cores taken to estimate the depth of the peat layer using the auger were consequently less than optimal for the purposes of calculating BD. The mean BD of auger samples in the 1–25 cm peat layer was 0.436 g/cm^3, 26% higher than the value of samples obtained with the soil ring. We suspect that distortion occurred because the auger compressed the soil cores when rotated to obtain samples.

Peat depth

Peat layer depths in tropical areas range from 0.5 m to >10 m (ASEAN Secretariat, 2014), although estuarine peat is typically 3 m thick (Donato *et al.*, 2011). As such, the peat layer in PKWS is relatively thin with an average of 1.1 m, which is similar to values in oceanic systems (Donato *et al.*, 2011). This may be due to the young age of mangrove forests in situ and their close proximity to open water, which may hinder formation of peat layers due to the disruptive nature of tides.

Organic carbon content

The organic carbon content of peat ranges from 18–58% when measured using the 'loss on ignition' (LOI) method (Agus *et al.*, 2011), although Donato *et al.* (2011) obtained values of 7.9% and 14.6% for estuarine and oceanic systems respectively. Our values of 33.8–40.2% for PKWS are somewhat lower than those for U Minh Ha National Park in Vietnam (53.4–54.0%: Quoi, 2010). The higher values at the latter site may be due to its greater distance from the shoreline, and therefore reduced tidal influences compared to PKWS which is located in an estuary. Tides can affect accumulation rates of soil organic carbon due to regular water movement disturbing and washing away decomposing material, and depositing mineral sediments. Water movement and mixing may also increase oxygenation of organic material and reduce accumulation rates by increasing aerobic mineralization (Alongi, 2009).

Carbon stock

The carbon stock of peatlands in PKWS is 904 Mg/ha, which is typical of estuarine (1,074 Mg/ha) and marine (990 Mg/ha) mangroves (Donato *et al.*, 2011). In contrast, because peat thickness varies at U Minh Ha, this affects the amount of carbon stored per area. For instance, where peat layers reach a depth of 70 cm, carbon content is about 814 Mg/ha and where these reach 120 cm, carbon content is about 1,480 Mg/ha (Quoi, 2010).

Carbon storage in peat

Peatlands sequester more carbon per area than terrestrial ecosystems (Parish *et al.*, 2008). According to Toriyama *et al.* (2011), soil carbon stocks range from 56.9–108 Mg/ha in evergreen forest soils and 34.9–53.2 Mg/ha in deciduous forest soils in Cambodia. In addition, the carbon stock of forest soils in the Mondulkiri and Kompong Thom provinces was at most 114 Mg/ha (Toriyama *et al.*, 2012). As mangrove peatlands store almost an order of magnitude more carbon per area (904 Mg/ha in this study, Fig. 5), this strengthens the case for prioritizing conservation of mangrove peatlands.

The total carbon stock of peat soils in PKWS is 4.47×10^6 Mg, approximately 0.15 % of the total carbon stored in Cambodia's terrestrial ecosystems (2.97×10^9 Mg) and about 0.007 % of the total carbon storage in Southeast Asian peatlands (58 Gt: Strack, 2008). Given the organic carbon to carbon dioxide emission factor of 3.67 (Agus *et al.*, 2011), the PKWS peatlands could release 1.64×10^7 Mg of carbon dioxide emissions if burnt or otherwise destroyed.

Soil carbon estimation

Carbon density can be calculated from soil bulk density as a low cost option for estimating carbon stocks in tropical peat (Warren *et al.*, 2012). To test the applicability of the regression equation developed by Warren *et al.* (2012) to PKWS, we calculated the theoretical carbon density and compared it with the value obtained from the LOI method. The former gave a value more than twice the latter, i.e. it over-estimated the amount of carbon in the peat by a factor of 2.2. However, Warren *et al.* (2012) recommend that the equation be used only for soils with

Fig. 4 A peat core showing living roots from Peam Krasaop Wildlife Sanctuary.

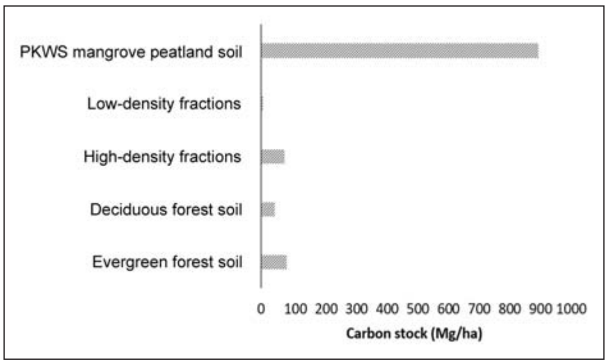

Fig. 5 Comparison of carbon stocks in Peam Krasaop Wildlife Sanctuary and forest soils (latter data taken from Toriyama *et al.*, 2011; 2012).

>40% carbon content. As this is higher than the organic content of peatlands in PKWS (33.8–40.2%), the linear relationship between BD and carbon density may not hold true due to physical properties of the soil affecting carbon content in low organic peat (Warren *et al.*, 2012). In fact, BD and carbon density were negatively correlated in our samples.

Conclusions

The carbon stock of peat soils has received little attention in Cambodia to date. Our study adds to knowledge of tropical peatlands, highlights their importance, and can contribute to improving awareness of the value of peatlands with implications for their management and conservation. Sand mining, drainage, and deforestation in peatlands is likely to impact these ecosystems and release their sequestered carbon into the atmosphere.

Our study can also inform further research in PKWS. In highlighting the importance of peatland and mangrove preservation, our results can support national climate change mitigation strategies and provide a basis for improving estimates of the potential of peatlands as carbon sinks in Southeast Asia.

Further work is required to characterize the peatlands of PKWS in detail. In particular, peat depths at the site should be validated because of the limited number of samples in our study. Further assessment of carbon for carbon credit programmes is also warranted to generate funds for conservation of PKWS through initiatives such as the Reduced Emissions from Deforestation and Degradation scheme. Other newly discovered peatlands in Cambodia, such as the Botum Sakor peatland, Koh Kong Province (Quoi *et al.*, 2015) should also be characterized to understand their function, identify possible threats, and develop effective management practices.

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Camera trapping of large mammals in Chhep Wildlife Sanctuary, northern Cambodia

SUZUKI Ai[1,*], THONG Sokha[2], TAN Setha[2] & IWATA Akihisa[1]

[1] Ecology and Environment, Division of Southeast Asia, Graduate School of Asian and African Area Studies, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan.

[2] Wildlife Conservation Society, No.21, Street 21, Tonle Bassac, Phnom Penh, 12000, Cambodia.

* Corresponding author. Email suzuki.ai.47a@kyoto-u.jp

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មូលន័យសង្ខេប

ដែនជម្រកសត្វព្រៃឆែបស្ថិតនៅភាគខាងជើងនៃប្រទេសកម្ពុជា សម្បូរដោយព្រៃរបោះ (DDF) យ៉ាងធំសម្បើម។ ការសង្កេតដោយម៉ាស៊ីនថតស្វ័យប្រវត្តិត្រូវបានធ្វើឡើងនៅក្នុងដែនជម្រក ក្នុងរយៈពេលពីររដូវប្រាំងបន្តបន្ទាប់គ្នាគឺ ឆ្នាំ២០១២ ដល់ ២០១៣ និង ២០១៣ ដល់ ២០១៤។ លទ្ធផលបានពីការដាក់ម៉ាស៊ីនថតស្វ័យប្រវត្តិ ៧៤៨៣យប់ ទទួលបានកំណត់ត្រា ៣៧៦៧ នៃថនិកសត្វធំ ៣០ប្រភេទ។ លទ្ធផលរបស់យើងបញ្ជាក់ពីភាពបន្តមាននៃថនិកសត្វធំក្នុងព្រៃរបោះមានដូចជា រមាំង(*Rucervus eldii*) ទន្សោង (*Bos javanicus*) និងឆ្មាព្រៃ(*Felis chaus*)។ សំខាន់ជាងនេះទៅទៀតគឺវត្តមានសំពោចធំ(*Viverra megaspila*) ជាប្រភេទរងគ្រោះជាសកល តែរូបថតរបស់វាត្រូវឃើញច្រើនលំដាប់ទី៤ ក្នុងចំណោមប្រភេទទាំងអស់នៅក្នុងដែនជម្រក។ នេះបង្ហាញពីសារៈសំខាន់ជាសកលនៃដែនជម្រកសត្វព្រៃឆែប សម្រាប់ការអភិរក្សក្រុមថនិកសត្វក្នុងដែនទេសភាពសម្បូរព្រៃរបោះទំនាប តែជាការពិតព្រៃរបោះនិងព្រៃទំនាបមិនត្រូវដាក់ជាតំបន់ការពារគ្រប់គ្រាន់នៅឡើយនៅអាស៊ីអាគ្នេយ៍ដីគោក។

Abstract

Chhep Wildlife Sanctuary in northern Cambodia comprises a large tract of deciduous dipterocarp forest (DDF). A camera trap survey was conducted in the wildlife sanctuary during two successive dry seasons, 2012–2013 and 2013–2014. A total of 7,483 camera-trap-nights yielded 3,787 records of 30 large mammal species. Our results confirm the continued occurrence of DDF-associated large mammals such as Eld's deer *Rucervus eldii*, banteng *Bos javanicus*, and jungle cat *Felis chaus*. Importantly, large-spotted civet *Viverra megaspila*, a globally Endangered species, was the fourth-most commonly photographed species in the wildlife sanctuary. This highlights the global significance of Chhep Wildlife Sanctuary for conservation of mammal assemblages in a lowland DDF-dominated landscape, given that DDF and lowland forests are under-represented by protected areas in mainland Southeast Asia.

Keywords

Carnivores, deciduous dipterocarp forest, large-spotted civet, Preah Vihear Protected Forest, semi-evergreen forest, *Viverra megaspila*.

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Introduction

Large areas of seasonally dry forest have disappeared across continental Southeast Asia and <10% of remaining deciduous dipterocarp forest (hereafter DDF) is in protected areas (McShea *et al.*, 2005). In Thailand, DDF is under-represented in protected areas (Tantipisanuh & Gale 2013) and experienced 4.44% of annual tree cover losses between 2000 and 2012 (Johnson, 2015). Similarly, in Myanmar, Laos, and Vietnam, DDF has received limited protection (Wohlfart *et al.*, 2014). In Cambodia, the large areas of DDF in the north and east of the country have received relatively better protection (Wohlfart *et al.*, 2014).

Chhep Wildlife Sanctuary, formerly Preah Vihear Protected Forest, is a protected area containing part of the largest contiguous tract of DDF in the northern plains of Cambodia. The wildlife sanctuary supports globally threatened species associated with DDF, such as Eld's deer *Rucervus eldii* (McShea *et al.*, 2005; Owen, 2009; McShea & Baker, 2011) and giant ibis *Thaumatibis gigantea* (BirdLife International, 2016). Despite its importance, ecological information on large mammals is limited in the landscape. This study aims to document records of large ground-dwelling mammals in Chhep Wildlife Sanctuary from intensive camera trapping surveys.

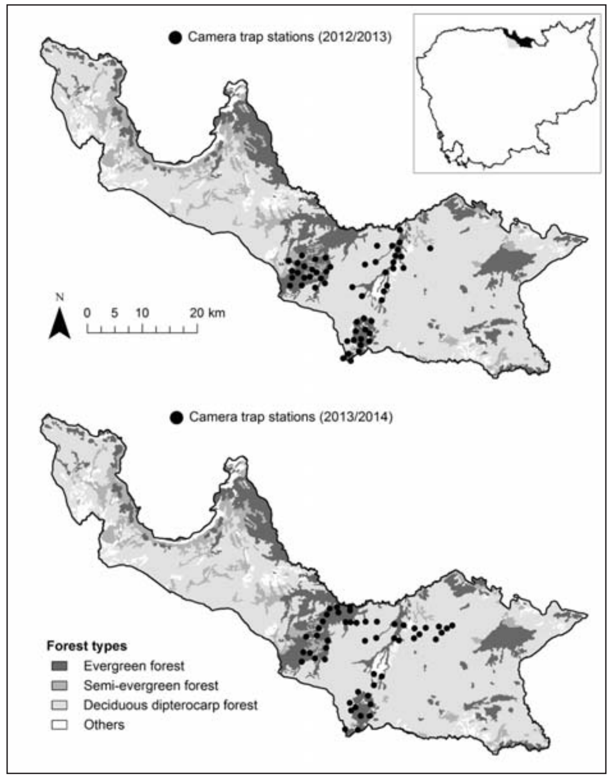

Fig. 1 Vegetation within Chhep Wildlife Sanctuary (Forestry Administration, 2010), and camera trap stations in the 2012–2013 (upper) and 2013–2014 (lower) dry seasons. Upper right: the location of Chhep Wildlife Sanctuary (black area) and Preah Roka Wildlife Sanctuary (grey area) in Cambodia.

Methods

Study area

Chhep Wildlife Sanctuary is located in northern Preah Vihear Province, and borders Thailand and Laos (Fig. 1). The southwestern part of the wildlife sanctuary is contiguous with Preah Roka Wildlife Sanctuary which forms a corridor between Chhep Wildlife Sanctuary and Kulen Promtep Wildlife Sanctuary. Chhep Wildlife Sanctuary covers 1,900.27 km^2 and comprises three main forest types: DDF (66.9%), evergreen forest (18.8%), and semi-evergreen forest (9.6%) (Forestry Administration, 2010) (Fig. 1). The wildlife sanctuary also contains smaller areas of seasonally-flooded grasslands, bamboo forests, seasonally-flooded riparian habitats and a network of temporary and permanent forest pools and streams.

Data collection

Our survey was conducted over two successive dry seasons from 2012 to 2014. Surveys during the wet season were not possible due to logistical and financial constraints. The purpose of the survey in the 2012–2013 dry season was to investigate the presence of carnivores as a part of feasibility study to determine future research targets among four carnivores: large-spotted civet *Viverra megaspila*, large Indian civet *Viverra zibetha*, leopard cat *Prionailurus bengalensis*, and jungle cat *Felis chaus*. Passive infrared digital cameras were mainly set on animal trails, footpaths, motorbike tracks and waterways in semi-evergreen forest, evergreen forest, and DDF, under the assumption this would maximize detection of these species. At other sites, the two *Viverra* species were frequently recorded from cameras set in such areas (Gray *et al.*, 2010) and leopard cats showed higher detectability along roads than off-trail locations (Sollomann *et al.*, 2013). Compared with these species, records of jungle cat in Indochina are very limited, but scats have mostly been found on roads, trails, and dry river beds in India (Majumder *et al.*, 2011), suggesting the species uses trails. Due to camera malfunctions, sampling efforts in DDF were limited and a total of 49 camera stations were set in the 2012–2013 dry season. Cameras were mounted approximately 30–50 cm above ground on trees at least 1 km apart and set to operate for 24 hours each day. No stations were baited.

In the 2013–2014 dry season, the survey purpose was to understand occupancy patterns of civets of the subfamily Viverrinae. A total of 53 camera stations were set and as six of these were <50 m from stations set in the previous season, they were considered the same stations in analysis. Camera placement was similar to the 2012–2013 dry season, except that more sampling effort was undertaken in DDF. Both survey periods employed trail-based sampling, which biases measurements of relative abundance (Sollmann *et al.*, 2013; Wearn *et al.*, 2013) and probably fails to detect large mammals that use off-trail areas (Blake & Mosquera, 2014). In terms of species detected, however, trail-based sampling is less likely to differ from random sampling where sampling efforts exceed 1,400 camera-trap-nights, especially during the dry season (Cusack *et al.*, 2015). Recognising the limitations of our non-random sampling approach, we consequently documented where species were detected and did not consider their relative abundances or compare levels of species richness with other sites.

Species identification

Species identifications employed the nomenclature of Wilson & Mittermeier (2009) for carnivores and Francis & Barrett (2008) for other species, and incorporated the taxonomic revisions of IUCN (2017). Because the survey targeted large non-volant mammals, small mammals such as treeshrews and most rodents were excluded (although porcupines were included). Species identifications for some mammals were unclear. For instance, though the presence of large-toothed ferret badger *Melogale personata* has been documented in Cambodia, it cannot be assumed that all ferret badgers recorded in the country represent this species (Schank *et al.*, 2009). Second, Meijaard & Groves (2004) suggest chevrotains (*Tragulus*) in Cambodia could be *T. kanchil affinis*, but Gray *et al.* (2012) cautiously identified *Tragulus* only to genus level in the eastern plains, which is bordered by Vietnam and close to where the silver-backed chevrotain *T. versicolor* occurs (Meijaard & Groves, 2004). In this study, all photographs of *Tragulus* were assigned to *T. kanchil*. Third, hybrid individuals of crab-eating macaque *Macaca fascicularis* and rhesus macaque *M. mulatta* have been reported in northeastern Cambodia (Heng *et al.*, 2010). The best feature for identifying these species is relative tail length, this being >90% for *M. fascicularis*, <60% for *M. mulatta*, and between these figures for hybrid individuals (Heng *et al.*, 2010). Because relative tail length could not be determined confidently from photographs, however, all macaques with characters similar to *M. fascicularis* were assigned to this species.

Data analysis

Because Yasuda (2004) found a large number of camera trap photographs of the same species occurred less than one minute after the first photograph and reached a plateau after 30 minutes, we defined a camera trap record as an independent record if it occurred at least 30 minutes after a photograph of the same species at a given station. Total sampling effort is expressed as the total number of camera-trap-nights, one camera-trap-night being defined as a continuous 24 hr period of normal camera operation. Records of large mammals in the two dry seasons are expressed as the proportion of camera stations where species were detected at least once (naïve occupancy), and encounter rates were calculated as the number of records / 1,000 camera-trap-nights.

Detection of large mammals within each forest type was calculated as a percentage, namely the number of stations where a species was detected in the forest type divided by the total number of stations which detected the species. Forest types at each camera trap station were determined by calculating the proportion of dominant forest types within a 500 m buffer area around each camera station using ArcGIS. Classification of forest types followed Forestry Administration (2011). Although this classification has limited accuracy, observations of forest types at camera trap stations suggested it is suitable for indicative purposes. Of the 53 camera trap stations set during the 2013–2014 season, 42 stations matched DDF, semi-evergreen forest or evergreen forest. However, difficulties were experienced in distinguishing between evergreen and semi-evergreen forest because 21 of 23 stations identified as being located in evergreen forest by FA (2011) were observed to be semi-evergreen forest in the field. We therefore adopt "semi-evergreen and evergreen forest" (hereafter S/EGF) as a combined forest category. When a dominant forest type comprised >70% of a buffer zone, the station was defined as either deciduous dipterocarp forest (DDF) or semi-evergreen and evergreen forest (S/EGF). When both forest types occurred in the 500 m buffer zone, the location was defined as a mosaic of DDF and S/EGF. Another limitation of the FA classification was that nine stations in small areas of semi-evergreen forest were broadly identified as DDF. Buffer analysis helped to determine that two of these were not in DDF but in a mosaic of DDF and S/EGF; however, seven camera stations remained in error.

Activity patterns for four daily periods (dawn, day, dusk, and night) were examined for species with >20 records. Local sunset and sunrise times during the survey were obtained from the US Department of Commerce, National Oceanic and Atmospheric Administration (http://www.esri.noaa.gov/). During the survey period, sunrise varied from 05:55 to 06:30 hrs and sunset from 17:29 to 18:11 hrs. Dawn was defined as the period from 05:00 to 07:00 hrs and dusk from 17:00 to 19:00 hrs.

Results

Thirty large mammal species were detected over the course of the two dry season surveys (Table 1). Asiatic black bears *Ursus thibetanus*, Sunda pangolins *Manis javanica*, and Indochinese silvered langurs *Trachypithecus germaini* were detected only in the 2012–2013 dry season while Eld's deer were recorded only in the 2013–2014 dry season (Fig. 2).

Survey effort during the 2012–2013 dry season was 2,370 camera-trap-nights and produced 1,198 records of confidently identified species (Table 1). Twenty-nine species representing seven orders were recorded, including, per IUCN (2017), one Critically Endangered species (Sunda pangolin *Manis javanica*) and six Endangered species including Asian elephant *Elephas maximus* (Fig. 2). The three most commonly photographed species were common palm civet *Paradoxurus hermaphroditus*, Eurasian wild pig *Sus scrofa*, and red muntjac *Muntiacus muntjak*.

Survey effort during the 2013–2014 dry season was 5,113 camera-trap-nights and produced 2,589 records of 27 confidently identified species (Table 1). The three most commonly photographed species were golden jackal *Canis aureus*, Eurasian wild pig and common palm civet.

Species occurrence and activity patterns

Of the 21 mammal species detected at more than five camera trap stations, five (leopard *Panthera pardus*, lesser Oriental chevrotain *Tragulus kanchil*, gaur *Bos gaurus*, northern pig-tailed macaque *Macaca leonina*, and Asian elephant) were almost exclusively detected in S/EGF (Table 2). Large Indian civets were detected at 31 stations, only one of which was in DDF. Conversely, jungle cats were not detected in S/EGF, but only in DDF or a mosaic of DDF and S/EGF.

Activity patterns of species with >20 records are shown in Fig. 3. Eleven species (comprising seven carnivores, two ungulates, Burmese hare *Lepus peguensis* and Malayan porcupine *Hystrix brachyura*) exhibited nocturnal patterns of activity, whereas five (two carnivores, one ungulate and two primates) exhibited diurnal patterns and lesser Oriental chevrotain showed crepuscular activity.

Discussion

Our results provide preliminary information on large mammal communities during the dry season in Chhep Wildlife Sanctuary. Over two successive dry seasons, 30 large mammal species were detected including one Critically Endangered species and six Endangered taxa per IUCN (2017). This confirms the conservation importance of the sanctuary and our records, particularly those of two DDF-associated Endangered species—banteng *Bos javanicus* and Eld's deer—highlight its significance in light of the under-representation of DDF in protected areas in Indochina.

Tordoff *et al.* (2005) emphasized the importance of semi-evergreen forest in DDF landscapes in Indochina. Our findings corroborate this: 27 of the 30 species we detected were recorded by at least one station in S/EGF. Though we are unable to infer species habitat preferences due to sampling bias, these clearly use S/EGF despite its relatively small extent, at least in the dry season. In particular, leopards, lesser Oriental chevrotains, northern pig-tailed macaques, and Asian elephants were almost exclusively detected in S/EGF, with no records in DDF. Though our data are confined to the dry season and further work is required to determine seasonal movements of large mammals in the wildlife sanctuary, it is possible that some species may use S/EGF seasonally or much less during the wet season. In Thailand, banteng use dry evergreen forests in the day during the dry season, especially in the late dry season whereas they remain in DDF throughout the day in the wet season (Bhumpakphan & McShea, 2011; N. Bhumpakphan pers. comm.). Similarly, large Indian civets were observed shifting the centre of their home range from mixed deciduous forest to evergreen forest in the early dry season, and small Indian civets were observed shifting from DDF to evergreen forest in the late dry season (Rabinowitz, 1991).

Carnivores

Our data confirms the occurrence of 16 carnivore species at Chhep Wildlife Sanctuary. Bears and leopards were recorded less frequently and only in S/EGF. The latter is somewhat surprising as leopards were recorded at approximately 70% of the camera trap stations in DDF in the eastern plains of Cambodia (Gray *et al.*, 2012) where un-baited camera trap pairs were spaced approximately 2–3 km apart along roads, trails, animal paths and ridgelines in mixed habitat types, with the highest proportion in DDF (R. Crouthers, per. comm.). Other studies in Indochina, where DDF persists, have also not found a strong association of leopards with evergreen forests and semi-evergreen forest (Simcharoen *et al.*, 2008; Gray

Table 1 Records of large mammals in Chhep Wildlife Sanctuary during the 2012–2013 and 2013–2014 dry seasons. IUCN status: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LC = Least Concern. ND = Not detected.

Species	IUCN status	2012–2013 dry season		2013–2014 dry season	
		Naïve occupancy[1]	Encounter rate[2]	Naïve occupancy[1]	Encounter rate[2]
Golden jackal *Canis aureus*	LC	0.26	23.63	0.61	84.88
Dhole *Cuon alpinus*	EN	0.02	0.42	0.02	0.20
Jungle cat *Felis chaus*	LC	0.06	1.69	0.11	2.74
Clouded leopard *Neofelis nebulosa*	VU	0.02	0.42	0.03	0.39
Leopard *Panthera pardus*	VU	0.06	2.95	0.06	1.56
Leopard cat *Prionailurus bengalensis*	LC	0.22	9.28	0.35	9.97
Small Asian mongoose *Herpestes javanicus*	LC	0.02	2.11	0.03	0.39
Crab-eating mongoose *Herpestes urva*	LC	0.22	14.77	0.26	13.69
Yellow-throated marten *Martes flavigula*	LC	0.10	2.11	0.19	4.11
Ferret badger *Melogale* sp.	LC	0.12	6.75	0.13	6.45
Sun bear *Helarctos malayanus*	VU	0.02	0.42	0.02	0.20
Asiatic black bear *Ursus thibetanus*	VU	0.02	0.42	ND	ND
Common palm civet *Paradoxurus hermaphroditus*	LC	0.66	81.01	0.69	61.22
Large-spotted civet *Viverra megaspila*	EN	0.44	62.45	0.56	59.07
Large Indian civet *Viverra zibetha*	LC	0.28	10.97	0.37	24.84
Small Indian civet *Viverricula indica*	LC	0.24	14.77	0.37	39.31
Gaur *Bos gaurus*	VU	0.08	1.69	0.05	1.76
Banteng *Bos javanicus*	EN	0.04	0.84	0.02	0.20
Sambar *Rusa unicolor*	VU	0.24	6.75	0.19	4.69
Eld's deer *Rucervus eldii*	EN	ND	ND	0.02	0.20
Red muntjac *Muntiacus muntjac*	LC	0.70	64.14	0.76	35.60
Eurasian wild pig *Sus scrofa*	LC	0.80	80.59	0.87	68.06
Lesser Oriental chevrotain *Tragulus kanchil*	LC	0.22	27.85	0.19	11.34
Burmese hare *Lepus peguensis*	LC	0.10	7.59	0.23	35.79
Sunda pangolin *Manis javanica*	CR	0.02	0.42	ND	ND
Crab-eating macaque *Macaca fascicularis*	LC	0.38	20.68	0.29	15.84
Northern pig-tailed macaque *Macaca leonina*	VU	0.26	18.99	0.26	9.00
Indochinese silvered langur *Trachypithecus germaini*	EN	0.06	1.27	ND	ND
Asian elephant *Elephas maximus*	EN	0.04	3.38	0.06	0.98
Malayan porcupine *Hystrix brachyura*	LC	0.36	37.13	0.27	13.89

[1] Proportion of stations a species was detected at least once; [2] Number of records / 1,000 camera-trap-nights.

& Phan, 2011; Gray, 2012). Although sampling effort in DDF increased during the second survey period at Chhep Wildlife Sanctuary, leopards were not detected there or at stations in mosaics of DDF and S/EGF. Lower detectability in DDF is unlikely to be the only plausible explanation and it may be that leopards occur at relatively low densities in the wildlife sanctuary. Severe declines have occurred in leopard populations across Indochina (Rostro-García *et al.*, 2016), and Chhep is unlikely to be an exception. The reasons for this decline are many, but hunting for external markets has played a role, at least in the 1990s (Loucks *et al.*, 2009). According to a hunter living near Chhep Wildlife Sanctuary, a leopard body was previously sold to a middleman for its skin and bones for about 200 USD. Bears were also were in demand. The gall bladder and bones of each Asiatic black bear sold for ca.

Table 2 Percentage of camera trap stations in three forest types where mammal species were recorded in Chhep Wildlife Sanctuary during the 2012–2013 and 2013–2014 dry seasons.

Species	No. of stations detected	DDF (n=28)[1]	S/EGF (n=43)[1]	DDF & S/EGF mosaic (n=19)[1]
Golden jackal *Canis aureus*	44	40.91	34.09	25.00
Dhole *Cuon alpinus*	2	50.00	50.00	0.00
Jungle cat *Felis chaus*	8	87.50	0.00	12.50
Clouded leopard *Neofelis nebulosa*	3	0.00	66.67	33.33
Leopard *Panthera pardus*	6	0.00	100.00	0.00
Leopard cat *Prionailurus bengalensis*	31	32.26	38.71	29.03
Small Asian mongoose *Herpestes javanicus*	3	66.67	33.33	0.00
Crab-eating mongoose *Herpestes urva*	24	25.00	42.00	33.00
Yellow-throated marten *Martes flavigula*	17	41.18	29.41	29.41
Ferret badger *Melogale* sp.	14	42.86	28.57	28.57
Sun bear *Helarctos malayanus*	2	0.00	100.00	0.00
Asiatic black bear *Ursus thibetanus*	1	0.00	100.00	0.00
Common palm civet *Paradoxurus hermaphroditus*	71	27.78	45.00	25.00
Large-spotted civet *Viverra megaspila*	52	42.31	25.00	30.77
Large Indian civet *Viverra zibetha*	31	3.13	74.00	23.00
Small Indian civet *Viverricula indica*	32	50.00	28.13	18.75
Gaur *Bos gaurus*	7	14.29	71.43	14.29
Banteng *Bos javanicus*	2	50.00	0.00	50.00
Sambar *Rusa unicolor*	23	21.74	52.17	26.09
Eld's deer *Rucervus eldii*	1	100.00	0.00	0.00
Red muntjac *Muntiacus muntjac*	76	31.58	46.05	21.05
Eurasian wild pig *Sus scrofa*	85	31.00	46.00	22.00
Lesser Oriental chevrotain *Tragulus kanchil*	20	0.00	90.00	10.00
Burmese hare *Lepus peguensis*	18	55.56	11.11	27.78
Sunda pangolin *Manis javanica*	1	0.00	100.00	0.00
Crab-eating macaque *Macaca fascicularis*	37	18.92	48.65	29.73
Northern pig-tailed macaque *Macaca leonina*	26	0.00	76.92	23.08
Indochinese silvered langur *Trachypithecus germaini*	3	33.33	33.33	33.33
Asian elephant *Elephas maximus*	6	0.00	83.33	16.67
Malayan porcupine *Hystrix brachyura*	32	12.12	60.61	27.27

[1] n = Number of camera trap stations. Stations used in both dry seasons are counted as one.

100 USD and those of sun bear were sold for 30 USD in the 1990s. Near the Thailand border in 1994, prices for these species were 140 USD for a leopard skin, 3.20 USD/kg for sun bear bones, and 80 USD for gall bladders from unidentified bears (Martin & Phipps, 1996).

Besides the leopard, three medium or small cat species were recorded in Chhep Wildlife Sanctuary: clouded leopard *Neofelis nebulosa*, jungle cat, and leopard cat. Clouded leopards were recorded at three stations including the edge of riverine forests and a juvenile was photographed in S/EGF. Leopard cats were recorded in all forest types, and a kitten with an adult was recorded in late December. The latter species (n=73) exhibited nocturnal (53.4%) and crepuscular (30.1%) behaviour in our study (Fig. 3) and its activity pattern varies from

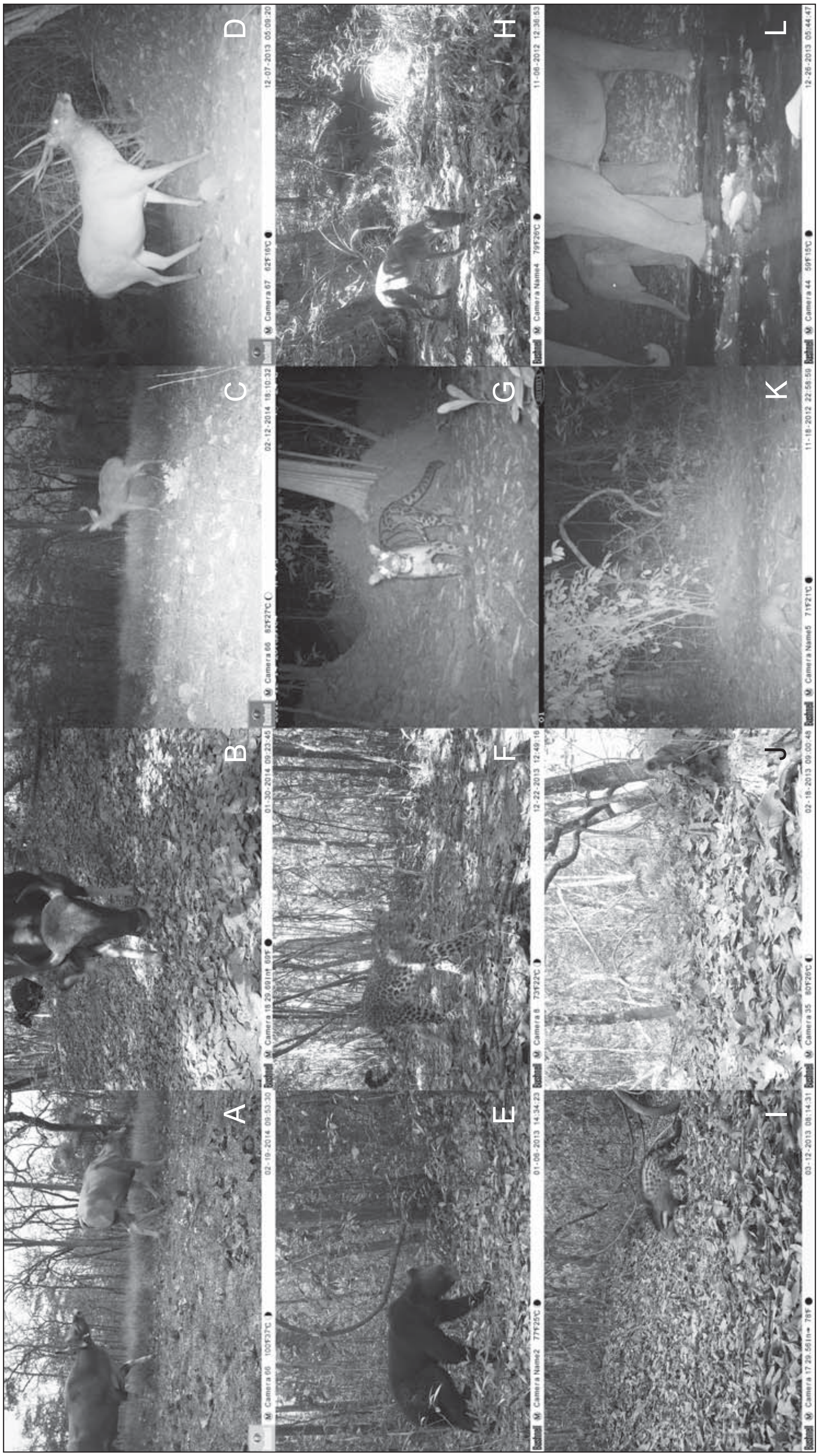

Fig. 2 Mammal species recorded during the 2012–2013 and 2013–2014 dry seasons in Chhep Wildlife Sanctuary. A) Banteng *Bos javanicus*; B) Gaur *Bos gaurus*; C) Eld's deer *Rucervus eldii*; D) Sambar *Rusa unicolor*; E) Asiatic black bear *Ursus thibetanus*; F) Leopard *Panthera pardus*; G) Clouded leopard *Neofelis nebulosa*; H) Dhole *Cuon alpinus*; I) Large-spotted civet *Viverra megaspila*; J) Indochinese silvered langur *Trachypithecus germaini*; K) Sunda pangolin *Manis javanica*; L) Asian elephant *Elephas maximus*.

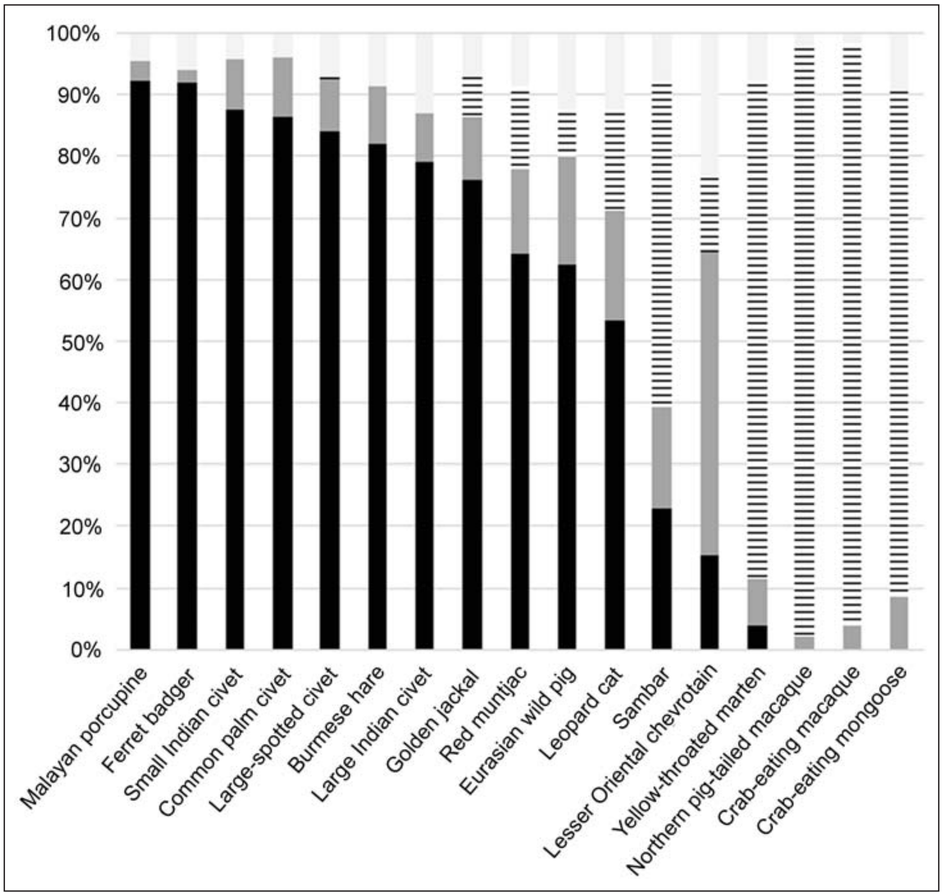

Fig. 3 Activity patterns of mammal species detected >20 times during the 2012–2013 and 2013–2014 dry seasons in Chhep Wildlife Sanctuary. Dawn (light grey): 05:00–7:00 hrs, day (horizontal lines): 07:01–16:59 hrs, dusk (dark grey): 17:00–19:00 hrs, night (black): 19:01–04:59 hrs.

arrhythmic to nocturnal in Indochina (e.g., Rabinowitz, 1990; Grassman *et al.*, 2005a; Austin *et al.*, 2007; Kitamura *et al.*, 2010; Gray *et al.*, 2012). Jungle cats were almost exclusively detected in DDF and not in S/EGF despite greater sampling effort in the latter. This species was photographed 18 times at eight camera trap stations in total, including near a small pool, motorcycle trails, and a very small pocket of semi-evergreen forest in DDF. This is consistent with data from eastern Cambodia, where 96% of encounters were in DDF (Gray *et al.*, 2012), and supports the idea that the species is strongly associated with DDF in Indochina (Duckworth *et al.*, 2005). Jungle cats are likely to be naturally rare, or have become rare in Indochina (Duckworth *et al.*, 2005) and recent studies suggest that the species is very rare in Vietnam (Willcox *et al.*, 2014) and Thailand (Simcharoen *et al.*, 2014; Tantipisanuh *et al.*, 2014). Our records consequently highlight the importance of Chhep Wildlife Sanctuary for jungle cats in Indochina, together with the eastern plains (Gray *et al.*, 2014). Fishing cats *Prionailurus viverrinus*, Asiatic golden cats *Catopuma temminckii*, and marbled cats *Pardofelis marmorata* were not recorded in our study, although all three species have previously been recorded in other areas in the northern plains (Rainy & Kong 2010; Edwards & Demski 2012; Suzuki *et al.*, 2015). Tigers *Panthera tigris* were also not recorded, although there are also historical records from the northern plains, including documentation that a minimum of 34 tigers was killed in 1998 (Sun, 2000).

The golden jackal was the most commonly photographed carnivore while dholes *Cuon alpinus* were recorded only twice in two dry seasons. Golden jackals were detected in all forest types, however, naïve occupancy and encounter rates increased greatly in the 2013–2014 survey period. Although comparisons between years in our dataset must be viewed with caution, this could be partially due to increased sampling effort in DDF in 2013–2014 (=22 camera trap stations vs. 8 in 2012–

2013). Like eastern Cambodia, where 98% of encounters were made in DDF (Gray *et al.*, 2012), encounter rates of this species were probably high in DDF at Chhep Wildlife Sanctuary. Of six camera stations where jackals were photographed >20 times, five were in DDF and one in a small area of semi-evergreen forest approximately 20 m from DDF.

In contrast to the golden jackal, dholes may occur in low densities at Chhep Wildlife Sanctuary. During our survey period, canine distemper virus (CDV) had possibly spread across Cambodia and could have lowered our detections of dholes which are susceptible to the disease (Kamler *et al.*, 2015). Although dholes are less likely to occur in human-dominated landscapes than golden jackal (Jenks *et al.*, 2015), they could be more susceptible to CDV (J. Kamler, pers. comm.) due to: 1) their requirement for larger group sizes to kill larger prey compared to jackals which hunt smaller prey (Johnsingh, 1982; Moehlman, 1983; Mukherjee *et al.*, 2004; Jaeger *et al.*, 2007); 2) amicable behaviour between within-group individuals (Fox, 1984). Further, when local people enter Chhep Wildlife Sanctuary they often bring dogs and dholes are often killed in snares in Cambodia (J. Kamler, pers. comm.).

Two species of mongoose (Herpestidae) were confirmed during our survey: small Asian mongoose *Herpestes javanicus* and crab-eating mongooses *H. urva*. Encounter rates of small Asian mongoose were very low in both survey periods, but may not accurately reflect their status in the area; rather, they likely reflect sampling bias (see Duckworth *et al.*, 2010). Villagers stated that the species is relatively common around villages (where no camera traps were set) and attacks poultry. In contrast, crab-eating mongooses were often photographed traveling in groups of up to four individuals during the day time in the wildlife sanctuary. The species was frequently recorded at three camera trap stations in particular. The first was at a river bed in DDF, and records began when the water became very shallow at the start of January. This station was set in both survey seasons, and produced the highest number of photographs of the species in both years, similar to the experience of Than Zaw *et al.* (2008) near a stream in the Hakaung Valley of Myanmar. The two other stations were in a small pocket of semi-evergreen forest near a dirt road in DDF and at a shallow water pool where water remains until February under the tangled branches of a shrub.

Two species of Mustelidae were recorded, yellow throated-marten *Martes flavigula* and ferret badger. Hog badgers *Arctonyx collaris* were not recorded, although the species is thought to occur, or have occurred, in the wildlife sanctuary. Villagers reported using hog badger oil for traditional medicinal use. Yellow-throated martens exhibited diurnal activity in line with previous studies (Grassman *et al.*, 2005b; Johnson *et al.*, 2009), and were recorded in both DDF and S/EGF. This species was mostly photographed once at each station where it was detected, but was photographed more than four times at two in particular. One of the latter stations was in a small dry stream (<5 m width) in DDF. The other was

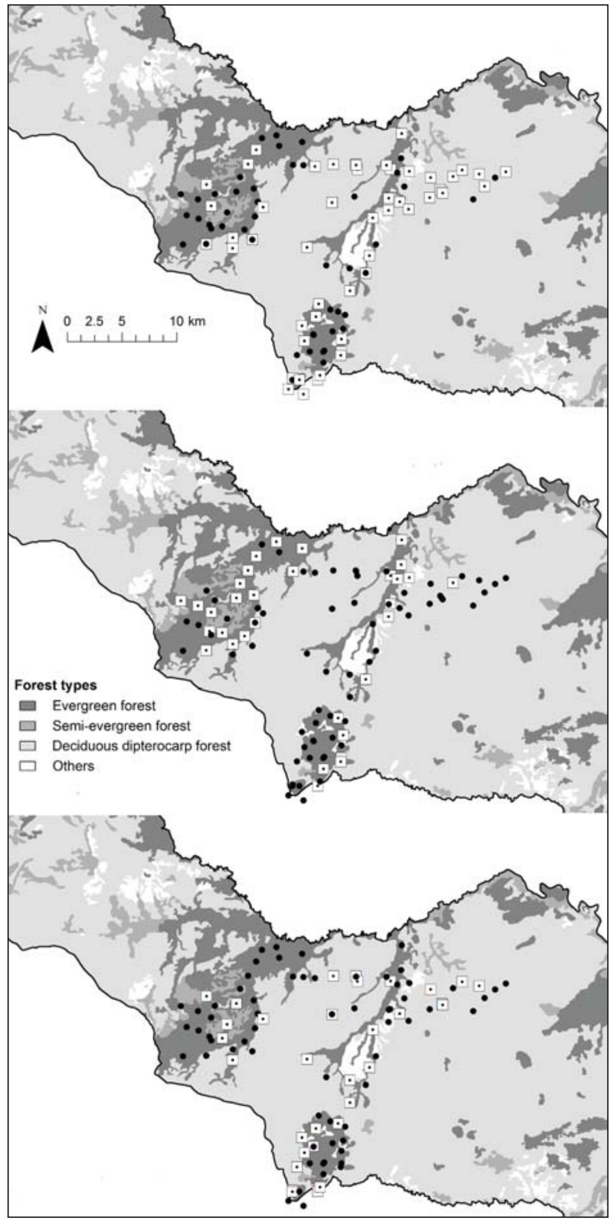

Fig. 4 Camera trap stations where large-spotted civet (top), large Indian civet (middle), and small Indian civet (bottom) were surveyed at Chhep Wildlife Sanctuary. White squares represent detections and black points non-detections.

in a small patch of bamboo forest close to a large pond in DDF where a leaf litter fire was observed at the end of February in the 2013–2014 dry season. Local people were also frequently photographed at this station. Ferret badgers were photographed at 14 camera trap stations. The most frequent capture station was in a dry river bed at the edge of S/EGF with 21 records from December to March. In Cambodia, the presence of large-toothed ferret badger is confirmed and the presence of small-toothed ferret badger *Melogale moschata* also remains a possibility (Schank *et al.*, 2009).

Four species of civet (Viverridae) were recorded with high encounter rates. This is likely due in part to bias in camera trap placement as the original purpose of the second survey was to investigate the occupancy of the subfamily Viverrinae. Nevertheless, the high encounter rate of the Endangered large-spotted civet is significant. This species is rarely recorded in Myanmar (Than Zaw *et al.*, 2008), southwestern Cambodia (Holden & Neang 2009), Malaysia (Hamirul *et al.*, 2015), Thailand (except for Khao Ang Rue Nai Wildlife Sanctuary) (Chutipong *et al.*, 2014), Laos, and Vietnam (W. Duckworth pers. comm.). In our study, the large-spotted civet was the second and third most commonly photographed carnivore in the 2012–2013 and the 2013–2014 dry seasons respectively, and the species was detected in all forest types (Fig. 4). This highlights the global conservation significance of Chhep Wildlife Sanctuary for the species and accords with records from Thailand (Chutipong *et al.*, 2014) and across its range (Timmins *et al.*, 2016). The camera trap stations with the top three highest encounter rates in our study were within or close to DDF, namely a shallow waterhole in a mosaic of DDF and S/EGF, a temporary pond in DDF, and a dry river bed in DDF. A high encounter rate was also reported near water sources in Thailand (Jenks *et al.*, 2010) and southwestern Cambodia (Holden & Neang 2009). In contrast, large Indian civets were rarely detected in DDF (Fig. 4). This is consistent with Gray *et al.* (2010), but differs from Thailand where the species is common in DDF (Chutipong *et al.*, 2014). The three stations with the highest encounter rates in our study comprised two at the intersection of animal trails in S/EGF and one on an animal trail close to a pond in S/EGF. The degree of spatial overlap between the sympatric large Indian civet and large-spotted civet is largely unknown (Gray *et al.*, 2010), and likewise with small Indian civet *Viverricula indica*. In our study, the former two species were both photographed at 15 of the same camera stations. Eight of these were in S/EGF, five in a mosaic of DDF and S/EGF, and two in DDF (Fig. 4). Large-spotted civets were photographed with small Indian civets more often at the same station (20 stations) than large Indian civets (3 stations). An occupancy study is currently underway to understand habitat use of these three Viverrinae in DDF-dominated landscapes at Chhep Wildlife Sanctuary.

Large ungulates

Large ungulates were detected at a minority of camera trap stations during our survey. However, gaur, banteng, Eld's deer and sambar *Rusa unicolor* were all photographed at a single station which targeted a trail a few meters from a relatively small water hole in DDF, approximately 2 km from semi-evergreen forest. The water hole was surrounded by grass which was burnt in January and became dry in February. The area surrounding the waterhole was open, lacking tall grass or scrubs, allowing large ungulates easy access from many directions. This also increased the detection range of the camera beyond the targeted trail resulting in photographs of these ungulates travelling off-trail. Away from this seasonal water hole, gaur was detected only in an area of contiguous evergreen forest, stretching from southern Laos to Preah Roka Wildlife Sanctuary (Cambodia). These cameras were located at the intersections of animal trails and along a dry river bed in S/EGF. Gaur occur in a wide range of habitats (Bhumpakphan & McShea, 2011), and their use of different forest types varies according to season (Ahrestani *et al.*, 2012), social class (Steinmetz *et al.*, 2008), and their populations in relation to the availability of and competition over high-quality habitat (Steinmetz *et al.*, 2010).

Encounter rates of gaur, banteng, sambar and Eld's deer were relatively low. This partly reflects bias in our placement of camera traps. Our surveys originally targeted small carnivores, and thus, if locations were deemed unsuitable for these or no signs of small carnivores were found, cameras were not set in locations even where salt licks or places where signs of large ungulates were present. This bias is evident when our results are compared with previous studies in Chhep Wildlife Sanctuary. For example, encounter rates of gaur and banteng were higher during small-scale camera trap surveys in 2010 and 2011 which targeted kouprey *Bos sauveli* (Wildlife Conservation Society, unpublished data). Although sampling bias must therefore be considered, large ungulates populations are likely to be decreasing in the wildlife sanctuary as well as many other places within their range. The status of banteng is especially of concern. Banteng almost exclusively uses DDF where plant species preferred by the species are common (Bhumpakphan & McShea, 2011), and the species was recorded in DDF during line transect surveys at Chhep Wildlife Sanctuary (Rainy *et al.*, 2010). However, sightings of banteng were very rare during our monthly visits to camera traps in DDF over two successive dry seasons. Though the potential for sightings would be less if banteng used evergreen forests in the wildlife sanctuary more in the day time during the dry season, as in West Thailand (Bhumpakphan & McShea, 2011), sightings were very rare even in mornings and evenings.

Conservation implications

DDF-dominated landscapes are threatened and poorly represented in protected areas in mainland Southeast Asia (McShea *et al.*, 2005; Tantipisanuh & Gale, 2013; Wohlfart *et al.*, 2014; Johnson, 2015). Lowland forests are also poorly protected: >90% of protected areas created after 1965 are located above 200 m a.s.l. (Déry & Vanhooren, 2011). Given this situation, the confirmed occurrence of DDF-associated species—namely jungle cat and two globally Endangered species, Eld's deer and banteng—highlights the conservation importance of Chhep Wildlife Sanctuary. In addition, the Endangered large-spotted civet, which likely prefers lowland areas, was commonly photographed in the wildlife sanctuary, suggesting potential for the site to provide a stronghold for the species. Consistent with Tordoff *et al.* (2005), small areas of S/EGF were used by 27 large mammal species, indicating that these areas are likely to be important components of DDF-dominated landscapes for some large mammals during the dry season. Further research on seasonal habitat use and movements would assist conservation management of large mammals in Chhep Wildlife Sanctuary.

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Ethnobotanical knowledge of the Kuy and Khmer people in Prey Lang, Cambodia

Nerea TURREIRA-GARCIA[1,*], Dimitrios ARGYRIOU[1], CHHANG Phourin[2], Prachaya SRISANGA[3] & Ida THEILADE[1,*]

[1] Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 25, 1958 Frederiksberg, Denmark.

[2] Forest and Wildlife Research Institute, Forestry Administration, Hanoi Street 1019, Phum Rongchak, Sankat Phnom Penh Tmei, Khan Sen Sok, Phnom Penh, Cambodia.

[3] Herbarium, Queen Sirikit Botanic Garden, P.O. Box 7, Maerim, Chiang Mai 50180, Thailand.

* Corresponding authors. Email n.turreira@gmail.com, idat@ifro.ku.dk

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ជនជាតិដើមភាគតិច និង សហគមន៍ដែលពឹងផ្អែកលើព្រៃឈើត្រូវបានគេដឹងថាមានចំណេះដឹងពិសេស លើធនធានធម្មជាតិនៅជុំវិញតំបន់ពួកគេរស់នៅ។ ទោះជាយ៉ាងណា ការខូចបរិស្ថានបានបន្ថយកម្រិតធនធានធម្មជាតិដែលធ្លាប់មាន និង គំរាមកំហែងដល់ភាពបន្តមាននៃជីវវប្បធម៌របស់ជនជាតិដើមនិងប្រជាជនក្នុងតំបន់ទូទាំងពិភពលោក។ ការសិក្សានេះបានចងក្រងឯកសាររុក្ខជាតិដែលប្រើប្រាស់ដោយប្រជាជនរស់នៅជុំវិញតំបន់ព្រៃទំនាបសេសសល់ចុងក្រោយមួយក្នុងប្រទេសកម្ពុជា។ ការប្រមូលទិន្នន័យបានធ្វើនៅចន្លោះឆ្នាំ២០១៤ និង ២០១៦។ ការធ្វើផែនទីសិក្សាដោយមានការចូលរួមពីសមាជិកសហគមន៍និងមានការប្រមូលគំនិតដោយសេរី (free-listing) ជាមួយប្រជាជនចំនួន៣១នាក់ អ្នកប្រមូលរុក្ខជាតិនិងការពិភាក្សាជាមួយក្រុមគោលដៅចំនួន១២នាក់ ត្រូវបានធ្វើក្នុងភូមិចំនួនបីក្នុងខេត្តព្រះវិហារនិងស្ទឹងត្រែង។ សរុបមានរុក្ខជាតិដែលគេនិយមប្រើចំនួន៣៧៩ប្រភេទ ដែលត្រូវបានកត់ត្រា ក្នុងនោះ៩០% ត្រូវបានប្រមូល និង ធ្វើចំណែកថ្នាក់។ ប្រភេទទាំងនេះភាគច្រើនត្រូវបានប្រើប្រាស់ជាឱសថ(៦៧%) អាហារ(៤៩%)និងជាសម្ភារៈប្រើប្រាស់(៣៧%) ហើយភាគច្រើនប្រភេទមួយត្រូវបានប្រើប្រាស់ច្រើនយ៉ាង។ ធនធានព្រៃឈើដែលសំខាន់ជាងគេសម្រាប់ជនជាតិគួយគឺជាប្រភេទឈើផ្តល់ជ័រនៃពួក*Dipterocarpus* ដែលត្រូវបានចាត់ក្នុងប្រភេទរងគ្រោះដោយអង្គការIUCN។ បុរសនិងស្ត្រីបានស្គាល់ប្រភេទរុក្ខជាតិដែលមានប្រយោជន៍ក្នុងចំនួនប្រហាក់ប្រហែលគ្នា ហើយមានរបៀបនៃការប្រើប្រាស់ខុសគ្នា (បុរសប្រមូលប្រភេទរុក្ខជាតិដូចគ្នាទៅនឹងប្រភេទដែលស្ត្រីប្រើប្រាស់)។ មានរបាយការណ៍ជាច្រើនស្តីពីប្រភេទរុក្ខជាតិមានប្រយោជន៍ដែលបង្ហាញពីប្រភេទដែលផ្តល់សារៈសំខាន់ផ្នែកសេដ្ឋកិច្ចនិងវប្បធម៌ ព្រមទាំងស្ថានភាពរបាយ និង អភិរក្ស។ ការអភិរក្សព្រៃឈើពិតជាមានសារៈសំខាន់ក្នុងការទ្រទ្រង់ជីវភាព និង ចំណេះដឹងពាក់ព័ន្ធនឹងរុក្ខជាតិនិងមនុស្សនៃប្រជាជនក្នុងតំបន់ និង ជនជាតិដើមនៅព្រៃឡង់។

Abstract

Indigenous peoples and forest-dependent communities are known to hold unique knowledge on natural resources in their surrounding environment. However, environmental degradation has diminished the availability of natural resources and threatens the bio-cultural survival of indigenous and local people world-wide. This study documented the plants used by people living in the vicinity of one of Cambodia's last remaining lowland rainforests. Fieldwork took

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place between 2014 and 2016. Participatory mapping exercises and 'free-listings' with 31 informants and participatory botanical collections and focus group discussions with 12 key informants were conducted across three villages in the Preah Vihear and Stung Treng provinces. A total of 374 useful 'folk taxa' were recorded, 90% of which were collected and identified. These species were mostly used as medicine (67%), food (44%) and/or materials (37%) with many species having multiple uses. The most important forest resources for the Kuy people were resin trees of the genus *Dipterocarpus*, some of which are listed as Endangered by IUCN. Men and women knew similar numbers of useful plants and played different roles in relation to these. Given the many useful plants reported, the indication of culturally and economically important species, and their distribution and conservation status, forest conservation appears to be essential to maintain the livelihoods and associated ethnobotanical knowledge of local and indigenous people in Prey Lang.

Keywords

Bio-cultural diversity, knowledge loss, Kui, Kuoy, local ecological knowledge, participatory plant collection, Prey Long, traditional ecological knowledge.

Introduction

Indigenous peoples and forest-dependent people in general hold a unique knowledge on natural resources in their surrounding environment (Martin, 2004). Among other things, their knowledge about plants useful for medicine, food, and construction improves their resilience to adversity. Worldwide, deforestation threatens the availability of natural resources useful for forest-dependent people, placing their bio-cultural survival under pressure. Ethnobotanical knowledge is directly related to the use of plant resources (Gadgil *et al.*, 1993): if a plant is no longer available, it cannot be used and knowledge related to it may disappear. Under rapidly changing socio-economic, political and environmental conditions, knowledge related to the use of natural resources can be lost within a single generation (Reyes-García *et al.*, 2013), especially given that ethnobotanical knowledge is usually orally transmitted and rarely documented (Case *et al.*, 2005; Turreira-García *et al.*, 2015). Documentation of ethnobotanical knowledge consequently provides an ancestal legacy for current and future generations. Ethnobotanical knowledge can also serve as an indicator of biodiversity (Salick *et al.*, 1999) and as a measure of dependency upon the surrounding environment (Araújo & Lopes, 2011).

There is a growing trend in employing local people as parataxonomists to provide biodiversity inventories (Janzen, 2004; Janzen & Hallwachs 2011; Zhao *et al.*, 2016) and local knowledge is increasingly used in ecological and conservation research and monitoring. Local people are rarely actively involved in the research process, however (Brook & McLachlan, 2008). According to a recent review on the status of ethnobiology in Southeast Asia, Cambodia is one of the least researched countries (Hidayati *et al.*, 2015) with only 13 ethnobiological publications between 1960 and 2014. Our reviews of recent ethnobotanical studies in Cambodia, Thailand, Vietnam, and Laos also reveal that most studies have been undertaken in Thailand and have mainly focussed on medicinal plants (Table 1). (Only studies that focused on ethnic groups and included (semi-)wild plants were taken into account. Studies that did not encompass local people's knowledge, reviewed only one species or strictly inventoried homegardens were excluded). The only ethnobotanical studies involving the Kuy people in the literature were one Master's thesis about *materia medica* employed by Kuy healers in Thailand, which documented the use of 333 medicinal plants (Virapongse, 2006), and a study of medicinal plants used for postpartum ailments (Grape *et al.*, 2016).

Prey Lang ('our forest' in Kuy language) covers 530,000 ha in the central plains of Cambodia and is considered the last intact lowland rainforest in mainland Indochina (MacDonald, 2004). In May 2016, 432,000 ha of Prey Lang were gazetted as a wildlife sanctuary. However, 4,700 ha of this area is affected by economic land concessions and mining concessions (Argyriou *et al.*, 2016) and about 50,000 ha of forests bordering the sanctuary are impacted by 53 concessions for agro-businesses (LICADHO, 2016). Forest clearance within and nearby these concessions and rampant illegal logging throughout Prey Lang threaten its biodiversity and natural resources (Olsson & Emmett, 2007). An estimated 250,000 villagers also live in the vicinity of Prey Lang and depend on it for their livelihoods (Hüls Dyrmose *et al.*, in press) and culture.

The aims of our study were to: i) document the ethnobotanical knowledge of Kuy and Khmer people living nearby the Prey Lang forests (specifically regarding forest types, important natural resources, useful plants

Table 1 Previous ethnobotanical studies in Indochina based on searches made in Scopus, Web of Science and the Royal Library of Denmark and Copenhagen library services on 16 March 2017. UC = Plant use category (WEP = wild edible plants; MED = general medicine; DSD = digestive system disorder; CI= cognitive impairment; WH = women's healthcare; REP = repellents and pesticides); Spp. = Number of species (not necessarily scientifically recognized species); Vill. = Number of villages; Inf. = Number of informants; n.s. = not stated; * = Includes cultivated species.

Reference	Ethnic group (Country)	UC	Spp.	Vill.	Inf.	Vegetation
Grape *et al.* (2016)	Kuy (Cambodia)	MED, WH	68	4	50	Evergreen, semi-evergreen & deciduous dipterocarp forest
Chassagne *et al.* (2016)	Buong (Cambodia)	MED	214	28	202	Savanna, evergreen, semi-evergreen, deciduous dipterocarp & bamboo forest
Whitney *et al.* (2016)	Dao, Hmon, Kinh, Ma-Lieng, Sach, Tai, Tay, Xinh-Mun (Vietnam)	n.s.	111	5	n.s.	n.s.
Cruz-Garcia & Struik (2015)	Isaan (Thailand)	WEP	20	1	7	Dry monsoon forest (dipterocarp forest)
Tangjitman *et al.* (2015)	Karen (Thailand)	MED, DSD	36	6	178	Deciduous, tropical evergreen & dry dipterocarp forest
Neamsuvan *et al.* (2015)	n.s. (Thailand)	MED	95	7	7	Mangrove & swamp forest
Offringa (2015)	Khon Muang (Thailand)	MED, CI	n.s.	n.s.	16	n.s.
Elkington *et al.* (2014)	Lao (Laos)	MED	250	n.s.	12	Evergreen-mixed & deciduous forest
Khuankaew *et al.* (2014)	Tai Yai (Thailand)	MED	141	4	126	n.s
Junsongduang *et al.* (2014)	Karen, Lawa (Thailand)	MED	103	2	67	n.s
Kosaka *et al.* (2013)	Lao, Tai Leu, Tai Dam, Tai Deng, Khmu, Hmong (Laos)	WEP	115	2	20	Paddy fields
Tangjitman *et al.* (2013)	Karen (Thailand)	MED, WH	379*	14	458	Mixed deciduous, coniferous & hill evergreen forest
Inta *et al.* (2013)	Yuan (Thailand)	MED	93	5	30	n.s.
Srithi *et al.* (2012)	Hmong (Thailand)	MED, WH	79*	3	153	n.s.
Cruz-Garcia & Price (2011)	Isaan (Thailand)	WEP	87	4	n.s.	Dry monsoon forest (dipterocarp forest)
Lamxay *et al.* (2011)	Kry (Laos)	MED, WH	49	3	20	n.s.
de Boer *et al.* (2010)	17 groups (Laos)	REP	92	66	n.s.	n.s.
de Boer & Lamxay (2009)	Brou, Saek, Kry (Laos)	MED, WH	55	10	38	Secondary forest
Inta *et al.* (2008)	Akha (Thailand & China)	MED	95	5	50	n.s.
Libman *et al.* (2006)	n.s. (Laos)	MED	55	8	n.s.	n.s.
Johnson & Grivetti (2002)	Karen (Thailand)	WEP	47	2	32	Degraded secondary forest
Van On *et al.* (2001)	Dao (Vietnam)	MED	200	n.s.	n.s.	Primary & secondary forest, bamboo thicket, grassland, plantation
Anderson (1986a)	Akha (Thailand)	MED	121	n.s.	n.s.	Dry evergreen & lower montane (moist evergreen) forest
Anderson (1986b)	Lahu (Thailand)	MED	68	n.s.	n.s.	Lower montane (moist evergreen) region

and forest-spirits); and, ii) investigate the ability of local and indigenous people to collect plant voucher specimens. We also compared the local names of plants and forest types to scientific classifications and assessed how much of their useful or culturally important flora was threatened. The study did not consider differences in knowledge between Kuy and Khmer people because of the cultural continuum between the two groups (Swift, 2013). Our findings will later be shared with the communities in the form of a book.

Methods

Study area and ethnicity

The greater Prey Lang area extends over four provinces in the central plains of Cambodia: Preah Vihear, Stung Treng, Kratie, and Kampong Thom. The area contains seven vegetation types among its evergreen, semi-evergreen, and deciduous forests, which differ significantly in species composition, dominant tree species and plant community structure (McDonald, 2004; Olsson & Emmett, 2007; Theilade *et al.*, 2011).

Approximately 250,000 people live in the greater Prey Lang area and the dominant ethnic groups are Kuy (indigenous) and Khmer (Cambodian). The Kuy (also recorded as Kui, Kuoy, Kuay, Kouy, Suoy or Suay) occur in northeastern Thailand, southern Laos, and northern and northeastern Cambodia. Most of the Kuy people in Cambodia live in the Prey Lang area, with an unverified population estimate of 23,000 (Swift, 2013).

Kuy and Khmer people are similar in terms of physical appearance, material culture, and religious practices: both groups are culturally and spiritually linked to the forest and practice of animism and Buddhism in Prey Lang (Swift, 2013). Lowland rice cultivation and swidden agriculture are widespread among both. The majority of inhabitants rely directly on the natural resources of Prey Lang for their livelihoods and resin tapping (extraction of oleoresin from dipterocarp trees) is the main source of cash income (Jiao *et al.*, 2015; Hüls Dyrmose *et al.*, in press).

Differences between the Kuy and Khmer groups have become subtle since national integration and assimilation policies were adopted by the Cambodian Government following independence in 1953 (Baird, 2011). These policies were strengthened during the Pol Pot regime in the 1970s, when Kuy communities were resettled to lowland areas such as Prey Lang and those speaking Kuy language were punished. Interaction and inter-marriage between Kuy and Khmer is frequent and many Kuy have adopted Khmer culture and traditions, although small differences still exist between the two groups. These include distinctive rituals (e.g., the Kuy practice communal fishing before the annual ceremony for the village spirit, perform rites for spirits before clearing new swiddens, or involve a certain species of turtle in weddings) and some characteristic crafts, foods, clothing and housing styles. While the two groups fomerly distinguished themselves through economic specialties such as iron production, their livelihood strategies of Kuy and rural Khmer are now very similar (Swift, 2013).

In recent decades, the Kuy identity has been based upon language and/or family descent, whereby a person may identify themself as Kuy if they speak the language and/or have a Kuy parent. However, Kuy people sometimes deny their ethnicity because they may be perceived as being of lower status (Swift, 2013). The Kuy language also shares many terms with Khmer, which may be due to their shared roots (because both are Mon-Khmer languages) or borrowed from Khmer (Mann & Markowski, 2005).

Three villages in Prey Lang were selected for the study: Thmea and Phneak Roluek in Preah Vihear Province and Spong in Stung Treng Province (Fig. 1). Thmea and Phneak Roluek were selected by representatives of the Prey Lang Community Network (PLCN) because they comprise traditional Kuy villages. The PLCN is a network of villagers within the Prey Lang area who advocate for forest protection through peaceful patrols and anti-logging interventions. Spong was selected by the authors due to its proximity to the core area of Prey Lang. This is the least disturbed area of the Prey Lang forests and is dominated by primary evergreen dipterocarp forest, with local residents reportedly being Khmer.

At the time of the study, Thmea was the largest village (2,024 people), closest to a paved road (36 km), surrounded by disturbed and deciduous forest, and furthest from evergreen forest. Spong was the smallest village (497 people), furthest from paved roads (73 km) and markets (76 km), and mainly surrounded by primary evergreen dipterocarp forest. Phneak Roluek Village was intermediate in size (587 people), distance to a paved road (44 km) and distance to evergreen forest (CDB Online, 2010) (Fig. 1).

Study formulation and methods

The idea to conduct an ethnobotanical study was initially discussed by the authors and PLCN steering committee. The committee agreed that it would be useful to document their knowledge and agreed to co-design the study and participate in the research process. Fieldwork took

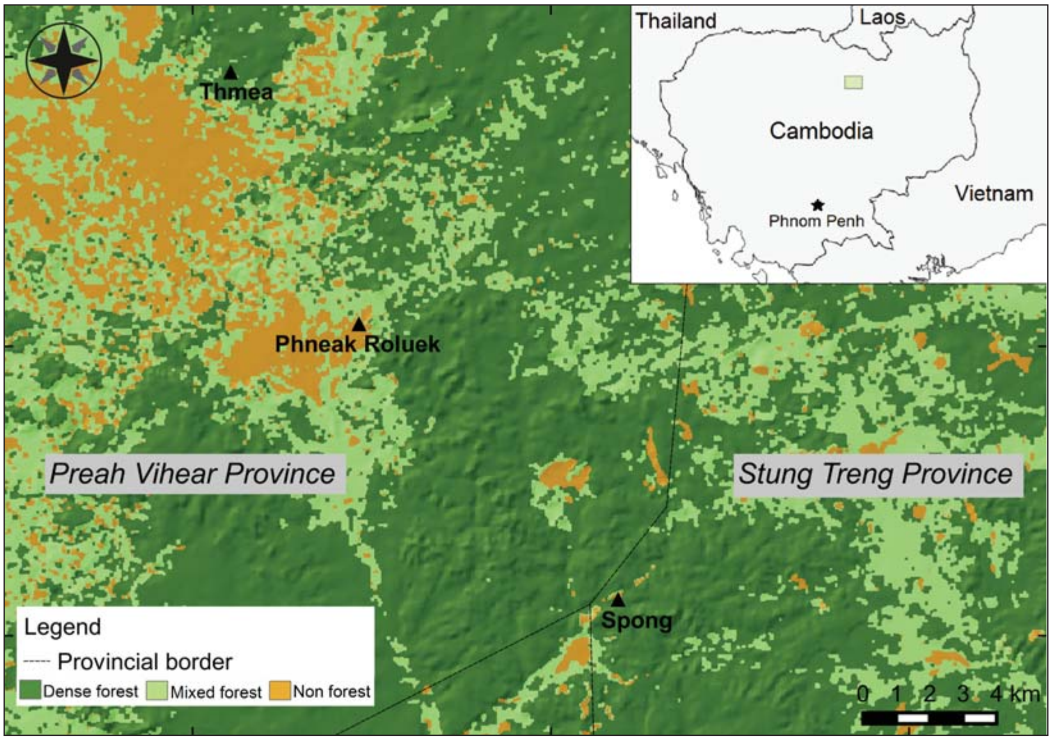

Fig. 1 Study sites in Prey Lang, Cambodia. Created using forest cover map (Open Development Cambodia, 2014) and natural earth data in QGIS.

Fig. 2 Kuy woman carrying a handmade basket outside a traditional house. Phneak Roluek Village, Preah Vihear Province, September 2014 (© Nerea Turreira-García).

Fig. 3 Plant collector in Prey Lang, near Spong Village, Stung Treng Province, May 2015 (© Nerea Turreira-García).

place during September 2014, April–May 2015, and December 2016. Field methods included participatory mapping exercises, rankings, free-listings, forest walks, botanical collections and focus group discussions, and are explained in more detail below.

To record local knowledge of plants used by the Kuy people at Prey Lang, the Thmea, Phneak Roluek, and Spong villages were visited three times. During the first visit, five to seven men and four to seven women participated in workshops led by the first author and an interpreter in each village. The men were 53 ±13 years old and women 52 ±3 years old on average. Workshop participants were decided by a PLCN representative from each village, based on participants' knowledge of the area and its natural resources. Following the International Society of Ethnobiology guidelines (ISE, 2006), the study objectives were explained and participants gave their prior informed consent. Sharing and publication of results, and confidentiality were agreed upon. The workshops consisted of a participatory mapping exercise where participants drew their community boundaries, forest types, zones of use, and the most important sites and natural resources (Gilmore & Young, 2012). This helped the authors to become familiar with the area and local terms and aided the design of later forest walks and botanical collections with the participants. Participants were also asked to describe the defining characteristics of each-forest type and natural resources identified in the mapping exercise were ranked in order of importance.

Men and women were separated into two gender-based groups to free-list useful plants, including those they did not use or only used infrequently. This allowed for smaller and more productive working groups, because men and women sometimes differ in their knowledge due to gender-based divisions of labour (Reyes-García *et al.*, 2007). This was especially valuable for engaging the women who otherwise might have contributed less. Each group recorded the name, growth form, habitat, uses and flowering season of each plant (Martin, 2004; Reyes-García *et al.*, 2006; Powell *et al.*, 2014) and took about 90 minutes to complete their free-lists.

During the second and third visits, plant species registered during the workshops (and others not included in the workshop lists) were collected during forest walks (Martin, 2004). Twelve people comprising two men and two women from each of the three villages assisted with the plant collection (Figs 2–3), seven of whom were Kuy and five Khmer. These were divided into male and female groups and trained in botanical specimen collection and note-taking. During the forest walks, local names for forest types were compared with the vegetation classifications and descriptions of McDonald (2004) and Rollet (1972).

A total of 704 specimens were collected, after which the collectors were asked about the uses, parts used, preparation methods, and local (folk) names for each plant. Local names that referred to the same scientific species were regarded as synonyms and counted as one taxon in analysis. At the end of each visit, plant collectors cross-checked information recorded during focus-group discussions. Information about forest spirits was collected through informal conversations with the plant collectors.

Plant uses were later categorised following Cook (1995), who defined 12 use categories, plus two additional categories defined by Gruca *et al.* (2014), namely 'cultural diseases and disorders' and 'ritual/magical' uses, and two categories defined by the authors, namely 'resin' and 'commerce' (Table 2). Ailments treated using medicinal plants were translated verbatim. Plant voucher specimen were dried and pressed at the Forest and Wildlife Research Institute in Phnom Penh. These were identified by two of the authors (CP & PS) and a full set of specimens were deposited in the Queen Sirikit Botanic Garden in Thailand. Species names and family classifications were confirmed using *The Plant List* (2013), and IUCN (2017) was used to determine the conservation status of species. In our analysis and interpretation, we refer to folk taxa based on local names, and to scientific species. Terms given in italics are in Khmer language.

Results

Forest types

During the participatory mapping exercise and forest walks, all three communities claimed to distinguish four types of forest (*prey* in Khmer, also used by Kuy):

1. *Prey robóh* ('sparse forest', Fig. 4), described as a non-dense, deciduous forest that grows nearby their rice fields and *chamkars* ('forest gardens'). *Prey robóh* corresponds to two forest types described by McDonald (2004), namely deciduous forest (<35 m tall) and short semi-evergreen forest (3–12 m tall). Local informants did not distinguish successional stages of the deciduous forest, whereas the short semi-evergreen forest is a combination of both deciduous and evergreen species.
2. *Prey sralao'* (no English translation, Fig. 5) was described by the local communities as a tall evergreen forest at Prey Lang, denser than *robóh* but easily traversable, and characterised by dominance of the *sralao'* trees (*Lagerstroemia* sp.). McDonald (2004) and Rollet (1972) classified this forest type with the same name.

Table 2 Description of plant use categories employed in this study for classifying plant use records (adapted from Cook (1995) and Gruca *et al.* (2014)).

Use category	Abbr.	Description
Food	F	Plants eaten by human beings, and plants used to make beverages
Food additives	Fa	Processing additives and other additive ingredients used in food or beverages preparation
Vertebrate food	V	Forage and fodder for domestic or wild vertebrates that are useful to humans
Invertebrate food	I	Plants eaten by invertebrates that are useful to humans
Apicolous	A	Plants that provide pollen, nectar or resins as sources for honey or propoleum production
Fuel	Fu	Plants used to produce charcoal, or used as petroleum substitutes, alcohols, tinder or firewood
Materials	Ma	Plants used for construction of houses, fences or bridges, or to elaborate handicrafts, music instruments, work tools, weapons, home objects, etc. This category includes fibres, waxes, oils, chemicals and their derived products (but not Resin), cosmetic products and dyes
Social	S	Plants used for cultural purposes, which are not definable as food or medicines. This category includes stimulants, and plants used for games (modified according to local beliefs)
Toxic to vertebrates	Tv	Plants that are poisonous to vertebrate animals, both accidentally and when deliberately applied, such as extracts and preparations used for fishing and hunting
Toxic to non-vertebrates	Tn	Plants that are poisonous to non-vertebrates, both accidentally and when deliberately applied. This category includes insecticides and herbicides
Medicinal	M	Plants used to cure human and animal sicknesses
Environmental	E	Plants used to protect, improve, and fertilise soils; to provide shadow, as living fences, ornamentals or that form a structural part of agroforestry systems
Cultural Diseases and Disorders	CDD	Plants used to treat disorders caused by spirits, such as mental illnesses and curses (modified according to local beliefs)
Ritual/Magical Uses	RMU	Plants used during healing ceremonies, incantations, prayers, offerings and sacrifices made to deities, fetishes/amulets/charms, divination/oracles, black magic/bad medicines, incense
Resin	R	This category is separated from 'Materials' due to its high importance in Cambodian livelihoods
Commerce	C	Plants used for trade and are part of the household economy

3. *Prey sdok* ('thick/narrow forest'), *prey thom* ('tall forest') and *prey chas* ('old forest') were Khmer synonyms for the 'hard to penetrate', tall forest at Prey Lang (Fig. 6). According to informants, this forest type is where more natural resources, expensive timber trees, resin trees, rattan and animals occur. It corresponds to the semi-evergreen and evergreen dipterocarp forests described by McDonald (2004) and the dense forest described by Rollet (1972).
4. *Prey choam* (in Kuy) or *prey roneam* (in Khmer, Fig. 7), was described as 'the forest growing on land permanently covered by shallow water'. McDonald (2004) distinguished two types of swamp forest, deciduous swamp forest and evergreen swamp forest, and Theilade *et al.* (2011) provided a detailed account of the latter. Both types of swamp forest are rare and endemic to the region.

Inhabitants of the three villages collect timber and non-timber forest products (NTFPs) in different areas of all four forest types. They usually follow rivers, trails which they create and maintain, and at Thmea Village, also a road built by a mining company. During their forest trips, they hunt and collect wood for construction, medicinal plants, resin and rattan. Trip frequency, duration, transportation and distance travelled vary according to the purpose and needs of each trip. In the dry season for example, men usually travel in pairs to the forest by *coyon* (local tractor) to collect oleoresin from dipterocarp trees. These trips last about three days and the collectors sleep in hammocks in forest shelters. Women usually walk or are carried by *coyon* or motorbike to collect NTFPs in daily trips throughout the year.

Importance of forest resources

Our ranking exercise revealed that the most important resources for all three villages are the resin trees belonging to the Dipterocarpaceae, followed by *pdao* (*Calamus viminalis* Willd.), a rattan used to make furniture for sale and local use. The Prey Lang area was also reported to be important for medicinal plants, wild edible plants, other kinds of NTFPs, wild animals and timber.

Fig. 4 Deciduous forest. Stung Treng Province, September 2014 (© Nerea Turreira-García).

Fig. 5 *Sralao'* (*Lagerstroemia* sp.) forest. Preah Vihear Province, April 2015 (© Nerea Turreira-García).

Fig. 6 Short semi-evergreen forest and evergreen dipterocarp forest. Preah Vihear Province, December 2016 (© Nerea Turreira-García).

Fig. 7 Evergreen swamp forest. Stung Treng Province, December 2016. (© Nerea Turreira-García).

Fig. 8 Spirit house near Phneak Roluek. Preah Vihear, September 2014 (© Nerea Turreira-García).

Folk taxa

Our free-listing exercises and plant collections yielded 374 folk taxa, 337 (90%) of which were collected and five photographed. Of the 337 folk taxa collected, eight were identified to family, 31 to genus and 288 to species (Appendix 1). Ten were not identified to species level. Thirty-two plants were not collected or photographed, either because they were locally extinct, occurred too far away or because (in two cases) our local plant collectors did not know them. Informants claimed to use at least 11 species of fungi, of which four belong to the Basidiomycota phyla. These are not considered further in our analysis.

The folk taxa recorded belonged to 83 families and the families most frequently listed were Leguminosae (10%), Rubiaceae (8%), Annonaceae (4%), Apocynaceae (4%), Malvaceae (4%), and Dipterocarpaceae (3%). Species known by most informants included highly valuable timber species such as *Hopea odorata* Roxb. (*korki*), *Afzelia xylocarpa* (Kurz) Craib (*beng*), *Heritiera javanica* (Blume) Kosterm. (*doungchem*), *Dalbergia oliveri* Prain (*neanghoun*), *Pterocarpus macrocarpus* Kurz (*thnong*), *Shorea roxburghii* G. Don (*porpael*), *Sindora siamensis* Miq. (*korkoh*), and *Terminalia mucronata* Craib & Hutch. (*bramdomleng*); *Lagerstroemia speciosa* (L.) Pers. (*kraol*), a medicinal plant with abundant and flashy purple flowers at the time of the collection; several resin-yielding species including *Dipterocarpus alatus* Roxb. & G.Don (*chhertheal*) and *D. intricatus* Dyer (*trach*); and finally, edible species and species with medicinal properties: *Azadirachta indica* A. Juss. (*sdao*), *Hymenodictyon orixense* (Roxb.) Mabb. (*aolaok*), and *Syzygium zeylanicum* (L.) DC. (*smarch*).

Most of the plants used were trees and shrubs (70%), followed by vines, including woody and non-woody lianas and climbers (24%), although herbaceous plants (5%) and palms (1%) were also registered. A total of 630 uses were recorded for the 374 folk taxa (Fig. 9) and each taxon had 2 ±1 (mean ± SD) uses on average. Most were used for medicine (*n*=249, 67%), food (*n*=165, 44%) or as material (*n*=138, 37%), especially for construction of houses, fences and huts.

Most medicinal folk taxa were used for a single ailment (51% of all medicinal folk taxa), 32% for two ailments, and 17% for more than two ailments. For instance, *Lagerstroemia speciosa* was reported to cure seven different illnesses. Almost 30% of the medicinal folk taxa were used to treat postpartum ailments, usually to stimulate appetite, milk production, blood circulation or uterus contraction. This was followed by plants that cured fever (20%), skin problems (17%) and stomach problems (10%).

Informants often agreed on the uses of folk taxa, although they sometimes used the same taxon for different ailments. For example, women from Phneak Roluek Village usually grind the leaves of *Drynaria sparsisora* (Desv.) T. Moore for boils, whereas men from Spong Village claimed that chewing the root of this plant cured urine infection. In addition, different parts of the same folk taxon were sometimes used for the same ailment. In Spong for example, the bark of *Terminalia mucronata* is

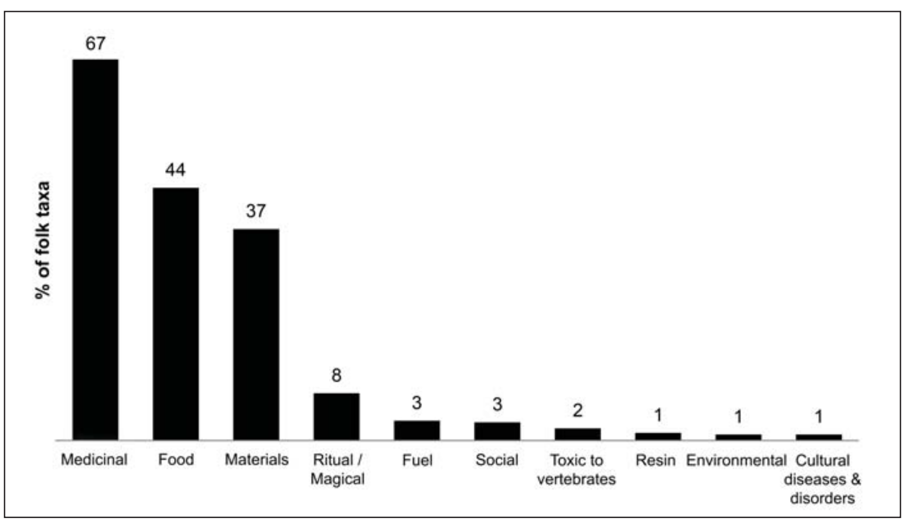

Fig. 9 Percentage of folk taxa (*n*=374) per plant-use category in Prey Lang, Cambodia.

boiled to treat diarrhoea, whereas women from Phneak Roluek Village boil the root for the same purpose. Men from Thmea Village claimed that the bark of *Ficus benjamina* should be boiled for skin infections, while men from Spong and women from Phneak Roluek prepare cold infusions of the root and/or leaves for the same purpose.

Men often knew the medicinal plants for postpartum ailments, but seldom knew their specific uses. The plant collectors from all three villages explained that men often collect the these plants for their wives and so recognize them, but that women usually prepare the medicines. Women consequently provided more information on the preparation of medicinal plants for postpartum ailments, although they did not always agree on what the postpartum plants were specifically used for. For example, women from Phneak Roluek boiled or made a tincture from the bark of *Hymenocardia punctata* Wall. ex Lindl. to improve postpartum blood circulation, whereas women from Spong boiled the root of the species to stimulate appetite, milk production and postpartum health.

Men collected and free-listed 237 species and women 235 species in total. Men knew 65 folk taxa that women did not free-list or collect, and women knew 81 folk taxa that men did not. Of the folk taxa known only to men, 47 were medicinal (19% of all medicinal folk taxa), 20 were materials (14%) and 12 were food (7%). Of the folk taxa only known to women, 46 were medicinal (18%, of all medicinal folk taxa), 40 were food (24%) and 18 were materials (13%). Informal conversations with the plant collectors on the differences between plants known and used by women and men revealed that they do not perceive knowledge as being influenced by gender. In their view, both men and women know the same plants.

Forest and village spirits

Informants explained during the plant collection that many spirits occur in the Prey Lang forest. Multiple forest spirits or village spirits exist, such that each community takes care of a particular forest-spirit, or group of spirits, and sometimes different communities take care of the same spirit. In addition, some trees have their own spirit. For example, when *Hopea odorata* (*korki*) and *Dipterocarpus alatus* (*chhertheal*) are large, these trees are inhabited by a spirit. Other large trees that possess their own spirit include *Irvingia malayana* Oliv. ex A.W.Benn. (*chombork*), *Sindora siamensis* (*korkoh*), *Lagerstroemia calyculata* Kurz (*sralao'*) and all resin-yielding trees. *Ficus pubilimba* Merr. (*chhrey*) trees also have a spirit, irrespective of size.

Spirit trees are not supposed to be cut, and villagers must ask permission from the spirit if they wish to do so. In general, people pray to the forest-spirit of the area in spirit houses (Fig. 8) and sacred sites before entering the forest. In their prayers they ask for permission to take its natural resources, and believe that if they fail to do so, the spirit will take revenge and harm them. They also make an offering to spirits before eating or drinking rice wine. Some people reported being angry at the spirits because they do not harm illegal loggers and companies that clearcut forest areas. However, they continue to praise the spirits out of respect (and possibly also fear).

A given spirit can either be male or female. The male spirit is usually called *neak ta* or *lok ta*, and the female spirit *yeay* in Khmer and *yeak* in Kuy. These names change according to the community. The culture of respect for the spirits is passed on through the generations. The forest and tree spirits can also have family members such as parents, spouse and/or children.

Conservation status

Thirty-five of the species recorded have been assessed by IUCN (2017) and a quarter of these belong to the Dipterocarpaceae, notably *Shorea guiso* Blume (*chorchong*, Critically Endangered), *Dipterocarpus alatus* (*chhertheal*, Endangered), *Shorea roxburghii* (*porpael*, Endangered) and *Anisoptera costata* Korth. (*pdeak*, Endangered). The dipterocarps are used for resin extraction and construction. *Pinus merkusii* Jungh. & de Vriese (*srorl*, Vulnerable) is also used for resin tapping. Some of the luxury wood species are also globally threatened, such as *Afzelia xylocarpa* (*beng*, Endangered), *Dalbergia oliveri* (*neanghoun*, Endangered), *Hopea odorata* (*korki*, Vulnerable), although *Sindora siamensis* is not (*korkoh*, Least Concern). A number of plant species used for food and medicine also occur on the IUCN list (though not necessarily in a threatened category), including *Curcuma sparganiifolia* Gagnep. (*kra chork anderk*, Near Threatened), *Aglaia edulis* (Roxb.) Wall. (*bang kau*, Lower Risk/Near Threatened) and *Irvingia malayana* Oliv. ex A.W.Benn. (*chombork*, Least Concern), as do species used for black magic such as *Xylopia pierrei* Hance (*kray sor*, Vulnerable).

Discussion

Prey Lang is a mosaic of forest types (McDonald, 2004; Theilade *et al.*, 2011) and its inhabitants are tightly linked to this area culturally, spiritually and economically. This forest-dependency has created a great body of ethnobotanical knowledge. The study participants, who were mainly middle-aged and older people, demonstrated extensive knowledge of useful flora in Prey Lang. Participants explained that some young people know less about the forest and do not show interest in such knowledge.

The youth would need time to accumulate ethnobotanical knowledge if they were interested to do so, if the resources were still available, and if their socio-political conditions were unchanged when they became adults (Reyes-García *et al.*, 2013).

The congruence between local and scientific forest classifications in our study supports the notion that local people can play a role in classification of forest types (Halme & Bodmer, 2007) and ecological conservation and research (Janzen, 2004). Most of the ethnobotanical terminology used by the participants was in Khmer, which suggests that use of the Kuy language for plant-related matters may be vanishing. As noted previously, the Kuy culture has largely been assimilated into Khmer culture in Cambodia (Swift, 2013). Study participants also reported that many children were separated from their parents during the Khmer Rouge (1963−1997) and lost the ability to speak Kuy. This contrasts with the culture of forest knowledge and respect for spirits, which has clearly survived.

The ethnobotanical knowledge of the inhabitants of Prey Lang encompasses mainly trees and shrubs, which may reflect the abundance and distribution of vegetation here. Most of the plants used were used for medicine, food and construction, similar to patterns of plant use by Kuy healers in Thailand (Virapongse, 2006). Compared with other studies in similar vegetation in Indochina, the numbers of medicinal plants used in Prey Lang (*n*=249) were similar or greater than those reportedly used by the Lao (*n*=250; Elkington *et al.,* 2013), Dao (*n*=200; Van On *et al.*, 2001), Akha (*n*=121; Anderson, 1986a) and Lahu (*n*=68; Anderson, 1986b) ethnic groups. Somewhat higher figures have been reported for Kuy healers (*n*=333; Virapongse, 2006) and the Karen ethnic group in Thailand, however (*n*=379; Tangjitman *et al.,* 2013), possibly due to greater survey coverage or because these studies included more cultivated species. The Kuy people also appear to know more wild edible plants (*n*=165) than the Isaan (*n*=87; Cruz-Garcia & Price, 2011) and Karen (*n*=47; Johnson & Grivetti, 2002) ethnic groups in Thailand.

Previous studies suggest postpartum ailments are the most frequent conditions treated with medicinal plants by the Kuy in Cambodia (Grape *et al.*, 2016). On revisiting the research sites of Grape *et al.* (2016), we found 11 new plants used for postpartum ailments, which suggests that potential remains to find additional useful plants in Prey Lang. This contrasts with other studies that have found that fever and digestive problems are the most frequently treated ailments in the region (Virapongse 2006; Tangjitman *et al.*, 2013; Elkington *et al.*, 2014; Neamsuvan *et al.,* 2015) and world-wide (e.g., Hanazaki *et al.*, 2000; Casagrande, 2002; Ayodele, 2005; Liu *et al.*, 2009).

Resin trees, the main source of income to local households (Jiao *et al.*, 2015; Hüls Dyrmose *et al.*, in press), were ranked in our study as the most important resources of Prey Lang, together with trees used for construction. Many of these trees were also considered spirit trees and thus constitute a strong bio-cultural and economic connection to the forest. Unfortunately, many of these trees are also luxury timber trees which have been logged illegally for decades, and are now endangered locally and globally. Illegal logging consequently threatens the bio-cultural life of the Kuy and Khmer people at Prey Lang.

Other studies have found gender-based differences in ethnobotanical knowledge across most use-categories (Nesheim et al., 2006; Araújo & Lopes, 2011; Müller et al., 2014). These are usually represented as differences in number of species known, and/or that men and women know different species because of their different roles in society. Our results suggest the reverse: that many plants are known by both men and women but their use is gendered (i.e., men collect the species whereas women oversee their use). Conversations with plant collectors on the differences between plants known and used by women and men revealed that they did not perceive plant knowledge as gendered: in their view, men and women know the same plants. Further studies are consequently warranted to determine if gender-specific plant knowledge exists in Prey Lang or not.

The participatory nature of our study encouraged local people to gain ownership of the research. As it was made clear from the onset that the results would be shared with the communities in the form of an ethnobotanical book, this motivatived study participants to extensively collect useful plants and explain their uses in detail. The plant collectors also felt that a book might motivate younger generations to take interest in the subject, and subsequently pass on their knowledge to future generations.

The plant list generated in this study was used to create a database to support community-based biodiversity monitoring and our study demonstrates that local experts can effectively contribute to forest categorisation and voucher specimen collection. As indigenous knowledge is constantly changing, being produced as well as reproduced, discovered as well as lost (Ellen *et al.*, 2000) and is also site-specific (Mutchnick & McCarthy, 1997), we acknowledge that additional plants may have been used in the past or in other regions of Prey Lang. Nevertheless, this study serves as an indicator of the bio-cultural diversity and importance of Prey Lang and it points to the need to conserve this ecosystem to sustain the livelihoods of its inhabitants.

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About the Authors

NEREA TURREIRA-GARCÍA is a PhD student at the University of Copenhagen, Denmark. She studied environmental sciences at the University of the Basque Country (Spain) and forest and nature management at the University of Copenhagen. Her main line of research concerns local ecological knowledge and forest monitoring and she has worked in Cambodia, Vietnam, Guatemala, Spain and the Netherlands.

DIMITRIOS ARGYRIOU is a consultant and data manager in the project "It's our forest too", concerning Prey Lang forest in Cambodia. He studied Agricultural engineering in Democritus University of Thrace, Greece and an MSc in Food Safety in Wageningen University, Netherlands. He has collaborated with research projects in Cambodia, Guatemala and the Netherlands.

PHOURIN CHHANG is the Deputy Director of the Forest and Wildlife Research Institute in Phnom Penh, Cambodia. He has extensive experience of botanical surveys in the central lowlands of Cambodia and Bokor National Park.

PRACHAYA SRISANGA is a curator at Queen Sirikit Botanic Garden Herbarium, Chiang Mai, Thailand. His main research is on species diversity of plants in mainland Southeast Asia (Laos, Myanmar and Thailand), especially within the Juglandaceae and Violaceae. He also has an interest in ethnobotanical studies of ethnic groups in Southeast Asia.

IDA THEILADE is a senior researcher at the University of Copenhagen. Her current research concerns community monitoring of forest biodiversity, carbon stocks and resources, and the role of local knowledge and institutions in conservation and management of tropical forests.

Appendix 1 Information on species free-listed and collected in northwestern Prey Lang, Cambodia.

Use categories: C = Commerce, CDD = Cultural diseases and disorders, E = Environmental, F = Food, FA = Food additives, Fu = Fuel, Ma = Materials, M = Medicinal, R = Resin, RMU = Ritual/Magical Uses, S = Social, TV = Toxic to vertebrates. Ethnospecies names in italics are in Kuy, otherwise Khmer. Vouchers are deposited at Queen Sirikit Botanic Garden, Chiang Mai, Thailand.

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Acacia harmandiana (Pierre) Gagnep.	Leguminosae	Thmea	Tree	76, 387PR, 904	M, Ma, CDD
Acacia pennata (L.) Willd.	Leguminosae	Mchoo Som Bour	Shrub	948	F
Acacia pennata subsp. *insuavis* (Lace) I.C. Nielsen	Leguminosae	Vor Em	Vine	580, 585	M, F
Acacia sp.	Leguminosae	Vor Torleng	Vine	92	M, TV
Acronychia pedunculata (L.) Miq.	Rutaceae	Tromel	Tree	480	M
Afzelia xylocarpa (Kurz) Craib	Leguminosae	Beng	Tree	227, 669, 676, 35, 43	M, Ma, F
Aganonerion polymorphum Spire	Apocynaceae	Vor Tneng	Vine	347	F
Aglaia edulis (Roxb.) Wall.	Meliaceae	Bang Kau	Tree	921	F
Aglaia lawii (Wight) C.J. Saldanha	Meliaceae	Bang Kau Sva	Tree	222, 664	M, F
Albizia lebbeck (L.) Benth.	Leguminosae	Chres	Tree	78	F, Ma
Allophylus cobbe (L.) Raeusch.	Sapindaceae	Sleuk Bei	Shrub	775	M
Alpinia galanga (L.) Willd.	Zingiberaceae	Rom Deng (Prey)	Herb	197, 246	M, F, Ma
Amaranthus spinosus L.	Amaranthaceae	Ptebanla	Herb	243	M, F
Amorphophallus sp.	Araceae	Teal	Shrub	934	M, F
Amphineurion marginatum (Roxb.) D.J.Middleton	Apocynaceae	Sralao' Ompae	Vine	515, 488, 46	M
Ancistrocladus tectorius (Lour.) Merr.	Ancistrocladaceae	Khanma, Ktong	Vine	147, 132, 651	M, Ma
Anisoptera costata Korth.	Dipterocarpaceae	Pdeak	Tree	193, 645, 668	Ma
Anisoptera sp.	Dipterocarpaceae	Stearng	Tree	196, 639, 666	Ma, R
Antidesma ghaesembilla Gaertn.	Euphorbiaceae	Dongkeabkdam	Tree	278, 489, 462	M, F, RMU, Fu
Antidesma japonicum Siebold & Zucc.	Euphorbiaceae	Trormouch, Mchoo Trormouch	Shrub	165, 172, 483, 915	M, F, RMU
Aporosa ficifolia Baill.	Phyllanthaceae	Krong	Tree	413, 526, 759	M
Aporosa planchoniana Baill. ex Müll. Arg.	Phyllanthaceae	Propech Chongva	Tree	565, 570	M
Ardisia crenata Sims	Primulaceae	Kandetmean	Shrub	158.2, 581, 574	M, F
Areca triandra Roxb. ex Buch.-Ham.	Arecaceae	Chnarb	Palm-like	463, 426	S, Ma, F
Argyreia mollis (Burm. f.) Choisy	Convolvulaceae	Vor Tror Jeark Tun Sai	Vine	527	Ma
Artocarpus chama Buch.-Ham.	Moraceae	Knorprey	Tree	266, 289	M, Ma, F
Artocarpus nitidus subsp. *lingnanensis* (Merr.) F.M.Jarrett	Moraceae	Sombour	Tree	359, 473, 690	M, S, Ma, F
Azadirachta indica A. Juss.	Meliaceae	Sdao	Tree	315, 286, 667, 678, 83	M, F, Ma
Baccaurea ramiflora Lour.	Phyllanthaceae	Pnheav	Tree	213, 118, 613, 618	F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Baeckea frutescens L.	Myrtaceae	Mrichtonsay	Tree	637, 670	M, F
Barringtonia acutangula (L.) Gaertn.	Lecythidaceae	Reang	Tree	99, 661, 624	M, F, Ma, TV
Bauhinia bracteata (Benth.) Baker	Leguminosae	Jerngkow, Klaenpor	Tree	603, 552, 510, 123	M, S, Ma
Bauhinia hirsuta Weinm.	Leguminosae	Cheungkhu	Tree	327, 174	M, F
Beaumontia murtonii Craib	Apocynaceae	Vor Thlork	Vine	785, 999	Ma
Berrya mollis Wall. ex Kurz	Malvaceae	Sor Seurm, Trorserm	Tree	373PR, 36, 907	M, Ma, Fu
Blumea balsamifera (L.) DC.	Compositae	Baymart	Shrub	457	M
Bombax anceps Pierre	Malvaceae	Rorkar	Tree	323, 302, 435, 608, 31	M, Ma
Breynia vitis-idaea (Burm.f.) C.E.C. Fisch.	Phyllanthaceae	Muntrei, *Miat Kar*	Vine	837	M, F
Bridelia ovata Decne.	Euphorbiaceae	Pnektrey	Tree	2	F
Bridelia sp.	Phyllanthaceae	Chhlikpork	Tree	62	M
Brucea javanica (L.) Merr.	Simaroubaceae	Bromatmunus, Damley Smang	Shrub	333, 38	M
Buchanania cochinchinensis (Lour.) M.R. Almeida	Anacardiaceae	Laingchey, Romchey	Tree	433, 450	M, F
Butea superba Roxb.	Leguminosae	Vor Char	Vine	326	M, Ma
Caesalpinia digyna Rottler	Leguminosae	Vor Kvav	Vine	912	M
Caesalpinia sappan L.	Leguminosae	Kvav Banla	Tree	6	M
Calamus palustris Griff.	Arecaceae	Pdao Chvang	Vine	229, 228, 13	M, Ma, F
Calamus rudentum Lour.	Arecaceae	Vor Dombong	Vine	320, 951	F, C, Ma
Calamus tetradactylus Hance	Arecaceae	Vor Seung	Vine	198	Ma, C, F
Calamus viminalis Willd.	Arecaceae	Chongpdao, Pdao	Vine	111, 455, 789, 21	M, Ma, F
Calophyllum calaba var. *bracteatum* (Wight) P.F.Stevens	Clusiaceae	Paong	Tree	395, 390, 199	Ma, F, Ma
Cananga latifolia (Hook.f. & Thomson) Finet & Gagnep.	Annonaceae	Chkaesraeng	Tree	295, 308, 595, 592, 39, 66	M
Capparis micracantha DC.	Capparaceae	Kounh Chur Beay Dach	Shrub	152	M
Careya arborea Roxb.	Lecythidaceae	Kondaul	Tree	385PR, 379SP, 492, 49	M, Ma
Caryota mitis Lour.	Arecaceae	Tunsae, Ansae, Chongsae	Tree	139, 116, 497, 620	M, Ma, F
Cassia javanica L.	Leguminosae	Kal	Tree	445	S
Cassytha filiformis L.	Lauraceae	Vor Rom saysork	Vine	449	M
Catunaregam tomentosa (Blume ex DC.) Tirveng.	Rubiaceae	Rorveang, Rveang Sor	Tree	382, 572	M, S
Ceiba pentandra (L.) Gaertn.	Malvaceae	Kor	Tree	698	F, Ma
Celastrus sp.	Celastraceae	Vor Kolab	Vine	622	M
Chionanthus ramiflorus Roxb.	Oleaceae	Spet, Marey	Tree	547, 505, 476	M, S
Chionanthus sp.	Oleaceae	Archdaek	Tree	7	Ma

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Chromolaena odorata (L.) R.M.King & H.Rob.	Compositae	Pka'Sor, Kon Traeng Kaet	Shrub	900	M, E, F
Cinnamomum bejolghota (Buch.-Ham.) Sweet	Lauraceae	Teppiroo	Tree	179	M
Cinnamomum cambodianum Lecomte	Lauraceae	Tepproo	Tree	821	M
Cinnamomum polyadelphum (Lour.) Kosterm.	Lauraceae	Slapok	Tree	101, 423, 563, 536	M, S
Citrus lucida (Scheff.) Mabb.	Rutaceae	Kror Sang	Tree	818	
Clausena excavata Burm. f.	Rutaceae	Kanhchrok	Shrub	241, 96, 484, 459	CDD, RMU
Cleistanthus sp.	Phyllanthaceae	Neang Leav	Tree	762	M, F, Ma
Colona auriculata (Desf.) Craib	Malvaceae	Preal	Shrub	437, 652, 168	M, Fu, Ma
Colona sp.	Malvaceae	Tangek	Tree	309	Ma
Combretum latifolium Blume	Combretaceae	Vor Rormeat	Vine	647, 314	M, F
Combretum micranthum G. Don	Combretaceae	Vor Khnos	Vine	230, 516, 471	M, F
Combretum quadrangulare Kurz	Combretaceae	Sangkae	Tree	363, 589	M, Ma, Fu
Connarus cochinchinensis (Baill.) Pierre	Connaraceae	Vor Lompoh	Vine	521, 496, 825	M
Coptosapelta flavescens Korth.	Rubiaceae	Vor Tonling Plerng	Vine	235	M
Costus speciosus (J.Koenig) C.D.Specht	Costaceae	Tar Thok	Herb	812	M, F
Cratoxylum formosum (Jacq.) Benth. & Hook.f. ex Dyer	Hypericaceae	Lngeang	Tree	45, 159	M, F, Ma, Fu
Crotalaria pallida Aiton	Leguminosae	Chongkrong Sva	Shrub	453, 810	M, F
Croton sp.	Euphorbiaceae	Montek	Tree	257, 764	M
Curculigo sp.	Hypoxidaceae	Tnoutley	Herb	322	Ma
Curcuma alismatifolia Gagnep.	Zingiberaceae	Chahouy	Herb	318, 930	F
Curcuma longa L.	Zingiberaceae	Rormeat	Herb	952	M, F, Ma
Curcuma sparganiifolia Gagnep.	Zingiberaceae	Kra Chork Anderk	Herb	593, 143, 914	F
Cyclea barbata Miers	Menispermaceae	Vor Phraskrong	Vine	905, 195, 44	M, F
Daemonorops jenkinsiana (Griff.) Mart.	Arecaceae	Saom	Vine	774	F, Ma
Dalbergia cochinchinensis Pierre	Leguminosae	Krornhong	Tree	573, 560, 84	Ma
Dalbergia oliveri Prain	Leguminosae	Neanghoun	Tree	290, 551, 502, 53	Ma
Dalbergia sp.	Leguminosae	Vor Chas	Vine	916	
Dalbergia thorelii Gagnep.	Leguminosae	Vor Ampil	Vine	523, 494	M, Ma
Dalbergia lanceolaria subsp. *paniculata* (Roxb.) Thoth.	Leguminosae	Snoul	Tree	303, 300, 441, 458, 25	M, F, Fu
Dasymaschalon macrocalyx Finet & Gagnep.	Annonaceae	Cheungchab	Shrub	110, 479	M, F
Dendrolobium lanceolatum (Dunn) Schinedl.	Leguminosae	Tronoumbangkhuy	Shrub	247, 310, 553, 460	M, F, RMU
Dialium cochinchinense Pierre	Leguminosae	Vor Kralarnh	Vine	770	Ma

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Dianella ensifolia (L.) DC.	Xanthorrhoeaceae	Kontoykrorper	Herb	409	M
Dillenia hookeri Pierre	Dilleniaceae	Ploosbart	Shrub	381PR, 87	M, F
Dillenia indica L.	Dilleniaceae	Plou	Tree	98, 411	M, F, Ma
Dillenia pentagyna Roxb.	Dilleniaceae	Rovey	Tree	75, 82	M, Fu, F
Dimocarpus longan Lour.	Sapindaceae	Meanprey	Tree	183, 102, 493, 582, 468, 16	M, F, Fu
Dioscorea brevipetiolata Prain & Burkill	Dioscoreaceae	Domlong Tean	Vine	203, 927	F
Dioscorea esculenta (Lour.) Burkill	Dioscoreaceae	Domlong Shar	Vine	935	F
Dioscorea pentaphylla L.	Dioscoreaceae	Vor Dom Loung Teuk	Vine	800	F
Dioscorea poilanei Prain & Burkill	Dioscoreaceae	Domlong Kour	Vine	926	F
Dioscorea polyclados Hook. f.	Dioscoreaceae	Domlong Romeat	Vine	950	F
Diospyros ehretioides Wall. ex G. Don	Ebenaceae	Mormeang	Tree	307, 288	M, TV
Diospyros filipendula Pierre ex Lecomte	Ebenaceae	Ambengprah	Tree	769, 917, 58	M, Ma, F, Fu
Diospyros lobata Lour.	Ebenaceae	Chherkmao	Tree	56	Ma, Fu
Diospyros pendula Hasselt ex Hassk.	Ebenaceae	Khchas	Tree	910	F, Ma
Diospyros sp.	Ebenaceae	Chaas, Ches	Tree	906	F, Fu
Diospyros sylvatica Roxb.	Ebenaceae	Khanhchas, Kror-chas	Tree	100, 814	M, Fu, F, Ma
Diospyros undulata Wall. ex G. Don var. *cratericalyx* (Craib) Bakh.	Ebenaceae	Chi Plerng	Tree	287, 561, 422, 771	TV, F
Diospyros venosa Wall. ex A.DC.	Ebenaceae	Chherkmao II	Tree	415, 520	Ma, Fu
Dipterocarpus alatus Roxb. & G.Don	Dipterocarpaceae	Chhertheal	Tree	107, 164, 621, 456	M, R, Ma
Dipterocarpus intricatus Dyer	Dipterocarpaceae	Trach	Tree	217, 208, 375SP, 376, 29	M, R, Ma
Dipterocarpus obtusifolius Teijsm. ex Miq.	Dipterocarpaceae	Tbaeng	Tree	383PR, 47	M, Ma
Dipterocarpus tuberculatus Roxb.	Dipterocarpaceae	Khlong	Tree	50	Ma
Dischidia major (Vahl) Merr.	Apocynaceae	Vor Bampong sromouch	Vine	569	M
Donax canniformis (G. Forst.) K.Schum	Marantaceae	Ron	Herb	777, 623, 627	M, Ma
Dracaena elliptica Thunb. & Dalm.	Asparagaceae	Tbaldaek	Shrub	542	M
Dracaena angustifolia (Medik.) Roxb.	Asparagaceae	Angraedaek	Shrub	482, 188, 173, 501	M, F, Ma
Drynaria sparsisora (Desv.) T. Moore	Polypodiaceae	Borbrok	Herb	270	M
Elephantopus scaber L.	Compositae	Chen Veal	Herb	758	F
Ellipanthus tomentosus Kurz	Connaraceae	Kdor Komprok	Shrub	267	M, F
Entada rheedii Spreng.	Leguminosae	Vor Ang Kunh	Vine	774	M, Ma
Erythrophleum teysmannii (Kurz) Craib	Leguminosae	Kreul	Tree	932	Ma

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Erythroxylum cambodianum Pierre	Erythroxylaceae	Chompussek, Changkung sek	Shrub	412, 406	M
Euonymus cochinchinensis Pierre	Celastraceae	Koomouy	Tree	519, 448	M
Eurycoma longifolia Jack	Simaroubaceae	Angtongsor	Shrub	321, 316, 567, 388	M, S
Fagraea fragrans Roxb.	Gentianaceae	Tatrav	Tree	Photo	Ma
Fagraea racemosa Jack	Gentianaceae	Changka Trong	Tree	786	Ma
Ficus annulata Blume	Moraceae	Chrey Vor, Vor Chrey	Vine	248	M
Ficus benjamina L.	Moraceae	Chhreykruem	Tree	686, 64	M
Ficus callophylla Blume	Moraceae	Chrey Klaok	Tree	628	M
Ficus hirta Vahl	Moraceae	Lavadey	Tree	533	F
Ficus hispida L.f.	Moraceae	Roveadey	Tree	242	M
Ficus pubilimba Merr.	Moraceae	Chhrey	Tree	537	F, Ma
Ficus pumila var. *awkeotsang* (Makino) Corner	Moraceae	Vor Krorbeytraos	Vine	830, 260	M
Ficus racemosa L.	Moraceae	Lovear	Tree	665, 674, 251	M, F
Firmiana simplex (L.) W.Wight	Malvaceae	Samroung	Tree	325	Ma
Flacourtia indica (Burm.f.) Merr.	Salicaceae	Krorkob (Prey)	Tree	607, 15	M, F
Garcinia celebica L.	Clusiaceae	Proos	Tree	129, 451, 9, 442	Ma, F
Garcinia cochinchinensis (Lour.) Choisy	Clusiaceae	Mchhoosandan, Sandan	Tree	834, 692	F
Garcinia merguensis Wight	Clusiaceae	*Kres*, Yeam	Tree	578, 220	M, F, S
Garcinia oliveri Pierre	Clusiaceae	Trormoong, Mchoo Trormoong, Tronoumseik, Tromongchea	Tree	421, 24	M, F, Fu
Garcinia vilersiana Pierre	Clusiaceae	Prorhoot	Tree	633, 656, 10	Ma, F
Gardenia angkorensis Pit.	Rubiaceae	Daiklar	Tree	375PR	M, C
Gardenia sootepensis Hutch.	Rubiaceae	Barkdong	Tree	293	M, F, Ma
Garuga sp.	Burseraceae	Sdavkhmoch	Tree	5	Ma
Getonia floribunda Roxb.	Combretaceae	Kor Nhours	Vine	813	M
Glochidion kerrii Craib	Phyllanthaceae	Sesach	Tree	486	M
Gmelina asiatica L.	Lamiaceae	Anhcharnh	Tree	93, 507	M
Gnetum montanum Markgr.	Gnetaceae	Khlout	Vine	233, 124, 465, 658	F, Ma
Gomphia serrata (Gaertn.) Kanis	Ochnaceae	Pesles	Tree	175, 112, 391, 380	M
Goniothalamus repevensis Pierre ex Fin. & Gagnep.	Annonaceae	Vor Krovan	Vine	138	M, Ma
Goniothalamus tamirensis Pierre ex Finet & Gagnep.	Annonaceae	Moom	Shrub	629	M, TV
Grewia sp.	Malvaceae	Jeay moa	Tree	336	M
Haldina cordifolia (Roxb.) Rids.	Rubiaceae	Kvav	Tree	606	M, Ma

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Harrisonia perforata (Blanco) Merr.	Simaroubaceae	Klentea	Vine	254, 598,793	M, F
Hedyotis sp.	Rubiaceae	Slabbrang	Tree	838	M
Helicteres hirsuta Lour.	Malvaceae	Phrealphnom, Preal Momis	Shrub	40, 454	M
Helicteres sp.	Malvaceae	Neang Moa	Shrub	753	M
Heliotropium indicum L.	Boraginaceae	Bromony Domrey	Herb	158, 68	M
Heritiera javanica (Blume) Kosterm.	Malvaceae	Doungchem	Tree	268, 625, 648, 700	Ma
Holarrhena curtisii King & Gamble	Apocynaceae	Tekdors, Vor Chhuy, Tuekdoh Veal	Vine	341, 279	M
Hopea odorata Roxb.	Dipterocarpaceae	Korki	Tree	640, 14	Ma
Hoya sp.	Apocynaceae	Vor Krobay	Vine	416	E
Hydnocarpus anthelminthicus Pierre ex Laness.	Achariaceae	Krorbao	Tree	335, 642	M, F
Hydnocarpus ilicifolia King (unresolved name)	Achariaceae	Chambokkaek	Tree	922	Ma
Hymenocardia punctata Wall. ex Lindl.	Phyllanthaceae	Komkhneang	Tree	185, 120, 619, 614	M, F, Fu
Hymenodictyon orixense (Roxb.) Mabb.	Rubiaceae	Ovlok	Tree	299, 284, 587, 77, 72	M, F
Imperata cylindrica (L.) Raeusch.	Poaceae	Sbaupleang	Herb	600, 778	M, Ma
Indigofera tinctoria L.	Leguminosae	Trom Prey	Shrub	121	M
Irvingia malayana Oliv. ex A.W.Benn.	Irvingiaceae	Chombork	Tree	161, 671, 474, 22, 170	M, F, Ma, Fu
Ixora javanica (Blume) DC.	Rubiaceae	Pkakroham	Shrub	549, 440, 91	M, F
Ixora nigricans R.Br. ex Wight & Arn.	Rubiaceae	Pkamuchol	Shrub	87PR	M
Ixora sp.	Rubiaceae	Chhongkonghing	Shrub	103	M
Jasminum scandens (Retz.) Vahl	Oleaceae	Vor Chuengpoh	Vine	485B	M
Lagerstroemia calyculata Kurz	Lythraceae	Sralao'	Tree	317, 584, 34	M, Ma, F, Fu
Lagerstroemia floribunda Jack (unresolved name)	Lythraceae	Trobekprey	Tree	125	M
Lagerstroemia ovalifolia Teijsm. & Binn. (unresolved name)	Lythraceae	Sralao' Trobek	Tree	503, 663	F, Ma
Lagerstroemia speciosa (L.) Pers.	Lythraceae	Kraol	Tree	345, 330, 447, 500, 634	M, Ma, E
Lasianthus hirsutus (Roxb.) Merr.	Rubiaceae	Skun	Shrub	150, 649, 650	M
Leea indica (Burm. f.) Merr.	Vitaceae	Baykdaing, Kandan Bay	Shrub	564	M, S
Leea thorelii Gagnep.	Vitaceae	Lounglang	Tree	361.2	M
Lepisanthes rubiginosa (Roxb.) Leenh.	Sapindaceae	Chunlous, Tumlos	Tree	166, 4, 938, 949	M, F
Licuala spinosa Wurmb	Arecaceae	Paav	Palm	903, 169, 146, 397, 399	F, Ma
Limnophila geoffrayi Bonati (unresolved name)	Plantaginaceae	Ma Orm	Herb	833	M, F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Limnophila sp.	Plantaginaceae	Bror Mae	Herb	836	F
Loeseneriella pauciflora (DC.) A.C. Sm. (unresolved name)	Celastraceae	Vor Angtong	Vine	660	M, Ma
Lygodium flexuosum (L.) Sw.	Lygodiaceae	Vor Trom, Vor Ovlor	Vine	176, 673, 680, 11, 779	M, Ma, RMU
Machilus thunbergii Siebold & Zucc.	Lauraceae	Yeangboung	Shrub	831	RMU
Macroptilium atropurpureum (DC.) Urb.	Leguminosae	Vor Sangdek bang-kuoy	Vine	791	
Madhuca butyrospermoides A.Chev.	Sapotaceae	Srorkom	Tree	475, 428	F, Ma, Fu
Mallotus glabriusculus (Kurz) Pax & K.Hoffm.	Euphorbiaceae	Kansamta oa	Shrub	89PR	M, F, Ma
Mallotus nanus Airy Shaw	Euphorbiaceae	Konsomthao	Tree	576	M
Mammea siamensis T.Anderson (unresolved name)	Calophyllaceae	Sophi	Tree	282	TV
Mangifera longipetiolata King (unresolved name)	Anacardiaceae	Svay Prey	Tree	274, 472	M, F, Ma
Markhamia stipulata (Wall.) Seem.	Bignoniaceae	Dakpor	Tree	137, 216	M, F
Melastoma malabathricum L.	Melastomataceae	Baynhenh	Shrub	119, 90, 119B	M, F
Melastoma saigonense (Kuntze) Merr.	Melastomataceae	Baynhenh (fem)	Shrub	399A	M
Melastoma sanguineum Sims	Melastomataceae	Baynhenh (male)	Shrub	401, 446, 410	M
Melientha suavis Pierre	Opiliaceae	Prech, Prechprey	Tree	945	F, Ma
Melodorum fruticosum Lour.	Annonaceae	Romduol	Tree	108, 477, 611	M, F, Fu, Ma
Memecylon caeruleum Jack	Melastomataceae	Phlorng	Tree	495, 8,211	Ma
Microcos tomentosa Sm.	Malvaceae	Porplear	Tree	225, 407	Ma, F, Fu
Mimosa pudica L.	Leguminosae	Phrasklob	Herb	756	M
Mischocarpus sp.	Sapindaceae	Promarksan	Shrub	181	M
Mitragyna hirsuta Hav.	Rubiaceae	Ktom, Ktomtom	Tree	355, 602	M, Ma
Mitragyna speciosa (Korth.) Havil.	Rubiaceae	Ktumphnom	Tree	294	M
Momordica cissoides Planch. ex Benth.	Cucurbitaceae	Vor M'reas Prey	Vine	832	F
Morinda coreia Buch.-Ham.	Rubiaceae	Nhio (Prey)	Tree	343, 334, 51, 931	M
Murraya siamensis Craib (unresolved name)	Rutaceae	Brohoungarkas	Shrub	232, 617, 797	M, RMU
Myrialepis paradoxa (Kurz) J. Dransf.	Arecaceae	Chnuo	Vine	283	Ma
Myristica iners Blume	Myristicaceae	Kuok	Tree	944	F, Ma
Nauclea orientalis (L.) L.	Rubiaceae	Kdol	Tree	601, 594, 513, 632	M, Ma
Ochna integerrima (Lour.) Merr.	Ochnaceae	Angkea Sel	Tree	312, 439, 384, 429B, 189A	M
Ocimum tenuiflorum L.	Lamiaceae	M'reas Prov	Shrub	177	F
Ocotea lancifolia (Schott) Mez	Lauraceae	Krolor	Tree	201	M, F
Olax scandens Roxb. (unresolved name)	Olacaceae	Orkktong	Vine	511	M, F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Oxyceros horridus Lour.	Rubiaceae	Thnungkanhchos, Vor Sneng kropey	Shrub	250, 772, 182	M
Paederia foetida L.	Rubiaceae	Vor Phorm	Vine	269	F
Pandanus humilis Lour.	Pandanaceae	Romchekprey	Screw -pine	171, 467, 530	M, Ma
Pandanus sp.	Pandanaceae	Chak	Screw -pine	761	F
Parinari anamensis Hance	Chrysobalanaceae	Thlork	Tree	223, 204, 373SP, 374, 80	M, F
Peliosanthes teta Andrews	Asparagaceae	Tbaldaek, *Tbaltark*	Herb	828, 659	M, RMU
Peltophorum dasyrrhachis (Miq.) Kurz	Leguminosae	Trorsek	Tree	94, 381SP, 432, 133, 19	Ma, F
Pentacme siamensis (Miq.) Kurz	Dipterocarpaceae	Reangphnom	Tree	294, 682, 60	Ma
Phyllanthus emblica L.	Phyllanthaceae	Kontoutprey	Tree	349, 324, 630, 583	M, F, Fu
Phyllodium pulchellum (L) Desv.	Leguminosae	Kom Prum Bae Kroy	Shrub	937	M
Physalis angulata L.	Solanaceae	Pengposprey	Herb	271	M, F
Pinus merkusii Jungh. & de Vriese	Pinaceae	Srorl	Tree	535, 504	M, R
Piper sarmentosum Roxb.	Piperaceae	Chhiplou	Herb	259	F
Ploiarium alternifolium (Vahl) Melch.	Bonnetiaceae	Sreurng	Tree	631, 544	Ma
Polyalthia cerasoides (Roxb.) Bedd.	Annonaceae	*Knaydael*, Snaydel	Tree	329, 615, 57	M, F, Ma
Polyalthia evecta Finet & Gagnep. (unresolved name)	Annonaceae	Sanghasbart	Tree	920	
Premna herbacea Roxb.	Lamiaceae	Ruschin	Shrub	371	M
Prismatomeris filamentosa Craib	Rubiaceae	Romdenhmeas	Shrub	210, 402, 189	M
Prismatomeris memecyloides Craib	Rubiaceae	Romdenh	Shrub	417	M, F
Prismatomeris sessiliflora Pierre ex Pit.	Rubiaceae	Romdenhmeas II	Shrub	55	M
Psychotria asiatica L.	Rutaceae	Sraomdav	Shrub	393	M, Ma
Psychotria sp.	Rubiaceae	Slerkreum	Shrub	531	M
Psychotria sp.1	Rubiaceae	Reum	Shrub	438	M
Psydrax dicoccos Gaertn.	Rubiaceae	Bongkorng	Tree	641	Ma
Psydrax pergracilis (Bourd.) Ridsdale	Rubiaceae	Mekorng	Tree	41	Ma
Pternandra caerulescens Jack	Melastomataceae	Changketbrak	Tree	559	F
Pterocarpus macrocarpus Kurz	Leguminosae	Thnong	Tree	205, 192, 487, 466	M, Ma
Rhodamnia dumetorum (DC.) Merr. & L.M.Perry	Myrtaceae	Plorng (Uol)	Shrub	539, 815	F
Rhodomyrtus tomentosa (Aiton) Hassk.	Myrtaceae	Pouch Uol, Trobek-prey	Shrub	541, 508	F
Rinorea anguifera Kuntze (unresolved name)	Violaceae	Dom Nek Pro Ma	Tree	136	M
Salacia chinensis L.	Celastraceae	Pengphorng, Vorveay	Vine	32, 400, 543, 313	M, F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Salacia cochinchinensis Lour.	Celastraceae	Vor Kondab-chongae	Vine	256	M, F
Salacia typhina Pierre (unresolved name)	Celastraceae	Kon Darb Jong Ae	Vine	924	M, F
Sandoricum koetjape (Burm. f.) Merr.	Meliaceae	Kompinhreach	Tree	823	M, Ma, F
Sauropus sp.	Phyllanthaceae	Thmehntrey	Shrub	249	M
Schleichera oleosa (Lour.) Merr.	Sapindaceae	Pongror, Tomroos, Ta Tok	Tree	902, 37, 291, 913	M, F, Fu, Ma
Scindapsus officinalis (Roxb.) Schott	Araceae	Vor Chum	Vine	272	M
Scleropyrum pentandrum (Denn.) Mabb.	Santalaceae	Rlokkeo, Aola-okkao	Tree	529, 524, 141	M
Senna alata (L.) Roxb.	Leguminosae	Donghet	Shrub	88, 763	M, F
Senna garrettiana (Craib) H.S.Irwin & Barneby	Leguminosae	Haisan	Tree	67	M
Shorea guiso Blume	Dipterocarpaceae	Chorchong, Pchuek Aodom	Tree	215, 154, 635, 662, 829	R, Ma
Shorea obtusa Wall. ex Bl. (unresolved name)	Dipterocarpaceae	Pchek	Tree	361.1, 328, 59	M, Ma
Shorea roxburghii G. Don	Dipterocarpaceae	Porpael	Tree	219, 296, 377SP, 386, 48	Ma, F
Sindora siamensis Miq.	Leguminosae	Korkoh	Tree	298, 682, 60	M, Ma, F
Smilax lanceifolia Roxb.	Smilacaceae	Porpreus, Vor Porpeay	Vine	130	M
Smilax megacarpa A. DC.	Smilacaceae	Porpreus, Vor Rombers	Vine	131, 525, 550, 663V, 672, 817	M, F
Smilax sp.	Smilacaceae	Vor Thnamchin	Vine	825	M
Spatholobus acuminatus Benth.	Leguminosae	Vor Tar Arn	Vine	236, 942	M, Ma, F
Spirolobium cambodianum Baill.	Apocynaceae	Chhertheal trang (young), Preay Kbalbromboy (old)	Tree	644, 827, 532	M, CDD, F
Spondias pinnata (L. f.) Kurz	Anacardiaceae	Mkark prey, *Phloch*	Tree	157, 234, 684, 754, 909, 754	M, F, FA, Ma
Stemona sp.	Stemonaceae	Kbeas	Shrub	263, 114	M
Stenochlaena palustris (Burm. f.) Bedd.	Blechnaceae	Vor Thnanh	Vine	127, 577, 777	M, F, Ma
Sterculia sp.	Malvaceae	Prorlob	Tree	688	Ma
Streblus asper Lour.	Moraceae	Snay	Tree	609, 604	M
Streptocaulon juventas (Lour.) Merr.	Apocynaceae	Vor Chuy, Vor Joch	Vine	339, 509, 396	M
Strychnos nux-blanda A.W. Hill	Loganiaceae	Kompolvek	Tree	389PR	M
Strychnos nux-vomica L.	Loganiaceae	Sleng	Tree	306	M
Strychnos polyantha Pierre ex Dop	Loganiaceae	Vor Sleng	Vine	518, 281	M
Suregada multiflora (A.Juss.) Baill.	Euphorbiaceae	Markdaok	Tree	490	M, F
Syzygium fruticosum DC.	Myrtaceae	Pring Angkam	Tree	953	M, F, Fu
Syzygium grande (Wight) Walp.	Myrtaceae	Pring Som Bork Krars	Tree	153, 387SP, 816	M, F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Syzygium siamense (Craib) Chantaran. & J.Parn.	Myrtaceae	Pring Kbal Nakta	Tree	943	M, Ma
Syzygium sp.	Myrtaceae	Smarch Tuk	Tree	557	F
Syzygium syzygioides (Miq.) Merr. & L.M.Perry	Myrtaceae	Pring Bay	Tree	81, 811	M, Ma, F
Syzygium zeylanicum (L.) DC.	Myrtaceae	Smarch	Tree	163, 190, 419, 404, 30	M, F, Ma, Fu
Tabernaemontana bufalina Lour.	Apocynaceae	Matesprey	Tree	534, 766	M
Tadehagi triquetrum (L.) H.Ohashi	Leguminosae	Angkrorng, Chang Kes Angkrong	Shrub	167, 126, 332	M
Tamarindus indica L.	Leguminosae	Ampil	Tree	VS2	M
Tamilnadia uliginosa (Retz.) Tirv. & Sastre	Rubiaceae	Rompok	Tree	292	M
Tarenna hoaensis Pit.	Rubiaceae	Chantornear	Shrub	527	M, Ma
Terminalia alata Roth (unresolved name)	Combretaceae	Chhlik	Tree	61	M, Ma
Terminalia bialata (Roxb.) Steud.	Combretaceae	Pealkhe, Porpa-elkae	Tree	1, 596	M
Terminalia chebula Retz.	Combretaceae	Sramor, Srormor Lau	Tree	351, 933	M, F, Ma
Terminalia mucronata Craib & Hutch. (unresolved name)	Combretaceae	Bramdomleng	Tree	357, 431, 498, 52	M, Ma
Terminalia nigrovenulosa Pierre	Combretaceae	Bayarm	Tree	599, 646, 28	M, F, Ma, Fu
Terminalia pierrei Gagnep. (unresolved name)	Combretaceae	Sev	Tree	751	M
Tetracera loureiri (Finet & Gagnep.) Pierre ex W.G. Craib	Dilleniaceae	Vor Dakun	Vine	113, 206, 128, 443, 378	M
Thunbergia sp.	Acanthaceae	Vor Dakpor	Vine	63	M
Thyrsanthera suborbicularis Pierre ex Gagnep.	Euphorbiaceae	Rus Bong Ki, Vongsa Preahatit	Vine	929, 752	M
Tiliacora triandra Diels (unresolved name)	Menispermaceae	Vor Yeav	Vine	568	Ma, F, Fu
Tinospora crispa (L.) Hook. f. & Thomson	Menispermaceae	Bondolpich	Vine	86	M
Tristaniopsis merguensis (Griff.) Peter G.Wilson & J.T.Waterh.	Myrtaceae	Srorngam	Tree	506	Ma
Urceola rosea (Hook. & Arn.) Midd.	Apocynaceae	Mchoo Tneng, Vor Tneng	Vine	936	F
Uvaria fauveliana Pierre ex Ast (unresolved name)	Annonaceae	Saomaoprey	Vine	186, 575	M, F, Ma
Uvaria hahnii (Finet & Gagnep.) J.Sinclair (unresolved name)	Annonaceae	Songkhouch	Vine	261, 258, 548	M, F
Uvaria rufa Blume	Annonaceae	Treal Sva	Vine	97, 750	F
Uvaria sp.	Annonaceae	Vor Doskrobey, Vor Treal, Teu Doh Krobai	Vine	262, 792	M, F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
Uvaria littoralis (Blume) Blume	Annonaceae	Vor Chekprey	Vine	765	M, F
Vatica odorata (Griff.) Symington	Dipterocarpaceae	Chrormas	Tree	385SP, 558, 27	Ma, F
Ventilago cristata Pierre (unresolved name)	Rhamnaceae	Vor Tonlueng	Vine	638	M, Ma
Vitex pinnata L.	Lamiaceae	Porpool	Tree	304, 427, 522, 54	M
Vitex sp.	Lamiaceae	Protespray	Shrub	224	M, RMU
Walsura villosa Wall. ex Hiern	Meliaceae	Sdok Sdao	Tree	928	M
Waltheria indica L.	Malvaceae	Preash Proa Veal	Shrub	89	M
Willughbeia edulis Roxb.	Apocynaceae	Koy	Vine	155, 389SP, 408	M, F
Wrightia arborea (Dennst.) Mabb.	Apocynaceae	Klengkong	Tree	3	M
Xanthophyllum colubrinum Gagnep.	Polygalaceae	Trop Tum	Tree	514, 545, 776	F, Ma
Xerospermum noronhianum (Blume) Blume	Sapindaceae	Mean Angkarm, Seman	Tree	135, 106, 657, 420, 917	F, Fu
Xylia xylocarpa (Roxb.) Taub.	Leguminosae	Sokrom	Tree	301, 280, 591, 17	M, Ma
Xylopia pierrei Hance (unresolved name)	Annonaceae	Kray Sor	Tree	212, 403, 394, 911	M, RMU, Ma, Fu
Xylopia vielana Pierre	Annonaceae	Kray Krahorm	Tree	901	M, Fu
Zanthoxylum nitidum (Roxb.) DC.	Rutaceae	Preah Kom Jart	Tree	605, 276, 586, 760	M, F, CDD
Zingiber zerumbet (L.) Roscoe ex Sm.	Zingiberaceae	Phtue	Herb	908	F
Ziziphus cambodianus Pierre (unresolved name)	Rhamnaceae	Vor Angkrong	Vine	20, 616	M, S, Ma
Ziziphus oenopolia (L.) Mill.	Rhamnaceae	Vor Sangkher	Vine	566, 555, 187, 178, 33	M, F
-	Acanthaceae	Bromatksan	Tree	180	M
-	Apocynaceae	Vor Preah Trorheng	Vine	696	M
-	Araceae	Vor Prork	Vine	767	Ma
-	Asclepiadaceae	Vor Chlous	Vine	554	Ma
-	Leguminosae	Sombour II	Tree	839	RMU
-	Primulaceae	Vor Preah Samkong	Vine	925	M
-	Rubiaceae	Lout	Tree	540	Ma
-	Scrophulariaceae	S'mao Kreung	Herb	820	F
-	-	Derm Kon Tuy Mian	Herb	Photo	M
-	-	Dermprus	Tree	-	Ma
-	-	K'Cheay	Shrub	-	F
-	-	K'Dourch	Vine	-	F
-	-	Kachdek	Tree	-	Ma
-	-	Khchaeng, Krorcheng	Tree	Photo	Ma, TV, F
-	-	Kom Pong Tro aoh	Tree	-	F
-	-	Korkithmor	Tree	-	Ma
-	-	Kramuon	Tree	-	M, F

Appendix 1 Cont'd

Scientific name	Family	Ethnospecies name	Life form	Voucher No.	Use(s)
-	-	Krasaeang	Tree	-	M, F
-	-	Krolanh	Tree	-	M, Ma
-	-	Krorlunch	Tree	-	F
-	-	Lovear dei	Shrub	Photo	M
-	-	Lumpoung	Tree	-	M
-	-	Mermchin		-	M
-	-	Ploo	Tree	923	M, F, Fu
-	-	Pouk	Shrub	-	Ma
-	-	Preah Oproveal	Tree	-	M
-	-	Preah Trorheng	Tree	-	M, RMU, F
-	-	Proteng	Herb	379PR	M, F, Ma
-	-	Ptheark	Tree	-	Ma
-	-	Ro Ngoung	Tree	-	RMU
-	-	Rodong	Tree	-	M
-	-	Rompukrorhorm	Tree	-	M, Ma, F
-	-	Rumduol Sbart	Shrub	-	M
-	-	Russey	Shrub	-	F, Ma
-	-	Russlar	-	-	M, S
-	-	Sluekprich	-	-	F
-	-	Smarkrorbey	Tree	-	M, F
-	-	Spong	Tree	-	M, Ma
-	-	Sro Kum Bay	Tree	819	F
-	-	Svarkhom	Tree	-	M
-	-	Tha'Kao	Tree	-	Fu
-	-	Thnenn	Vine	577, 127	F
-	-	Trameng	Tree	-	M
-	-	Treal Var/ Kon Treal Var	Vine	-	F
-	-	Trouyprich	Tree	-	F
-	-	Tuntreankhet	Shrub	-	M, E
-	-	Vor K'morng	Vine	Photo	TV
-	-	Vor Lanchoeung	Vine	929	Ma
-	-	Vor Pouh Vien Mean	Vine	252	M
-	-	Vor Tasan	Vine	-	Ma

Movement of captive-reared Siamese crocodiles *Crocodylus siamensis* released in the Southern Cardamom National Park, Cambodia

EAM Sam Un[1,*], SAM Han[1,2], HOR Leng[1,2], Me'ira MIZRAHI[1] & Jackson L. FRECHETTE[1]

[1] Fauna & Flora International - Cambodia Programme, No.19, Street 360, Boeung Keng Kang 1, PO Box 1380, Phnom Penh, Cambodia.

[2] Forestry Administration, Phnom Penh, No. 40 Preah Norodom Boulevard, Phsar Kandal 2, Khann Daun Penh, Phnom Penh, Cambodia.

* Corresponding authors. Email samun.eam@fauna-flora.org

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មូលន័យសង្ខេប

ធ្លាប់តែមានរបាយធំទូលាយនៅអាស៊ីអាគ្នេយ៍ ក្រពើភ្នំ(*Crocodylus siamensis*) បច្ចុប្បន្នជាប្រភេទជិតផុតពូជធ្ងន់ធ្ងរបំផុតជាសកលនៅក្នុងចំណោមពពួកក្រពើទាំងអស់។ គេជឿជាក់ថាប្រទេសកម្ពុជាជាជម្រកដ៏ធំជាងគេបំផុតនៃប៉ូពុយឡាស្យុងព្រៃដែលនៅសេសសល់នេះ ដូច្នេះការពង្រឹងការអភិរក្សក្រពើភ្នំក្នុងប្រទេសកម្ពុជា ជាការងារអាទិភាពបំផុត។ ការសិក្សានេះមានគោលបំណងស្វែងយល់ពីបំលាស់ទីនិងការរស់នៅរបស់ក្រពើភ្នំដែលបានលែងទៅក្នុងព្រៃធម្មជាតិ ដែលជាកម្មវិធីថ្នាក់ជាតិស្តីពីការស្តារក្រពើភ្នំឡើងវិញ។ នៅក្នុងការសិក្សានេះ ក្រពើភ្នំមានចំនួន១៥ក្បាលត្រូវបានបំពាក់ឧបករណ៍វិទ្យុទាក់ទងនិងតាមដានរយៈពេល១៨ខែ បន្ទាប់ពីបានលែងទៅក្នុងឧទ្យានជាតិជួរភ្នំក្រវាញខាងត្បូង ប៉ែកនិរតីនៃប្រទេសកម្ពុជា។ ក្រពើភ្នំចំនួន១៣ក្បាលបានផ្លាស់ទីប្រមាណ៧០០មពីទីកន្លែងលែង ក្នុងអំឡុងពេលតាមដាន (ការតាមដានប្រព្រឹត្តទៅនៅរដូវប្រាំង)។ លទ្ធផលនេះ បង្ហាញថាអាកប្បកិរិយារបស់ក្រពើភ្នំភាគច្រើនមិនផ្លាស់ទីឆ្ងាយពីកន្លែងលែងទេ ដែលត្រូវគ្នាទៅនឹងការសិក្សាកន្លងមកលើក្រពើភ្នំធម្មជាតិនៅក្នុងតំបន់ជួរភ្នំក្រវាញ។ ការរស់នៅជិតកន្លែងលែងអាចជាប្រយោជន៍ចំពោះខ្លួនវា ព្រោះវាបន្ថយឱកាសក្នុងការខិតជិតជាយជម្រកឬតំបន់ដែលបង្កឲ្យពួកវាមានជម្លោះជាមួយមនុស្ស។

Abstract

Once widely distributed throughout Southeast Asia, the Siamese crocodile *Crocodylus siamensis* is currently one of the world's most Critically Endangered crocodilian species. Because Cambodia is home to the largest remaining wild population, conservation efforts within the country should be considered of upmost importance. This study was aimed to understand the movement and survival of captive-reared Siamese crocodiles released as a part of a national reintroduction and reinforcement programme. In the study, 15 juvenile and sub-adult crocodiles fitted with VHF radio transmitters were monitored for up to 18 months after release in the Southern Cardamom National Park, southwestern Cambodia. Thirteen of the crocodiles were detected within 700 m of the release site during monitoring, which occurred mostly during the dry season. Their sedentary behaviour was consistent with previous studies of young Siamese crocodiles in the Cardamom Mountains. Remaining close to release sites may be beneficial for crocodiles by reducing chances of their moving to more marginal habitats or areas where conflict could potentially occur with people.

Keywords

Movement patterns, radio-tracking, reintroduction, Siamese crocodile.

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Introduction

The Siamese crocodile *Crocodylus siamensis* is considered one of the world's most Critically Endangered crocodilian species (IUCN, 2015), and is one of the least studied in the wild. The species was once widely distributed throughout Southeast Asia, specifically in Indonesia, Malaysia, Thailand, Laos, Cambodia, Vietnam and possibly Myanmar and Brunei (Ross, 1998). By the early 1990s, Siamese crocodile was reported to be effectively extinct in the wild, but scattered populations have since been discovered in Cambodia, Laos and Indonesia (Kalimantan) (Daltry & Chheang, 2000; Kurniati *et al.*, 2005; Platt *et al.*, 2006; Simpson *et al.*, 2006). Cambodia has the largest remaining wild population, but this is widely fragmented across the country and very few nests are recorded annually (Bezuijen *et al.*, 2006; Sam *et al.*, 2015).

Populations of the Siamese crocodile have been greatly depleted and fragmented in Cambodia by illegal poaching for the skin trade, live capture for stock farms, egg-collection, and hunting for meat (Nao & Tana, 1994; Thorbjarnarson, 1999). Additionally, crocodile farms frequently hybridize Siamese crocodile with Cuban crocodile *C. rhombifer* and saltwater crocodile *C. porosus*, and there is at risk of such hybrids escaping or being released into the wild (Simpson & Bezuijen, 2010; Starr *et al.*, 2010; Daltry *et al.*, 2016). Although the threat of hunting and wild capture has reduced in Cambodia, recovery of wild populations is still impeded by poor reproductive rates, habitat conversion and degradation, and incidental deaths from drowning in fishing gear (Simpson & Sam, 2004). Furthermore, the chances of unaided population recovery are reduced by the small and scattered nature of existing populations in the wild.

Although Siamese crocodile was originally described over 200 years ago, very little is known about ecology and biology of the species in the wild (Simpson & Sam, 2004). The few studies published indicate that the species inhabits a wide range of freshwater habitats including slow-moving rivers, streams, oxbow lakes, seasonal lakes, marshes, and swamps up to 730 m a.s.l. (Daltry *et al.*, 2003; Simpson *et al.*, 2006). Studies conducted during the dry season (December–April) in the Cardamom Mountains of southwestern Cambodia have found wild crocodiles to be highly sedentary, typically remaining within a lake or short length of river (Simpson *et al.*, 2006). Conversely, during the wet season (May–November) adult Siamese crocodiles have been recorded dispersing up to 25 km before returning to a dry season site (Simpson *et al.*, 2006).

Because remaining populations of the species are small and fragmented, reintroduction and/or reinforcement via the release of captive-bred animals into secure natural habitats is an important strategy to recover wild populations (Thorbjarnarson, 1992; National Crocodile Conservation Network, 2012). Understanding how released animals adapt to their new environment is critical to the success of any reintroduction or reinforcement programme. We present the results of radio-tracking conducted on 15 captive-reared Siamese crocodiles that were released in the Southern Cardamom National Park in 2012 (n=10) and 2014 (n=5). The aim of our study was to understand the movements and survival of crocodiles taken from captivity and released into the wild.

Methods

Study site

The crocodiles were released in one of eight sites identified by the Cambodia Crocodile Conservation Programme for reintroduction and reinforcement of Siamese crocodile in the Cardamom Mountains (National Crocodile Conservation Network, 2012) (Fig. 1). The site is located in Srae Ambel District, Koh Kong Province within the Southern Cardamom National Park and comprises hill evergreen forest, semi-evergreen forest and open forest and grassland, with an elevation range of 10–600 m a.s.l.

Names of localities and landscape features at the release site are not provided in this paper to protect the crocodiles. The release site comprised a section of river located at an elevation of 70 m a.s.l., approximately 5 km from its headwaters. The nearest village was located 12 km downstream. The width of the river ranged from 30 to 50 m, and riverine habitats included a mixture of rocks, sandbars, and vegetation in the water, with rapids separating deepwater sections (*anlong* in Khmer) which have an average minimum dry season depth of 4.39 m (± 1.95m SD) and length of 300–1,000 m.

Release procedures

Release of the crocodiles followed protocols given in the *Siamese Crocodile Reintroduction and Reinforcement Strategy and Action Plan* (National Crocodile Conservation Network, 2012). Prior to release, all of the crocodiles in this study were cared for at the Phnom Tamao Wildlife Rescue Centre (PTWRC), and originated from confiscations made by law enforcement officials and donations from other captive facilities. All of the animals were identified as 'purebred' Siamese crocodiles through DNA testing (Starr *et al.*, 2010). They were also medically cleared by veterinarians belonging to the Wildlife

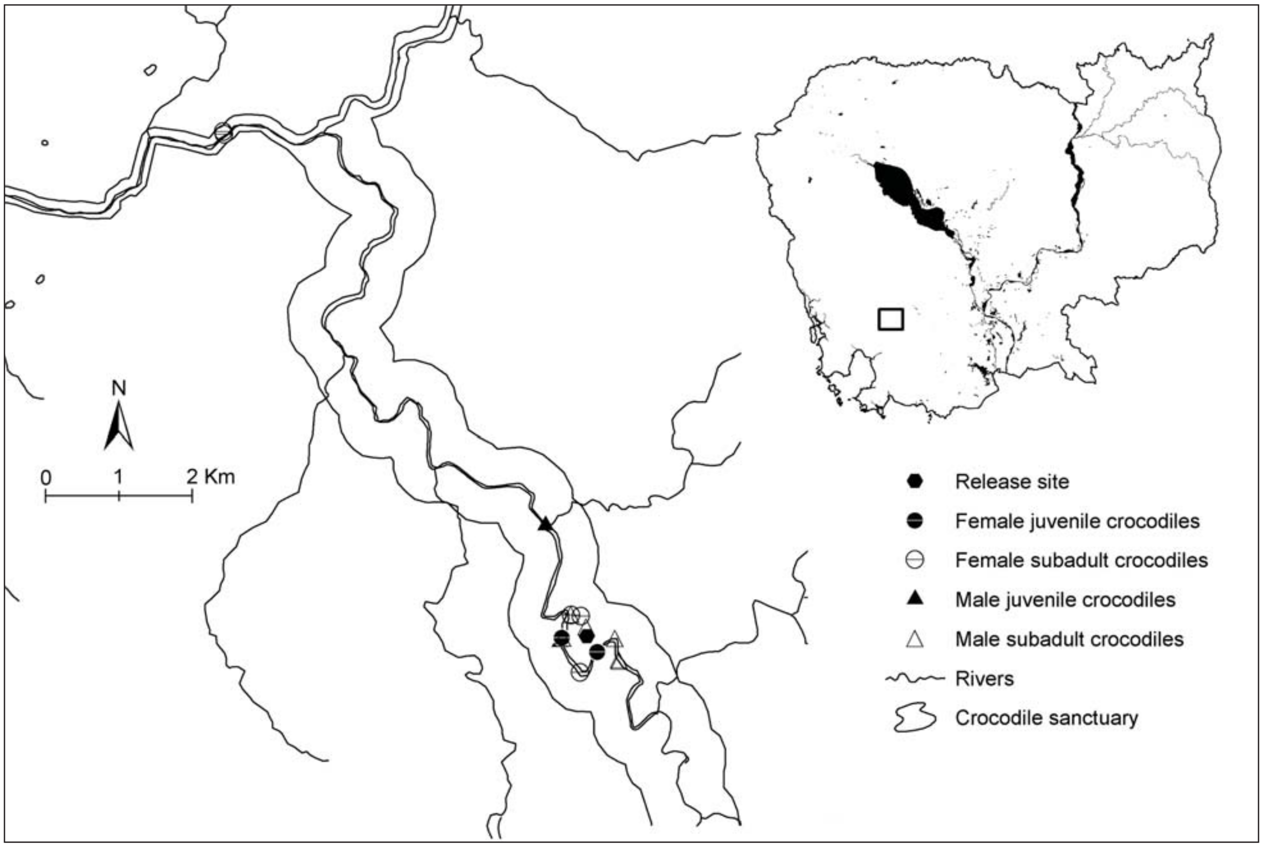

Fig. 1 General location of Siamese crocodile release area in Cambodia and last recorded locations of crocodiles.

Conservation Society to ensure they were in good health before release.

A temporary enclosure (5 m x 8 m) was constructed on the river bank at the release site which extended four metres into the river. The crocodiles were kept in the enclosure for about one week to allow them to recover from the journey from PTWRC and to monitor their condition and ensure they were ready for release. Eighteen crocodiles were released in the project site in 2012 and eight in 2014. Ten and five of these, respectively, were fitted with VHF radio-transmitters (150 MHz, Sirtrack Ltd, New Zealand) (Table 1). Small radio-transmitters (weighing ca. 40 g) with expected battery life of 13 months were attached to the dorsal base of the tail of four juvenile animals (ranging from 132 to 149 cm in total length). Larger radio-transmitters (weighing ca. 50 g) with expected battery life of 18 months were attached to the same part of 11 sub-adult crocodiles (ranging from 155 to 183 cm in total length).

Data collection and analysis

Radio-telemetry of the 15 crocodiles was undertaken for a total of 282 days from December 2012 to June 2015. Because the release site and surrounding area were inaccessible in July–October due to the wet season, all data collection was conducted during the dry season. Monitoring was conducted for 5–7 days every month when the site was accessible (specifically November–June). Observations were carried out on boat or on foot using a portable 3-element Yagi antenna attached to a 16-channel receiver (Advanced Telemetry Systems, USA). Signals could usually be detected from distances up to 500 m and 5–10 m in depth and crocodile locations were registered using hand-held GPS receivers. A 9-km stretch of river was surveyed (comprising 2 km upstream and 7 km downstream of the release site) for five days during each survey. If crocodiles were not located during this period, one to two additional days were devoted to surveying areas beyond the aforementioned stretch of river.

The mean minimum daily distance travelled by individual crocodiles was calculated using location data from successive days and calculating Euclidean distances between points. The release site was used as the reference point to determine average distances that crocodiles travelled from the release site. ArcGIS (vers. 10.2.2) and MS Excel were used for calculations.

Results

The number of times each crocodile was detected after release varied greatly. One individual (M11) was detected only once, three days after release; five (M1, F2, M8, M12 & F13) were detected less than six months after release; and five (M3, F4, F6, M9 & F14) were found six to seven months after release. Four crocodiles (M5, M7, F10 & F15) were detected after one year and the latest detection occurred 18 months after release (Table 1). None of crocodiles released were found or reported dead.

Thirteen of the 15 crocodiles remained within 700 m of the release site during the survey period. The two exceptions were sub-adult females (F6 and F15; Table 1) whose final detections were in the same *anlong* ca. 10 km downstream of the release site and ca. 3 km upstream of the nearest village (Fig. 5). The mean minimum distance travelled by crocodiles per day was 280.91 m (SD = 189.87) and the mean minimum distance crocodiles were located from the release site was 741.12 m (SD = 1,095.28) (Table 1).

There was little difference between the distances travelled by male and female crocodiles. On average, females (*n*=7) travelled 349.56 m/day (SD = 250.86), whereas males (*n*=8) travelled 220.84 m/day (SD = 96.55 m/day) (Fig. 2). Mean distances from the release site recorded for female crocodiles were 1,138 m (SD = 1561.71) and 393.28 m (SD = 111.37) for males (Fig. 3). However, the figures for females are likely distorted by the two individuals that travelled 10 km downstream of the release site, while the remaining five females travelled a minimum distance of 435 m (SD = 234.09) from the release site.

Juvenile crocodiles (*n*=4) appeared to move less than sub-adult crocodiles (*n*=11), travelling 171.68 m/day (SD = 32.12) and 320.63 m/day (SD = 208.93) on average, respectively (Fig. 4). Juveniles were located 368.87 m (SD = 169.85) from the release site on average, whereas the equivalent figure for sub-adults was 876.49 m (SD = 1,263.03) (Fig. 5). Again however, the latter figures are likely distorted by the two individuals that travelled 10 km downstream from the release site.

Table 1 Siamese crocodiles released and monitored in southwestern Cambodia from 2012 to 2015.

Code name	Status	Total length (cm)	Start date	End date	No. of times recorded	Mean minimum distance (m) travelled per day	Mean distance from release site (m)
M1	Juvenile	132	13 December 2012	27 February 2013	19	203.33	388.64
F2	Sub-adult	156	13 December 2012	30 January 2013	11	260.36	161.44
M3	Sub-adult	176	13 December 2012	12 June 2014	20	327.66	609.98
F4	Juvenile	144	13 December 2012	19 January 2014	31	134.38	596.12
M5	Sub-adult	183	13 December 2012	10 May 2014	40	138.68	282.33
F6	Sub-adult	160	13 December 2012	21 May 2013	28	330.46	1,201.67
M7	Sub-adult	163	13 December 2012	12 June 2014	43	175.71	430.39
M8	Sub-adult	168	13 December 2012	26 February 2013	6	319.98	329.07
M9	Juvenile	148	13 December 2012	12 June 2014	17	193.03	290.15
F10	Juvenile	149	13 December 2012	12 June 2014	39	155.98	200.58
M11	Sub-adult	173	17 January 2014	20 January 2014	1	333.79	333.79
M12	Sub-adult	172	26 February 2014	20 March 2014	5	74.56	481.94
F13	Sub-adult	173	27 February 2014	12 June 2014	9	732.12	648.28
F14	Sub-adult	155	26 February 2014	12 June 2014	10	671.88	569.05
F15	Sub-adult	155	19 January 2014	25 April 2015	4	161.77	4,593.49

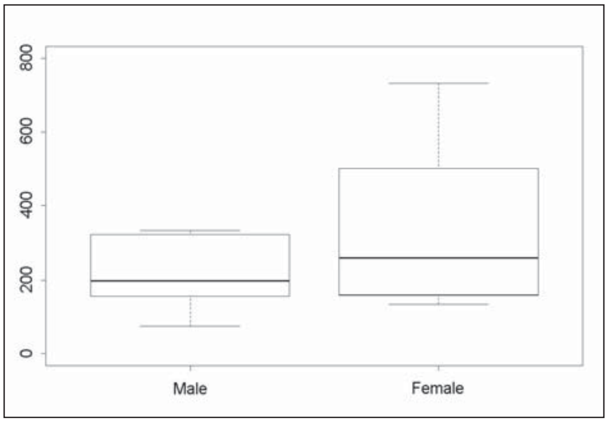

Fig. 2 Mean minimum daily distances (m) travelled by eight male and seven female Siamese crocodiles in southwestern Cambodia. Bold lines represent mean values, whiskers represent minimum and maximum values and boxes respresent lower and upper quartiles.

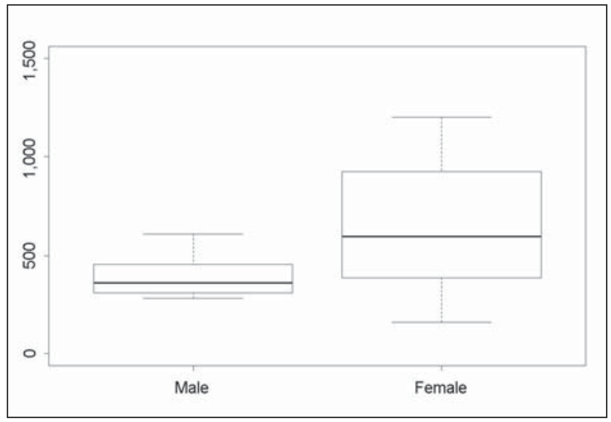

Fig. 3 Mean minimum distances (m) travelled from release site by eight male and seven female Siamese crocodiles in southwestern Cambodia. Bold lines represent mean values, whiskers represent minimum and maximum values and boxes respresent lower and upper quartiles.

Fig. 4 Mean minimum daily distances (m) travelled by four juvenile and eleven sub-adult Siamese crocodiles in southwestern Cambodia. Bold lines represent mean values, whiskers represent minimum and maximum values and boxes respresent lower and upper quartiles.

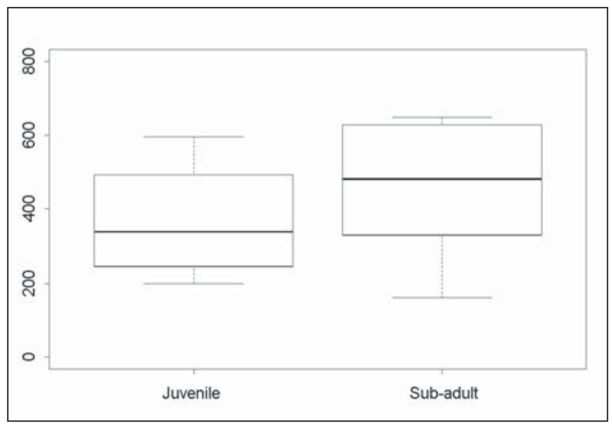

Fig. 5 Mean minimum distances (m) travelled from release site by four juvenile and eleven sub-adult Siamese crocodiles in southwestern Cambodia. Bold lines represent mean values, whiskers represent minimum and maximum values and boxes respresent lower and upper quartiles.

Discussion

Few studies have monitored the movements of captive-reared Siamese crocodiles released as part of a reintroduction programme, although similar releases have been undertaken e.g., Cat Tien National Park in Vietnam (Polet *et al.*, 2002). Our study suggests that captive-reared juvenile and sub-adult Siamese crocodiles released into novel environments show site fidelity during the dry season, at least for the first year after release. This suggests that such animals may have good prospects for surviving at suitable release sites.

Because visual sightings of the released crocodiles were rare due to their wariness, the fate of those not observed could not be confirmed. More than half of our study animals could not be located after six months, but no dead crocodiles were found or reported by local communities. The lack of observations in these cases could be due to other factors, such as equipment failure. For instance, Strauss *et al.* (2008) found that only 50% of batteries in VHF transmitters affixed to Nile crocodiles lasted longer than six months. Other crocodile release programmes have also experienced similarly high rates of 'disappearance' (e.g., Ballouard *et al.*, 2010), but without direct evidence of mortality, it is difficult to know if this might be due to batteries expiring, device failure, or dispersal beyond detection range and/or death of crocodiles outside of the study area. Because no evidence of mortality was observed or reported during the study period, we suspect that most, if not all, of our study crocodiles survived.

Previous studies of Siamese crocodile movements during the wet season reveal that the species can travel further than our study animals did during the dry season. Simpson *et al.* (2006) recorded a juvenile female moving 2–4 km across flooded forests and between the Areng River (southwestern Cambodia) and oxbow lakes from March to September. They also monitored an adult male which moved up to 11.9 km along the same river over three and a half months during the dry season. Studies on saltwater crocodiles *Crocodylus porosus* in Australia have demonstrated that the linear range of the species varies from 1.3 ± 0.9 km during the dry season to 62 km in the wet season (Kay, 2005). On release, captive-bred gharials *Gavialis gangeticus* also varied greatly in their movements, with some remaining close to the release site and others settling up to 40 km away (Ballouard *et al.*, 2010). Because habitat quality is likely a driver of site fidelity among released crocodiles (van Weerd *et al.*, 2011), the fact that most of our crocodiles stayed near the release site could indicate its habitat quality was good. However, the real measure of success for reintroduction and reinforcement programmes is breeding success. As the first animals we released in 2012 will take at least five years to reach sexual maturity, further surveys should be conducted to search for evidence of nests and juveniles.

With fewer than three wild nests reported each year for Siamese crocodiles in Cambodia, existing populations are too small and fragmented to recover in the absence of reintroduction and reinforcement efforts. This study is part of ongoing efforts to establish viable populations of the species in the country, and our discovery that young crocodiles typically remain near release sites during the dry season is encouraging because it suggests the risk of crocodiles straying from release sites into areas with less suitable habitat or greater risk from people may be low. Our release of captive-reared animals follows a decade of conservation work to determine the distribution and natural history of Siamese crocodiles (Sam *et al.*, 2015) and secure key areas as sanctuaries. It was of course critical to understand the historical distribution and habitat needs of this species before any sort of reintroduction, and to eliminate the reasons it was extirpated in the first place. Another critical step was to engage with the communities to garner support for the recovery of an animal that has the potential for conflict with humans.

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Stand carbon dynamics in a dry Cambodian dipterocarp forest with seasonally flooded sandy soils

ITO Eriko[1], FURUYA Naoyuki[1], TORIYAMA Jumpei[2], OHNUKI Yasuhiro[2], KIYONO Yoshiyuki[2], ARAKI Makoto[2], SOKH Heng[3], CHANN Sophal[3], KHORN Saret[4], SAMRETH Vanna[4], SO Thea[3], TITH Bora[3], KETH Samkol[3], LY Chandararity[3], OP Phallaphearaoth[3], MONDA Yukako[5] & KANZAKI Mamoru[5]

[1] Hokkaido Research Center, Forestry and Forest Products Research Institute, No. 7 Hitsujigaoka, Toyohira, Sapporo, Hokkaido, 062-8516 Japan.

[2] Forestry and Forest Products Research Institute, No. 1 Matsunosato, Tsukuba, Ibaraki, 305-8687 Japan.

[3] Institute of Forest and Wildlife Research and Development, Forestry Administration, Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

[4] Department of Forestry and Community Forestry, Forestry Administration, No. 40 Preah Norodom Boulevard, Phnom Penh, Cambodia.

[5] Graduate School of Agriculture, Kyoto University, Kyoto City, Kyoto, 606-8502 Japan.

* Corresponding author. Email iter@affrc.go.jp

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មូលន័យសង្ខេប

ដើម្បីអនុវត្តវិធានការ ‵កំណើន-បាត់បង់″ នៃគម្រោងផ្តួចផ្តើម ″ការកាត់បន្ថយការសាយភាយកាបូន បណ្តាលមកពីការកាប់និងការបំផ្លាញព្រៃឈើ″ យើងផ្តល់ការប៉ាន់ស្មានកំណើនកាបូន ពីការកើនឡើងនៃជីវម៉ាសដើមឈើប្រចាំឆ្នាំ និង ការបាត់បង់ជីវម៉ាសមានជីវិតបណ្តាលមកពីធម្មជាតិនិងសកម្មភាពមនុស្ស នៅក្នុងព្រៃរបោះដីល្បាយខ្សាច់នៃប្រទេសកម្ពុជា។ យើងបានត្រួតពិនិត្យព្រៃរបោះដីល្បាយខ្សាច់ ជាព្រៃដែលសម្បូរដោយដើមត្បែង (*Dipterocarpus obtusifolius*) ដែលដុះនៅតំបន់ដីល្បាយខ្សាច់។ យើងបានវិភាគពីអត្រានុកូលសាស្រ្ត និង កំណើនអង្កត់ផ្ចិតកម្ពស់ទ្រូង ដែលមានអង្កត់ផ្ចិត>៥សម ដោយផ្អែកលើការធ្វើជំរឿនដើមឈើអស់រយៈពេល១១ឆ្នាំ(២០០៣ ដល់ ២០១៤)កន្លងមក។ ទីតាំងសិក្សាបានបង្ហាញពីកម្រិតទាបនៃកំណើនកាបូន(០,១៨មក្រ កាបូន/០,២៤ហិចតា/ឆ្នាំ) ចំពោះការស្តុកកាបូនដំបូងមាន(១១,៣មក្រ កាបូន/០,២៤ហិចតា) ធៀបទៅនឹងប្រភេទព្រៃឈើកម្ពុជាដទៃទៀតដែលត្រូវបានសិក្សាកន្លងមក។ អត្រាងាប់នៃដើមឈើដែលមានអង្កត់ផ្ចិតកម្ពស់ទ្រូង ≥១០សម មានកម្រិតទាប(១,០៣%/ឆ្នាំ) ជាហេតុនាំឲ្យមានការបាត់បង់កាបូនតិចតួច(០,១២មក្រ កាបូន/០,២៤ហិចតា) ពីដើមឈើងាប់ដោយធម្មជាតិ ក្នុងអំឡុងពេលមុនកាប់(២០០៣ ដល់ ២០១១)។ ការកាប់ឈើដោយជនអនាមិកបានកាត់បន្ថយការស្តុកកាបូនប្រមាណ៥,៣៧មក្រ កាបូន/០,២៤ហិចតា (៤២,៧% នៃតម្លៃមុនពេលកាប់) ជាមួយនឹងការខូចខាតបន្ទាប់បន្សំ (០,០០៦មក្រ កាបូន/០,២៤ហិចតា) ដែលសមាមាត្រទៅនឹងកំណើនកាបូនក្នុងរយៈពេល ៣០ឆ្នាំកន្លងមក។ កំណើនកាបូនដាច់ខាត កំណើនកាបូនទាប និង ការកាប់ឈើក្នុងទ្រង់ទ្រាយធំដែលបានអង្កេតនៅក្នុងទីតាំងសិក្សា បង្ហាញថាព្រៃរបោះដុះនៅតំបន់ដីល្បាយខ្សាច់ ចាំបាច់ត្រូវតែមានការបែងចែកជាក្រុមរងនៃព្រៃជ្រុះស្លឹកនេះ នៅពេលអនុវត្តវិធានការ ‵កំណើន-បាត់បង់″ នេះ។

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Abstract

To implement the gain-loss approach from the 'Reducing Emissions from Deforestation and Forest Degradation' initiative, we provide estimates of gains from the annual increase in tree biomass and losses in live biomass caused by natural and anthropogenic processes in a sandy dry dipterocarp forest in Cambodia. We examined a sandy dry dipterocarp forest—a form of forest characterised by the strong dominance of *Dipterocarpus obtusifolius*—which was distributed on sites with sandy soils. We analysed the demography and diameter increment of trees with diameters at breast height (DBH) >5 cm based on an 11 year tree census (2003–2014). The study plot showed a low carbon (C) increment (0.18 Mg C 0.24 ha^{-1} y^{-1}) for the initial C stock (11.3 Mg C 0.24 ha^{-1}) compared to other Cambodian forest types that have been studied in the past. The low mortality of trees with DBH ≥10 cm (1.03% y^{-1}) resulted in a small C loss from naturally dying trees (0.12 Mg C 0.24 ha^{-1}) in the pre-cutting period (2003–2011). Logging by unknown parties decreased C stocks by 5.37 Mg C 0.24 ha^{-1} (42.7% of the pre-logging value) with relatively less collateral damage (0.006 Mg C 0.24 ha^{-1}); this was equivalent to C increments that had accrued over 30 years. The low absolute C increment, the relatively low C increment, and the intensive logging observed in the study plot suggest that sandy dipterocarp forests need to be stratified into subdivisions of deciduous forests when implementing the gain-loss approach.

Keywords

Carbon stock, *Dipterocarpus obtusifolius*, forest degradation, mortality, recruitment, Reducing Emissions from Deforestation and Forest Degradation (REDD), tree increment.

Introduction

Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) is an effort to create financial incentives for developing countries to reduce carbon (C) emissions from forested lands (UNFCCC, 2009). To implement the global climate change mitigation programme, IPCC (2006) presented two methods for calculating changes in C stocks: the gain-loss method and the stock-difference method. The choice of method largely depends on a country's available data, domestic capacity, and forest transition stage (GOFC-GOLD, 2008; Murdiyarso *et al.*, 2008).

Cambodia has attracted the attention of the REDD+ programme because it is a hotspot for deforestation and forest degradation (FAO, 2010; 2011). In recent years, a several studies have attempted to prepare a full implementation programme for REDD+ activities in Cambodia (Sasaki *et al.*, 2006, 2011, 2012, 2013, 2016; Sasaki & Yoshimoto, 2010). To reduce uncertainties in C estimation for countries experiencing significant forest degradation (Sasaki, 2006), application of the gain-loss method was recently examined in Cambodia (Sasaki *et al.*, 2006, 2012, 2013, 2016; Kiyono *et al.*, 2017). The gain-loss method is built around the gains from annual increases in biomass and the losses in live biomass caused by natural and anthropogenic processes (Murdiyarso *et al.*, 2008). Those estimates must be obtained for each forest type, appropriately stratified by eco-types and degradation processes (Murdiyarso *et al.* 2008; Pearson *et al.*, 2014; GOFC-GOLD, 2016).

Cambodia has a diversity of forest types (Rollet, 1972; Rundel, 1999) and the extent of their degradation varies, adding a layer of complexity to the task of data collection. The Cambodian Forestry Administration (FA) classified forest cover into four types: evergreen, semi-evergreen, deciduous, and other forests including different types such as forest re-growth, inundated forests, stunted forests, mangrove forests, and forest plantations (FA, 2011). Specific information for each forest-type has been obtained from ground-based studies in Cambodia, and includes data on forest structure (Kimphat *et al.*, 2000, 2002a; Kao & Iida, 2006; Ouk, 2006; Pin *et al.*, 2013; Toyama *et al.*, 2015; Chheng *et al.*, 2016), biomass (Top *et al.*, 2004a; Kiyono *et al.*, 2010; Khun *et al.*, 2012; Samreth *et al.*, 2012; Chheng *et al.*, 2016; Monda *et al.*, 2016), and biomass increment (FA, 2004; Top *et al.*, 2004a; Kiyono *et al.*, 2017). Despite these, data collection is still fragmented. For example, data on annual increment are relatively limited, possibly because neither the continuous maintenance of permanent sample plots nor frequent tree measurements for forest biomass increment are necessarily straightforward in countries with frequent deforestation and forest degradation (Kiyono *et al.*, 2017).

Positive relationships have been reported between annual above-ground biomass increment and above-ground biomass for Cambodian forests without stratifying forest types (Top *et al.*, 2004a; Kiyono *et al.*, 2017). The coefficients of determination for this relationship in both previous studies were relatively low. Top *et al.* (2004a) suggested that stand age, soil types, microtopography, or species composition might explain the residuals, whereas Kiyono *et al.* (2017) could not explain these by differing mean annual precipitation or the soil fertility index. The gain-loss method should be built on an ecological understanding of how forests grow (Murdiyarso *et al.* 2008). Additional data on C increment is still required, in addition to data on fundamental forest structure and dynamics for the various forest types.

Deciduous forests comprising dry mixed deciduous forests and dry dipterocarp forests predominate in Cambodia, and cover 24.68% of its land area (FA, 2011). Dry dipterocarp forests are described as *forêt claire* (Rollet, 1972), deciduous dipterocarp forests or woodlands (Rundel, 1999). They exist throughout Indo-Burma (Ashton, 2014) and are scattered among lowland forest areas in Cambodia (JICA, 2002). The name of this community is a result of dominance by a small number of deciduous species of Dipterocarpaceae, such as *Shorea siamensis*, *S. obtusa*, *Dipterocarpus tuberculatus*, *D. intricatus* and *D. obtusifolius* (Rundel, 1999). Dry dipterocarp forests have been further subdivided into four forms, with different combinations of soil type and dominant dipterocarp species (Rollet, 1972).

One form of dry dipterocarp forest is characterised by the strong dominance of *D. obtusifolius* (*Tbeng* in Khmer), which favours sandy soil, gravelly soil or laterite (Smitinand *et al.*, 1980). This forest (hereafter sandy dipterocarp forest) has been referred to as *forêt claire à Dipterocarpus obtusifolius* (Vidal, 1960), *D. obtusifolius* on sand or grey soil (*à D. obtusifolius, sur sable ou terre grise*: Rollet, 1972), *D. obtusifolius* community (Baltzer *et al.*, 2001) and *D. obtusifolius* stand type (Hiramatsu *et al.*, 2007). Sandy dipterocarp forests are most characteristic of areas east of the Mekong River in Cambodia at sites with thin sandy soils over laterites (Rundel, 1999) and are often scattered as forest patches among evergreen forests at sites with deep sandy soils subject to seasonal flooding in Kampong Thom Province, northeast of the Tonle Sap Lake (Hiramatsu *et al.*, 2007).

Sandy dipterocarp forests are often low in species richness (Hiramatsu *et al.*, 2007) and have open structures with 40–70% canopy cover (Rundel, 1999; Hiramatsu *et al.*, 2007; FA, 2011). They are associated with ground fires (Rundel, 1999; Hiramatsu *et al.*, 2007), have nutrient-poor sandy soils (Rollet, 1972; Toriyama et al., 2007a, b), and experience seasonal flood and drought conditions (Rollet, 1972; Rundel, 1999; Baltzer *et al.*, 2001; Araki *et al.*, 2007). Nevertheless the predominant *D. obtusifolius* is ecologically plastic and stress tolerant (Rundel, 1999). Its annual growth is still unknown; in other words, it is unclear whether sandy dipterocarp forests achieve C increments to the same degree as other deciduous forests (Top *et al.*, 2004a; Kiyono *et al.*, 2017).

There is also a dearth of data related to C emissions due to forest degradation, which is a significant contributor to C emissions in the atmosphere (GOFC-GOLD 2008). Considerable international variation exists in C emissions from tropical forest degradation caused by selective logging (Pearson *et al.*, 2014). Forest degradation from uncontrolled tree cutting has resulted in significant losses of C stock in Cambodian evergreen forests (Sasaki & Putz, 2009). As such, further data on deciduous forest degradation would contribute to implementation of the gain-loss approach in Cambodia.

We established a permanent sample plot (30 × 80 m) to investigate stand structure and dynamics in a sandy dipterocarp forest in the Kampong Thom Province of Cambodia. During a chronological tree census (2003–2014), logging by unknown parties occurred in the plot. The plot, while small and isolated, had the potential to provide useful information about sandy dipterocarp forests. The objectives of our study were to clarify the stand dynamics and annual increment in sandy dipterocarp forest based on 11 years of tree census data, and to assess C emission from cutting events and related collateral damage.

Methods

Study site

We conducted our study in the Kampong Thom Province in central Cambodia (12.8°N, 105.5°E; elevation: 70 m a.s.l., Fig. 1). The site was positioned on quaternary sedimentary rock and located on a largely flat, slightly undulating alluvial plain (Toriyama *et al.*, 2011). The tropical climate is seasonal, and the months between November and April are dry. The mean annual temperature was 27°C, and the annual rainfall (mean ± SD) was 1,542 ± 248 mm (2000–2010; NIS, 2012).

We established a permanent sample plot (30 × 80 m) for vegetation in a sandy dipterocarp forest with a canopy openness of 50% (Hiramatsu *et al.*, 2007, Fig. 2). The forest includes *D. obtusifolius* (ca. 50% of stand basal area and 60% of stand tree numbers) and *Gluta laccifera* (35% and 6%, respectively) as the dominant species (Hiramatsu *et al.*, 2007). These are the major species in seasonal tropical forests in Asian monsoon areas and are indicative of a dry forest type (Rundel & Boonpragob, 1995; Eiadthong, 2011). The forest lacked auxiliary deciduous species such as *Shorea obtusa*, *Pterocarpus macrocarpus*, and *Xylia*

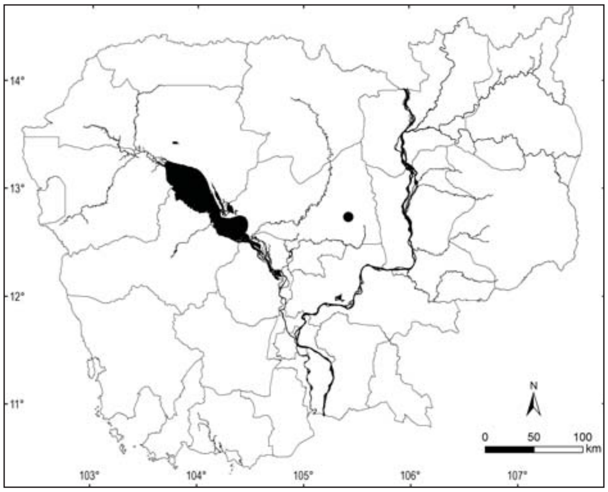

Fig. 1 Location of the study site (solid circle) in Kampong Thom Province, Cambodia.

xylocarpa, which usually co-occur in dry dipterocarp or deciduous dipterocarp forests (Royal Forest Department, 1962; Tani *et al.*, 2007; Hiramatsu *et al.*, 2007; Eiadthong, 2011; Pin *et al.*, 2013). Edaphic limitation is a potential factor limiting species richness (Hiramatsu *et al.*, 2007). The forest was classified as a deciduous forest using FA (2011); however, the component tree species showed irregular and incomplete leaf shedding (Ito *et al.*, 2007). For example, leaf longevity of *D. obtusifolius* often exceeded one year (Ito *et al.*, unpublished data), a trend which has also been observed in the Thai highlands (Elliott *et al.*, 2006). The soil of the study area was generally sandy and nutrient-poor, similar to other *G. laccifera* habitats (Eiadthong, 2011). The soils have been classified as acrisols (WRB), but with albic and arenic features that suggest a closer relationship with arenosols (WRB) (Toriyama *et al.*, 2007a). The ground surface was waterlogged several times in the middle of the rainy season (August through September: Araki *et al.*, 2007) and the ground vegetation includes *Xyris complanata* R.Br. and insectivorous plants (*Drosera* sp. and *Nepenthes* sp.), which suggest low-nutrient edaphic conditions (Hiramatsu *et al.*, 2007).

Data collection

Field surveys were conducted in 2003, 2008, 2009, 2010, 2011, 2012 (pre-logging), and 2014 (post-logging) to investigate tree growth and demography. Censuses in 2003, 2011, and 2014 were conducted in February each year. Censuses in 2009 and 2010 were conducted in December each year. Censuses in 2008 and 2012 were conducted in June and November, respectively. All standing woody stems with a diameter at breast height (DBH) ≥5 cm were enumerated and identified to species (except for one specimen which was identified to genus, Appendix 1). We measured stem girth to the nearest 1 mm (1.3 m above ground level) during the tree censuses except in the 2010 census. The height of each tree was measured in 2010 using either a Vertex III clinometer (Haglöf, Långsele, Sweden) or a telescopic height-measuring pole. We spatially mapped stems with an accuracy <1 m and measured crown diameters of major and minor axes in 2012 (Fig. 2).

Analysis

Annual mortality and recruitment rate were calculated using commonly used logarithmic models (e.g., Swaine *et al.*, 1987; Phillips & Gentry, 1994; Lewis *et al.*, 2004). More specificially, mortality rate (λ) and recruitment rate (k) were calculated as follows:

$$\lambda = (\ln(n_0) - \ln(n_0 - n_d))/t \quad \text{(Eq. 1)},$$

$$k = (\ln(n_0 + n_r) - \ln(n_0))/t \quad \text{(Eq. 2)},$$

where n_0 is the number of trees present at the beginning of the census interval, and n_d and n_r are the number of trees that died of natural causes and the recruited trees during time (t) of the census interval. We used a 2 × 2 contingency table to assess differences in mortality and recruitment rate between individuals with a DBH of 5–10 cm and ≥10 cm. Given the stems present during the initial 2003 inventory, the numbers of surviving and dying stems at the end of the census interval (2014) provided the values for mortality analysis. Recruited stems were omitted from this analysis. Using the stems present at the end of the 2014 inventory, numbers of existing stems during the initial 2013 inventory and recruited stems during the 11-year census, we were able to identify values for recruitment rate analysis. Dying stems were omitted from this analysis. Hypothesis tests were performed using one-tailed probabilities based on Fisher's exact test. The observed number of dying or recruited trees with DBH ≥5 cm was compared to the expected number of dying or recruited trees. The expected number was calculated by assuming that there were no mortality or recruitment rate differences during the 11-year census. Significance was tested by the chi-squared test for goodness of fit. To avoid periods with fewer than five expected dying or recruited trees, we divided our observations from all 11 years into three periods: 2003–2008, 2008–2011, and 2011–2014. Numbers of observed and predicted dying or recruited trees for each period were compared to a significance level of p=0.05. Diameter distributions of the predominant *Dipterocarpus obtusifolius* were evaluated for skewness (s) and kurtosis (κ), and were compared to a normal distribution using the pre-logging 2011 census

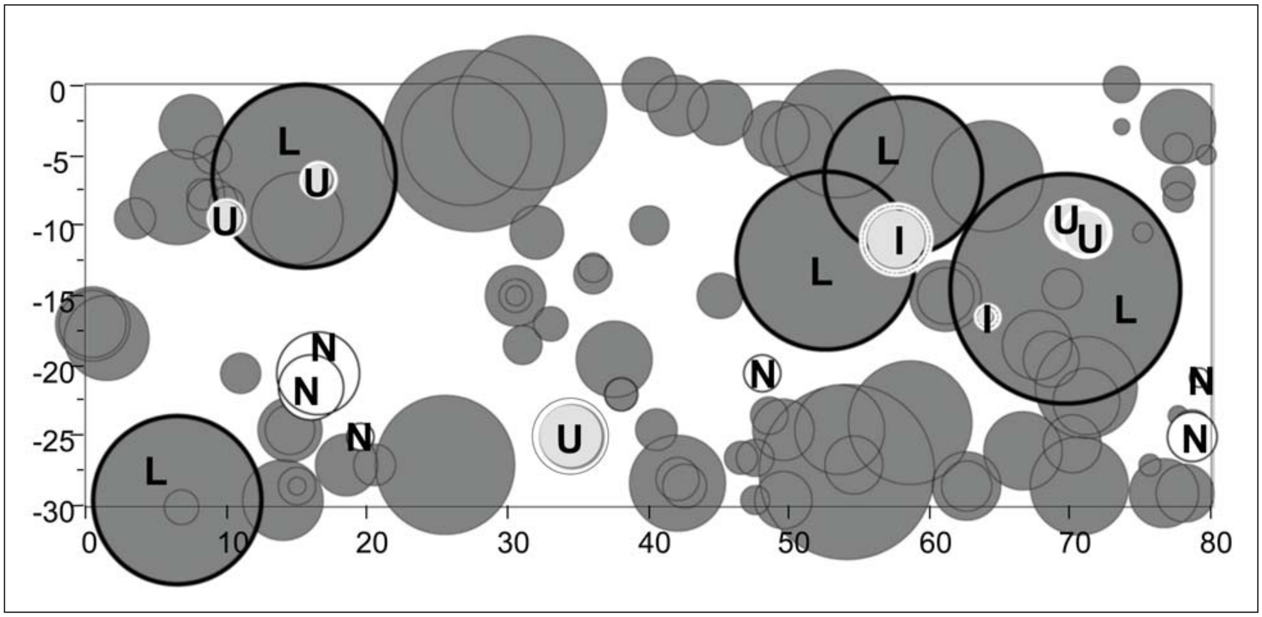

Fig. 2 Individual tree locations and crown sizes within a 30 × 80 m study plot in Kampong Thom Province, Cambodia. Symbol sizes are canopy areas calculated from crown diameters and assume each crown was circular. Letters indicate status changes between 2012 and 2014: L = logged for timber (n=5); I = collateral damage from logging (n=2); U = cut for unknown reasons (n=5); N = natural death (n=6).

data and the Shapiro-Wilk test. We used a log-normal distribution to best describe the diameter distribution of *D. obtusifolius*, where we estimated two parameters, μ (scale) and σ (shape). A goodness-of-fit test was examined using the Kolmogorov-Smirnov test. We assessed whether the log-normal distribution fitted for *D. obtusifolius* was significantly different from those of associated species using the Kolmogorov-Smirnov test. Four of the tested species were selected based on their basal area in the 2011 census (*G. laccifera*, *Parinari anamensis*, *Syzygium oblatum*, and *Memecylon scutellatum*).

Diameter increments per year were compared between the 2003–2011 census and the 2011–2014 census for trees that had survived since the 2003 (first) census to the 2014 post-logging census (n=69) using a Wilcoxon signed rank test. We estimated the total biomass (TB) of the trees using the latest published allometric equations developed in a deciduous dipterocarp forest in Kratie Province, Cambodia (Model 4: Monda *et al.*, 2016):

$$\ln(AGB) = -2.438 + 2.518 \ln(DBH)$$

$$\ln(BGB) = -3.734 + 2.521 \ln(DBH) \qquad \text{(Eq. 3)},$$

where AGB and BGB represent the dry above-ground biomass and dry below-ground biomass of each tree (kg), respectively, and DBH (cm) is the diameter of the stem 1.3 m above-ground. TB was obtained by calculating the sum of AGB and BGB. Field-measured DBH's of each tree in the 2003, 2011, and 2014 censuses were applied to the equation for evaluating chronological changes in stand C storage, C emissions, and C increment because these three censuses were conducted in the same month of the dry season (February), which avoids DBH swelling in the rainy season. Allometry equations with tree height parameters were not applicable because tree height was measured only during the 2010 census. To evaluate the difference in biomass estimates, we estimated tree biomass for the corresponding DBH dataset from the 2011 census and tree height from the 2010 census using an allometry equation with parameters for tree height (H, m) (Model 2: Monda *et al.*, 2016):

$$\ln(AGB) = -2.710 + 0.924 \ln(DBH^2 \times H)$$

$$\ln(BGB) = -4.030 + 0.928 \ln(DBH^2 \times H) \qquad \text{(Eq. 4)}.$$

The difference (%) in the stand TB results between Equations 3 and 4 was calculated as: (stand TB by Eq. 3 − stand TB by Eq. 4) / (stand TB by Eq. 3) × 100.

We found a difference of 6.8% in the study plot, which was considered small, although it suggests relatively low tree height in the study plot compared to the deciduous dipterocarp forest in Kratie where the equations were developed. Besides the TB estimates found using Equation 3, we obtained tree biomass by applying various equations identical to several previous studies to maintain consistency in the biomass estimates among comparative studies. Top *et al.* (2004a) estimated the AGB of trees with DBH >10 cm using the equation developed by Brown (1997):

$$AGB = 42.69–12.800DBH + 1.242DBH^2 \quad \text{(Eq. 5).}$$

Kiyono *et al.* (2017) estimated the ABG of trees with DBH >5 cm using the equation developed by Kiyono *et al.* (2006):

$$AGB = 11545\ BA^{1.24} \quad \text{(Eq. 6),}$$

where BA is the basal area of a stem at a height of 1.3 m (m^2). Samreth *et al.* (2012) estimated the TB of trees with DBH >7.5 cm using the equation developed by Kiyono *et al.* (2011):

$$TB = 4.08 \times BA^{1.25} \times WD^{1.33} \quad \text{(Eq. 7),}$$

where WD is the basic density (kg m^{-3}) of the stem wood. The species-specific WD data obtained from neighbouring countries used for Equation 7 were selected from a global WD database provided by Chave *et al.* (2009) and Zanne *et al.* (2009). When species-specific data were not available in the database, we used 570, which is the default value for tropical Asian wood (Brown, 1997). The values of WD used for each species are listed in Appendix 1. Kimphat *et al.* (2002b) and Khun *et al.* (2012) presented biomass as standing volume (SV, m^3). We converted AGB to SV similar to Sasaki *et al.* (2016) using the equation developed by Brown (1997):

$$AGB = SV \times 0.001\ WD \times BEF \quad \text{(Eq. 8),}$$

where BEF is the biomass expansion factor (1.74). Stand tree C stock in the study plot was obtained for the 2003, 2011, and 2014 censuses. The C stored in the trees was obtained by multiplying the C content in the dry wood biomass (0.5: IPCC, 2003) by the estimated biomass of each tree. Plot-specific values of tree C emissions by natural causes and C increment without anthropogenic effects were estimated for the 2003–2011 censuses. For stand C emissions estimation, the biomass of all the trees that died during the interval were summed, and the biomass of each tree was estimated from their last measured diameters during the interval. Stand C increment was calculated using a revised method of Clark *et al.* (2001). Increments for surviving trees during the interval were calculated as the difference between their estimated biomass at the beginning (2003) and end of the interval (2011). Increments for recruited trees during the interval were calculated as the difference between their estimated biomass at the end of the interval (2011) and the biomass of a tree of the minimum measured diameter (DBH of 5 or 10 cm). Increments for dying trees during the interval were calculated as the difference between their estimated biomass at the beginning and end of the interval. For stand C increment, biomass increments were summed for all trees that had survived, were recruited, and were dying. To compare our results with previous studies, the indices of stand structure, biomass, and increment were rescaled per hectare, given that the number of individuals increased linearly with area. A combination of the plot-wise annual AGB increment and the initial AGB in the study plot was compared to previous studies (Top *et al.*, 2004a; Kiyono *et al.*, 2017). These studies were conducted for Cambodian forests without stratifying forest types, which derived positive relationships between annual AGB increment and initial AGB. A logarithmic relationship was obtained for trees with DBH >10 cm using data from 32 plots (four deciduous forest plots, where the details of the forest type were unknown) located in Kampong Thom (Top *et al.*, 2004a). A linear relationship was obtained for trees with DBH >5 cm using data from 49 plots (24 deciduous forest plots, not including sandy dipterocarp forests, Kiyono, pers. comm.) in nine provinces (Kiyono *et al.*, 2017). To maintain consistency in the biomass estimates between the present and previous studies, we used Equations 5 and 6 for biomass estimation and set tree size criteria identical to these particular studies. We recorded the presence of logged trees and collaterally damaged trees from the 2014 census. C loss associated with the cutting procedure was estimated based on DBH from the 2011 census. Tree C emissions by natural and anthropogenic causes were compared during the 2011–2014 censuses. Plot canopy coverages from the 2011 and 2014 censuses were estimated based on crown diameters measured in 2012. We assumed that each crown was circular, and plot canopy coverage was therefore provisionary and calculated as the sum of the crown area within the rectangular plot, with overlapping crown areas excluded.

Results

Stand structure and dynamics

Stand-level tree density ranged 91 to 104 stems 0.24 ha^{-1} and 56 to 61 stems 0.24 ha^{-1}, for individuals with DBH ≥5 cm and ≥10 cm across five pre-logging censuses (2003, 2008, 2009, 2011, 2012) respectively (Fig. 3). During the 11-year census, 121 stems with DBH ≥5 cm were enumerated, of which 23 died from natural causes and 23 were recruited (Table 1). Sixty-three stems with DBH ≥10 cm were enumerated, of which six died from natural causes and six were recruited (Table 1). Individuals in the 5–10 cm DBH class that died comprised *M. scutellatum* (n=10),

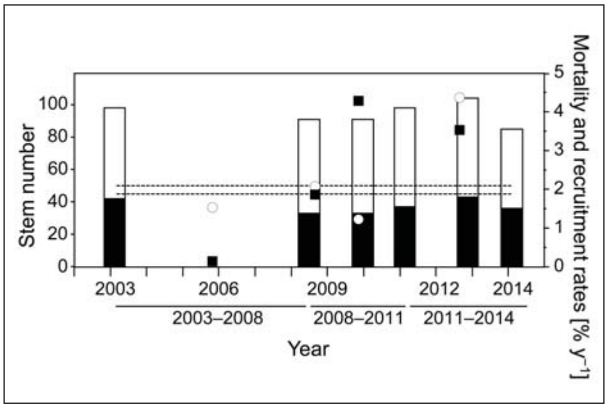

Fig. 3 Chronological changes in stem density, mortality, and recruitment rate. This is a bar-plot of the number of stems in the study plot (0.24 ha) across five pre-logging censuses (2003, 2008, 2009, 2011, 2012) and one post-logging census (2014). Black and white bars show stems with DBH of 5–10 cm and ≥10 cm, respectively. Open circles and closed squares indicate mortality and recruitment rates for stems with DBH ≥5 cm, respectively. Rates were calculated for the periods 2003–2008, 2008–2011, 2011–2014, and 2003–2014 (dotted lines).

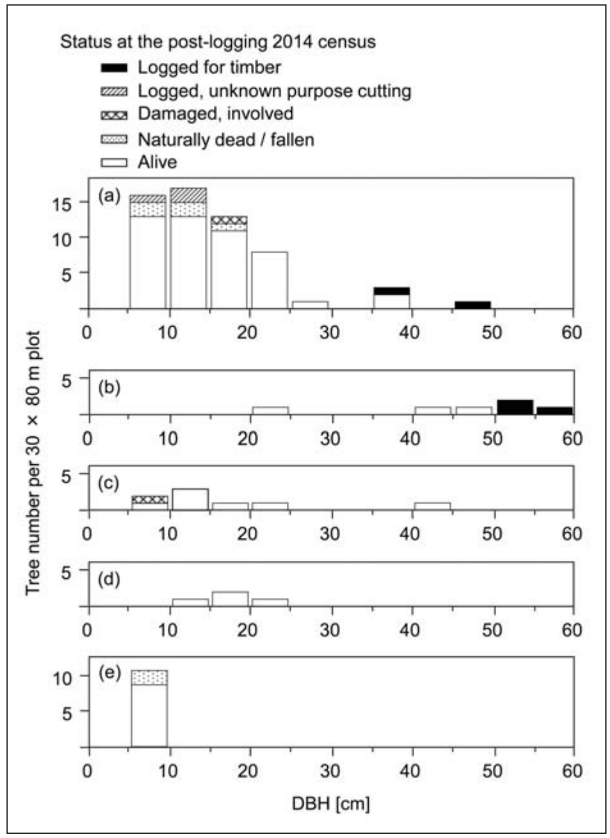

Fig. 4 Frequency distribution of DBH for predominant and associated tree species in the study forest based on pre-logging 2011 census data. Hatched patterns in the bars indicate tree status during the pre-logging 2011 census. A) *Dipterocarpus obtusifolius*; B) *Gluta laccifera*; C) *Parinari anamensis*; D) *Syzygium oblatum*; E) *Memecylon scutellatum*.

Artocarpus sp. (n=5), and *D. obtusifolius* (n=2). Individuals with DBH ≥10 cm that died comprised *D. obtusifolius* (n=3), *Syzygium oblatum* (n=1), *Artocarpus* sp. (n=1), and *Anneslea fragrans* (n=1). Recruited individuals in the 5–10 cm DBH class were *M. scutellatum* (n=7), *D. obtusifolius* (n=6), *Xylopia vielana* (n=4), *Parinari anamensis* (n=3), and *Calophyllum calaba* var. *bracteatum* (n=3). Recruited individuals in the DBH ≥10 cm class were *D. obtusifolius* (n=3), *P. anamensis* (n=3), and *Symplocos cochinchinensis* (n=1). Mortality (λ) for stems with DBH ≥5 cm during 2003–2014 was 2.08% y^{-1} (Fig. 3). Significantly higher λ was found for stems of 5–10 cm DBH (3.69% y^{-1}) than for stems with DBH ≥10 cm (1.03% y^{-1}) (one tailed Fisher's exact test, p=0.0031). The chi-squared test for goodness of fit indicated that there was a significant difference in the occurrence of dying trees among the different census periods (2003–2008, 2008–2011, 2011–2014) (χ^2=7.242, df=2, p<0.05) and only the number of dying trees between the 2011 and 2014 censuses were larger than expected values (Fig. 3).

The recruitment rate (k) for stems with DBH ≥5 cm in 2003–2014 was 1.92% y^{-1} (Fig. 3). The recruitment rate for 5–10 cm DBH stems (3.98% y^{-1}) significantly exceeded ≥10 cm DBH stems (1.07% y^{-1}) (one-tailed Fisher's exact test, p=0.0010). Chi-squared test for goodness of fit showed that the expected number of trees recruited in each period between censuses significantly differed from the occurrence of period categories within the study plot (χ^2=18.447, df=2, p<0.05); where the expected figure was greater than their actual occurrence during the 2003–2008 censuses (Fig. 3). Size distributions according to basal area in the 2011 census are shown for five representative tree species in the study plot in Fig. 4. The diameter distribution of *D. obtusifolius* was significantly different from a normal distribution (Shapiro-Wilk test, n=59, W=0.87, p<0.0001). *Dipterocarpus obtusifolius* showed significant positive skewness (coefficient s=1.52, p<0.05) and large kurtosis (coefficient κ=2.93, p<0.05), with a peak in the 10–15 cm DBH class and a long tail indicating several rare adults (Fig. 4a). The diameter distribution of *D. obtusifolius* did not differ significantly from a log-normal distribution (Kolmogorov-Smirnov test, n=59, D=0.07, p=0.150). The best fitting parameters with a 95% CI were 2.63 (2.50–2.76) and 0.51 (0.43–0.61) for μ and σ, respectively. The species-specific diameter

Table 1 Transition of DBH size classes and conditions over the 11-year study period (2003–2014) for stems in study plot, Kampong Thom Province, Cambodia.

Stem size class in 2014	Condition in 2014	Stem size class in 2003			
		<5 cm DBH[a]	5–10 cm DBH	≥10 cm DBH	Total
5–10 cm DBH	Alive	16	20		
	Dieback[b]	0	1		
	Dead	3	14		58
	Cut	3	0		
	Collateral damage	1	0		
≥10cm DBH	Alive		6	43	
	Dieback		0	0	
	Dead		0	6	63
	Cut		1	6	
	Collateral damage		0	1	
Total		**23**	**42**	**56**	**121**

[a] Not enumerated in 2003; [b] Dieback of primary stems reduced the height of the stem by less than 1.3 m.

distributions of associated species were significantly different from *D. obtusifolius* (*G. laccifera*, *n*=6, *D*=0.85, *p*=0.010, Fig. 4b; *S. oblatum*, *n*=4, *D*=0.42, *p*=0.015, Fig. 3d; *M. scutellatum*, *n*=11, *D*=0.93, *p*=0.010, Fig. 3e), except for *P. anamensis* (*n*=8, *D*=0.23, *p*=0.150, Fig. 4c). Visual inspection suggested that *G. laccifera* had a distinct distribution skewed to the larger size class (Fig. 4b), and *M. scutellatum* had a distinct distribution limited to the 5–10 cm DBH class (Fig. 4e). Detailed structure data for each species are given in Appendix 2.

Size increment and C emissions

Annual diameter increments during the 2003–2014 censuses averaged 0.14 ± 0.12 cm y^{-1} and 0.11 ± 0.08 cm y^{-1} for all of the specimens (*n*=69) and the *D. obtusifolius* (*n*=48) trees that survived over the course of the censuses. Diameter increments for trees that survived the 2003–2014 censuses were significantly higher between the 2011 and 2014 censuses (0.18 ± 0.16 cm y^{-1}) than between the 2003 and 2011 censuses (0.12 ± 0.12 cm y^{-1}) (Wilcoxon signed rank test, *p*<0.0001). Plotwise and species-specific diameter increments for each size class are described in Appendix 3. Visual inspection suggested that *P. anamensis* and *C. calaba* var. *bracteatum* showed relatively high increments. The bark of *M. scutellatum* was often peeling, which resulted in highly variable increments. Basal areas of stems with DBH ≥5 cm and ≥10 cm increased from 11.24 to 12.31 m^2 ha^{-1} and from 10.54 to 11.74 m^2 ha^{-1} between the 2003 and 2011 pre-logging censuses, respectively (Appendix 2). Emissions of C for dying individuals with DBH ≥5 cm and ≥10 cm during the 2003–2014 census were 0.36 Mg C 0.24ha^{-1} and 0.25 Mg C 0.24ha^{-1}, respectively (Table 2). The DBH classes for dying trees of five representative tree species in the study plot during the 2011–2014 censuses are described in Fig. 4. Tree C increments were larger than C emissions from dead trees from 2003 to 2011; thus, tree C stock in the stand slightly increased (from 11.26 to 12.60 MgC 0.24 ha^{-1} for trees with DBH ≥5 cm, Table 2). Above-ground tree C stock estimates derived from several equations are also shown in Table 2. Annual above-ground biomass increments in the study plot were lower than estimated values from previously reported regression relationships between the annual above-ground biomass increment and the above-ground biomass (Fig. 5). The annual above-ground biomass increment in this study plot (1.61 Mg ha^{-1} y^{-1}, estimated using Eq. 5) was 48% of the expected value derived from the logarithmic relationship developed by Top *et al.* (2004a) (3.38 Mg ha-1 y-1) given an initial above-ground biomass of 113.4 Mg ha^{-1} (estimated using Eq. 5). The annual above-ground biomass increment (1.08 Mg ha^{-1} y^{-1}, estimated using Eq. 6) was 32% of the expected value derived from the linear relationship reported by Kiyono *et al.* (2017) (3.34 Mg ha^{-1} y^{-1}), given an above-ground biomass of 69.2 Mg ha^{-1} (estimated using Eq. 6). Estimates of stand structure and tree biomass are summarised and compared to previous studies of Cambodian forest in Table 3.

Table 2 Plot-wise tree carbon (C) dynamics in study plot, Kampong Thom Province, Cambodia.

Item (MgC 0.24 ha⁻¹)	Census year	DBH size criteria (cm)	Total biomass	Above-ground biomass		
			Eqs. 3[a]	Eqs. 3[a]	Eq. 5[b]	Eq. 6[c]
C stock	2003	≥5	11.26	8.8	14.0	8.3
		≥10	10.93	8.6	13.6	8.0
	2011	≥5	12.60	9.87	15.53	9.27
		≥10	12.32	9.65	15.24	9.05
	2014	≥5	7.56	5.9	9.6	5.6
		≥10	7.28	5.7	9.4	5.4
C emissions from dead trees	2003–2011	≥5	0.12	0.10	0.14	0.09
		≥10	0.06	0.05	0.07	0.05
	2011–2014	≥5	0.24	0.19	0.29	0.18
		≥10	0.19	0.15	0.24	0.14
C emissions from logging and collateral damage	2011–2014	≥5	5.37	4.21	6.33	3.90
		≥10	5.36	4.19	6.30	3.88
C increment	2003–2011	≥5	1.42	1.12	1.66	1.04
		≥10	1.31	1.02	1.54	0.95

[a] Monda *et al.* (2016); [b] Brown (1997) used in Top *et al.* (2004a); [c] Kiyono *et al.* (2011) used in Kiyono *et al.* (2017).

Cutting operations in sandy dipterocarp forests

Logging by unknown parties occurred at the study site between November 2012 and February 2014, likely in late 2013 or early 2014, judging from the freshness of stumps. Ten logged trees were scattered within the 0.24 ha plot (Fig. 2). Five large logged stems were either removed from the plot or left behind partially sawn. Another five small fallen trunks were left behind; their locations were not related to visible skid trails, which indicated normal removal operations. The average DBH of the former was 50.1 cm (35.9 and 46.9 cm for *D. obtusifolius*, *n*=2; 54.3–57.8 cm for *G. laccifera*, *n*=3) in the 2011 census (Fig. 4a, b). The average DBH of the unlogged trees of these two species was 16.4 cm (range: 5.3–39.0 cm for *D. obtusifolius*, *n*=54; 23.4–47.1 cm for *G. laccifera*, *n*=3). The average DBH of the latter was 8.2 cm (range: 5.5–13.8 cm for *D. obtusifolius*, *n*=3; 5.9 cm for *C. calaba* var. *bracteatum*, *n*=1; 4.9 cm for *P. anamensis*, *n*=1) in the 2011 census (Fig. 4a, c; *C. calaba* not shown). In addition to the logged trees (*n*=10), logging operations caused collateral damage to remaining individuals (Figs 2 & 4). Broken-stemmed trees (*n*=2) occurred in the vicinity of logged tree stumps; a form of damage directly attributable to cutting operations. From 2011 to 2014, densities of trees with DBH ≥5 cm and ≥10 cm fell 87.6% (from 97 to 85 stems 0.24 ha⁻¹) and 80.3% (from 61 to 49 stems 0.24 ha⁻¹), respectively (Fig. 3). Basal areas of individuals with DBH ≥5 cm and ≥10 cm declined to 67.3% (from 12.31 to 8.29 m^2 ha⁻¹) and 65.7% (from 11.74 to 7.71 m^2 ha⁻¹), respectively (Appendix 2). Basal area depletion as a result of cutting and collateral damage was 34.4% of the initial area (4.23 of 12.31 m^2 ha⁻¹). Total tree C stock for trees with DBH ≥5 cm was 12.60 Mg C 0.24 ha⁻¹ in the 2011 census, where 5.37 Mg C 0.24 ha⁻¹, 0.006 Mg C 0.24 ha⁻¹ and 0.24 Mg C 0.24 ha⁻¹ were lost to logging, damage and natural mortality until 2014, respectively (Table 2). Logging intensity and collateral damage associated with cutting are summarised and compared to previous tropical forest studies in Table 4.

Discussion

Stand structure and dynamics

Sandy dipterocarp forests are characterised by the strong dominance of *D. obtusifolius*, with poor associated species richness (Appendix 1; Hiramatsu *et al.*, 2007; Tani *et al.*, 2007). Generally, numbers of dying and recruited trees of *D. obtusifolius* were similar in our study, suggesting a stable dynamic, resulting in a positively skewed log-normal distribution (Fig. 4a). These results are not inconsistent with previous reports of the species adapting well to edaphic and meteorological conditions specific to sandy dipterocarp forests (Norisada & Kojima, 2005a, 2007; Miyazawa *et al.*, 2014a, 2014b). However, it remains

Table 3 Stand structure and tree biomass estimates reported in previous studies of Cambodian deciduous forests.

Index (unit)	This study (pre-logging)	Previous studies	Forests and measurement details in previous studies[a]	References
Tree density (trees ha^{-1})	379–433	626	Mixed deciduous forest in Kampong Thom- Sandan; trees with DBH >5 cm; tree components lacking *Do*, *Di*, *Dt*, *Ss*, and *Ta*	Kimphat *et al.* (2002a)
Basal area (m^2 ha^{-1})	11.2–12.3	32.0		
Standing volume (m^3 ha^{-1})	74.1–83.0	179.2		
Aboveground biomass (Mg ha^{-1})	113.4–127.0	189	Deciduous forest in Kampong Thom; trees with DBH >10 cm; forest details unknown	Top *et al.* (2004)
Basal area (m^2 ha^{-1})	11.2–12.3	24.8	Deciduous forest in Mondulkiri-Seima; trees with DBH >5 cm; dominated by *Dt*	Khun *et al.* (2012), Sasaki *et al.* (2016)
Standing volume (m^3 ha^{-1})	74.1–83.0	192.1		
Above-ground C stock (Mg C ha^{-1})	36.8–41.1	95.1		
Total (above-ground + below-ground) biomass (Mg ha^{-1})	131.7–147.6	257.8 ± 92.0[b]	Deciduous forest in Preah Vihear, Kratie-Snoul, Kratie-Sandan; trees with DBH >5 cm; dominated by *Dt*, *Di*, *So*, and *Ta*	Kiyono *et al.* (2010)
Total tree C stock (Mg C ha^{-1})	66.7–74.8	55.2 ± 6.9[c], 56.2 ± 6.7[d]	Deciduous forest in Ratanakiri, Siem Reap, Kampong Thom, Kratie; trees with DBH >7.5 cm; common species are *Do*, *Dt*, *Ss*, *So*, and *Ta*	Samreth *et al.* (2012)
Total biomass (Mg ha^{-1})	93.9–105.0	32.2–158.9	Deciduous dipterocarp forest in Kratie; trees with DBH >5 cm; forest details unknown	Monda *et al.* (2016)
Annual diameter increment (cm y^{-1})	0.14 ± 0.12[e] 0.12 ± 0.08[f] 0.19 ± 0.15[g]	0.32	Deciduous forest in Kampong Thom; trees with DBH > 3 cm; commercial species; forest details unknown	FA (2014)
		0.45	Same; in Kratie	
		0.56	Same; in Siem Reap	
		0.14	Same; in Ratanakiri	

[a] *Do = Dipterocarpus obtusifolius; Di = D. intricatus; Dt = D. tuberculatus; Ss = Shorea siamensis; So = S. obtusa; Ta = Terminalia alata.* [b] Mean ± SD. [c] 1998 census, Mean ± SE. [d] 2000–2001 census, Mean ± SE. [e] All species, 2003–2014, Mean ± SD. [f] *D. obtusifolius*, 2003–2014, Mean ± SD. [g] Trees with DBH >30 cm, *D. obtusifolius* and *G. laccifera*, 2003–2011, Mean ± SD.

unclear why *D. obtusifolius* did not expand to occupy ground spaces which lacked tree canopy occupants (Fig. 2) and this is unlikely to be related to low-light conditions or a lack of flowering trees. Flowering was observed in much smaller trees (minimum diameter for flowering 11.8 cm; Ito *et al.*, 2016) than other dipterocarps (≥50 cm, Sist *et al.*, 2003b). Mycorrhizal limitation is a potential factor limiting recruitment, as symbiotic fungi promote the survival and growth of juveniles (Alexander *et al.*, 1992). As adult dipterocarps are a source of mycorrhizal colonisers that infect juvenile plants, logging of adult trees reduces the size of the fungal source pool.

The average mortality of trees with DBH ≥10 cm in the tropics is well documented (1.81 ± 0.16% y^{-1}, mean ± 95% CI; Lewis *et al.*, 2004). Our study site had very low tree mortality for these individuals over the 11-year census (1.03% y^{-1}). High mortality for trees in the 5–10 cm DBH class (3.69% y–1) was mainly due to high turnover of some shrubby species (e.g., *M. scutellatum*; Fig. 4e). Numbers of recruited trees were balanced with the number of dying trees for trees with DBH ≥5 cm and ≥10 cm. Plotwise stem density was condequently relatively stable until the 2012 census (Fig. 3). This implies that the study forest is likely to be sustained in the absence of anthropogenic disturbance. Over the course of the study, we found that plot-wise mortality and recruitment rates were relatively high between the 2011–2014 censuses, followed by the 2008–2011 censuses and the 2003–2008 censuses (Fig. 3). Diameter increments for trees that survived during the course of the study were also higher during 2011–2014 than 2003–2011 (Appendix 3). The casual relationship underlying these trends in stand

Table 4 Collateral damage associated with forest logging reported in previous studies.

Index of collateral damage (unit)	This study	Previous studies	Conditions of forests and logging operations in previous studies	References
No. of collaterally damaged trees per felling of a single tree (tree tree^{-1})	<1	ca. 10	Closed-canopy neotropical forests with DBH 60–140 cm harvested	Jackson *et al.* (2002), Feldpausch *et al.* (2005)
Ratio of carbon stock, collateral trees to logged trees (%)	3.2	110	Amazonian humid tropical forest	Feldpausch *et al.* (2005)
Carbon stock loss to collateral tree damage (Mg C ha^{-1})	0.7	3.2	Amazonian humid tropical forest	Feldpausch *et al.* (2005)
Cutting intensity normalised by proportion of damaged trees (2.5% of original tree population) (trees ha^{-1})	20.8	<4	East Kalimantan forest	Sist *et al.* (1998)
Proportion of canopy lost at cutting intensity of 50 m^3 ha^{-1} (%)	20.8	39.1	Regression from 11 previous studies including a Brazilian moist tropical forest, conventional cutting operations	Pereira *et al.* (2002)
		22.7	Same, reduced-impact logging operations	Pereira *et al.* (2002)
Ratio of skidding damage of original stand area (%)	Not measured	25	Dense evergreen forest in Indonesian Borneo	Sist *et al.* (2003a)

dynamics are unknown, but they may reflect changing climatic or edaphic conditions.

Stand C storage and increments

Sandy dipterocarp forests are characterised by an open structure (Rundel, 1999; Hiramatsu *et al.*, 2007; FA, 2011). This is consistent with lower plot-wise C storage and its relating forest structure indices found in the study plot compared with various Cambodian deciduous forests (Table 3). Given the positive relationship between annual above-ground biomass increment and above-ground biomass (Top *et al.*, 2004a; Kiyono *et al.*, 2017), the biomass increment in sandy dipterocarp forests is expected to be lower than other types of deciduous forests. The mean increment for above-ground stand biomass for the average initial above-ground stand biomass has been estimated to be 4.59 Mg ha^{-1} y^{-1} for deciduous forests (Top *et al.*, 2004a), and 4.79 Mg ha^{-1} y^{-1} for unstratified forest categories (Kiyono *et al.*, 2017). These estimates are fairly high compared to the values estimated in our study (1.61 Mg ha^{-1} y^{-1} and 1.08 Mg ha^{-1} y^{-1}, using Eqs. 5 and 6, respectively). The latest application of the gain–loss method nationally in Cambodia assumed that a more conservative mean annual increment would be identical to all of the forest categories (1.5 MgC ha^{-1} y^{-1}, Sasaki *et al.*, 2016), which was twice our study estimate (0.74 MgC ha^{-1} y^{-1}, using Eq. 3). It is also noteworthy that the above-ground biomass increments in our study plot were 48% and 32% of the expected values for initial aboveground biomass using regression relationships (Fig. 5). The absolute and relative low C increment in our study plot suggests that sandy dipterocarp forests might need to be stratified into

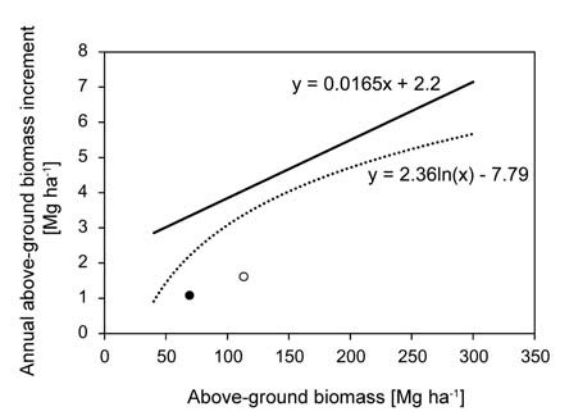

Fig. 5 Relationship between plot-wise annual above-ground biomass increment and initial above-ground biomass. Dotted and solid lines represent regression lines of the relationships reported by Top *et al.* (2004a) and Kiyono *et al.* (2017), respectively. Circles indicate a combination of annual above-ground biomass increment and initial above-ground biomass in study plot. Open and closed circles indicate biomass estimation using equations identical to Top *et al.* (2004a) and Kiyono *et al.* (2017), respectively.

subdivisions of deciduous forests when implementing the gain–loss approach. Given the low mortality and balanced recruitment of our study plot, the relatively low increment suggests that tree growth was limited. Though seemingly lower diameter increments were found at our study site than those reported for Cambodian deciduous forests (FA, 2004), lack of detailed information for the latter prevent meaningful comparisons (Table 3; Appendix 3). We still do not know why sandy dipterocarp forest has a relatively low increment, although this is not related to light availability. *Dipterocarpus obtusifolius* physiologically adapts to seasonal flood and drought conditions (Miyazawa *et al.*, 2014a, 2014b), high irradiance levels (Norisada & Kojima, 2005a), and high temperatures (Norisada & Kojima, 2007). The nutritional responses of the species are also similar to other canopy-dominating dipterocarp species in sandy soils (Norisada & Kojima, 2005b). Acrisols underlying sandy dipterocarp forests are generally nutrient-poor soils compared to more nutrient-rich plinthite in dry dipterocarp forests on the east bank of Mekong (Toriyama *et al.*, 2007a, 2010). Thus, growth of *D. obtusifolius* might be limited by the nutrient-poor edaphic conditions of our study site.

Logging and its impact on C stock

The four logged and fallen tree species in our study are often targets for both timber and fuel extraction (Top *et al.*, 2004b; San *et al.*, 2012). The wood of *D. obtusifolius* is graded as durable (Grade II: MAFF, 2005) and subject to commercial exploitation (Kim Phat *et al.*, 1999). Large logged trees of *D. obtusifolius* and *G. laccifera* in the studied plot were possibly used for timber, while the small trunks (<30 cm DBH) left behind may have been felled for fuel (Top *et al.*, 2004b) or used to test chainsaw performance. Over-exploitation of forest resources has been reported in the region (KimPhat *et al.*, 2001; Top *et al.*, 2004c). Basal area depletion from logging in our study plot (34.4%) was above the indicative criteria for sustainable logging operations (<15%) proposed in East Kalimantan (Sist & Nguyen-Thé, 2002). For Cambodian mixed forests, Kimphat *et al.* (2002a) tentatively proposed a sustainable harvest potential as selective felling of 30% of the stand volume during a 30-year cutting cycle. Logging in the study plot removed substantial C stocks (5.37 MgC 0.24 ha^{-1}, 42.6% of the pre-logging value), which is equivalent to a C increment of 30 years (accrual rate 1.42 Mg C 0.24 ha^{-1} $8y^{-1}$; Table 2). Notably, the annual tree C stock increment would decline after cutting operations. A sustainable cutting cycle prediction should be based on the remaining basal area after felled trees are deducted (Sist *et al.*, 2003c; Kimphat *et al.*, 2004).

Selective logging, particularly in operations without a sustainable management plan, is frequently associated with serious collateral forest damage (Pereira *et al.*, 2002; Sasaki & Putz, 2009). The extent of collateral damage in our study plot, however, appeared to be less than that reported for logging operations in other tropical forests (Table 4). This is obviously due to the low tree density of our study plot. Tree density and basal area for individuals with <10 cm DBH values in previous studies were ca. 525 trees ha^{-1} and 57 m^2 ha^{-1}, respectively (Sist *et al.*, 1998; Pereira *et al.*, 2002; Feldpausch *et al.*, 2005; Table 4). The respective values for our study plot were rescaled to 254 trees ha^{-1} and 11.7 m^2 ha^{-1}, respectively. Such low tree densities and basal areas are found in other sandy dipterocarp forests (e.g., 235 trees ha^{-1} and 5.5 m^2 ha^{-1}: FA, unpublished data). Directional felling without collateral damage to other trees is greatly simplified in sparse forests (Feldpausch *et al.*, 2005). Skid damage could also be minimised with basic requirements for logging roads in sparse forests compared to dense forests (Sist *et al.*, 2003a).

How intensive logging alters stand dynamics in sandy dipterocarp forests is still unknown. Logging has the potential to accelerate the growth of surviving trees (Putz *et al.*, 2001), as light conditions improve when a dense forest is thinned (Kao *et al.*, 2011). However, our open-canopied sandy dipterocarp forest likely had unlimited light availability. Along increasing environmental stress gradients, sandy dipterocarp forests become increasingly open in structure and lower in stature, grading eventually into savanna woodlands with decreasing woody cover (Rundel, 1999). Further studies are necessary to clarify whether over-exploitation increases environmental stress and leads to further forest degradation.

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Appendix 1 List of component species in study plot, Kampong Thom Province, Cambodia.

Family (APG III)	Species [a]	Khmer name [a]	Basic density [b] (kg m^{-3})	Data source [c]
Anacardiaceae	*Gluta laccifera* (Pierre) Ding Hou	Krouel	689	Cambodia
Annonaceae	*Xylopia vielana* Pierre	Kray Krahom	570	Default
Calophyllaceae	*Calophyllum calaba* L. var. *bracteatum* (Wight) P.F.Stevens	Phaong	570	Default
Chrysobalanaceae	*Parinari anamensis* Hance	Thlok	641	Cambodia
Dipterocarpaceae	*Dipterocarpus obtusifolius* Teijsm. ex Miq.	Tbeng	650	Vietnam
Melastomataceae	*Memecylon scutellatum* (Lour.) Hook. & Arn.	Phlorng	570	Default
Moraceae	*Artocarpus* sp.	Kroung	570	Default
Myrtaceae	*Syzygium oblatum* (Roxb.) Wall. ex A.M.Cowan & Cowan	Pring	570	Default
Pentaphylacaceae	*Anneslea fragrans* Wall.	Sorphy	634	Myanmar
Rubiaceae	*Catunaregam tomentosa* (Blume ex DC.) Tirveng.	Ror Veang	570	Default
Symplocaceae	*Symplocos cochinchinensis* subsp. *laurina* (Retz.) Nooteboom	Luot	538	Cambodia

[a] Scientific names and Khmer names refer to Toyama *et al.* (2013); [b] Chave *et al.* (2009) and Zanne *et al.* (2009) were used for data selection; [c] Country name indicates place where original data were obtained, while default indicates the default value for tropical Asia (Brown, 1997).

Appendix 2 Species-specific basal area and stem density per DBH class in the first (2003), pre-logging (2011), and post-logging (2014) censuses at study plot, Kampong Thom Province, Cambodia.

2003 (first) census. Basal area is given as $m^2\ ha^{-1}$ and stem density (in parentheses) is given as trees $0.24\ ha^{-1}$. Only genus names are shown (see Appendix 1 for full scientific names).

Genus	DBH class (cm)													
	5–10		10–20		20–30		30–40		40–50		50–60		Total	
Gluta	–	(–)	–	(–)	0.15	(1)	–	(–)	2.07	(3)	1.81	(2)	4.03	(6)
Xylopia	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Calophyllum	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Parinari	0.07	(3)	0.06	(1)	0.44	(2)	–	(–)	–	(–)	–	(–)	0.57	(6)
Dipterocarpus	0.34	(18)	2.06	(28)	1.31	(8)	1.36	(3)	0.69	(1)	–	(–)	5.76	(58)
Memecylon	0.16	(13)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.16	(13)
Artocarpus	0.07	(5)	0.03	(1)	–	(–)	–	(–)	–	(–)	–	(–)	0.10	(6)
Syzygium	–	(–)	0.33	(4)	0.17	(1)	–	(–)	–	(–)	–	(–)	0.50	(5)
Anneslea	–	(–)	0.06	(1)	–	(–)	–	(–)	–	(–)	–	(–)	0.06	(1)
Catunaregam	0.03	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.03	(2)
Symplocos	0.03	(1)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.03	(1)
Total	**0.70**	**(42)**	**2.54**	**(35)**	**2.07**	**(12)**	**1.36**	**(3)**	**2.76**	**(4)**	**1.81**	**(2)**	**11.24**	**(98)**

2011 (pre-logging) census. Basal area is given as $m^2\ ha^{-1}$ and stem density (in parentheses) is given as trees $0.24\ ha^{-1}$.

Genus	DBH class (cm)													
	5–10		10–20		20–30		30–40		40–50		50–60		Total	
Gluta	–	(–)	–	(–)	0.18	(1)	–	(–)	1.38	(2)	2.90	(3)	4.46	(6)
Xylopia	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Calophyllum	0.04	(3)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.04	(3)
Parinari	0.03	(2)	0.20	(4)	0.20	(1)	0.41	(1)	–	(–)	–	(–)	0.84	(8)
Dipterocarpus	0.30	(16)	2.30	(30)	1.52	(9)	1.39	(3)	0.71	(1)	–	(–)	6.22	(59)
Memecylon	0.14	(12)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.14	(12)
Artocarpus	0.03	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.03	(2)
Syzygium	–	(–)	0.27	(3)	0.18	(1)	–	(–)	–	(–)	–	(–)	0.46	(4)
Anneslea	–	(–)	0.06	(1)	–	(–)	–	(–)	–	(–)	–	(–)	0.06	(1)
Catunaregam	0.03	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.03	(2)
Symplocos	–	(–)	0.04	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.04	(1)
Total	**0.57**	**(36)**	**2.87**	**(39)**	**2.08**	**(12)**	**1.8**	**(4)**	**2.09**	**(3)**	**2.9**	**(3)**	**12.31**	**(97)**

Appendix 2 Cont'd

2014 (post-logging) census. Basal area is given as m^2 ha^{-1} and stem density (in parentheses) is given as trees 0.24 ha^{-1}.

Genus	DBH class (cm)													
	5–10		10–20		20–30		30–40		40–50		50–60		Total	
Gluta	–	(–)	–	(–)	0.19	(1)	–	(–)	1.45	(2)	–	(–)	1.64	(3)
Xylopia	0.04	(4)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.04	(4)
Calophyllum	0.06	(3)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.06	(3)[a]
Parinari	0.02	(1)	0.24	(4)	0.21	(1)	0.44	(1)	–	(–)	–	(–)	0.91	(6)
Dipterocarpus	0.31	(16)	1.92	(23)	1.74	(10)	0.98	(2)	–	(–)	–	(–)	4.95	(51)
Memecylon	0.12	(10)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.12	(10)
Artocarpus	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Syzygium	–	(–)	0.16	(2)	0.33	(2)	–	(–)	–	(–)	–	(–)	0.49	(4)
Anneslea	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Catunaregam	0.03	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.03	(2)
Symplocos	–	(–)	0.05	(1)	–	(–)	–	(–)	–	(–)	–	(–)	0.05	(1)
Total	**0.58**	**(36)**	**2.37**	**(30)**	**2.47**	**(14)**	**1.42**	**(3)**	**1.45**	**(2)**	**–**	**(–)**	**8.29**	**(85)**

[a] One tree was cut higher than 1.3 m, but still alive.

Appendix 3 Species-specific diameter increments per DBH class for the first (2003), pre-logging (2011), and post-logging(2014) censuses in study plot, Kampong Thom Province, Cambodia.

2003–2011 (first to pre-logging) census. Diameter increments are given as mean ±SD, (cm $year^{-1}$). Sample sizes are given in parenthesis. Only genus names are shown (see Appendix 1 for full scientific names).

Genus	DBH class (cm)													
	5–10		10–20		20–30		30–40		40–50		50–60		Total	
Gluta	–	(–)	–	(–)	0.22	(1)	–	(–)	0.29 ±0.09	(3)	0.33 ±0.04	(2)	0.29 ±0.07	(6)
Xylopia	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Calophyllum	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Parinari	0.33 ±0.14	(3)	0.38	(1)	0.52 ±0.27	(2)	–	(–)	–	(–)	–	(–)	0.40 ±0.18	(6)
Dipterocarpus	0.10 ±0.09	(17)	0.11 ±0.07	(28)	0.08 ±0.05	(8)	0.05 ±0.08	(3)	0.07	(1)	–	(–)	0.10 ±0.07	(57)
Memecylon	0.04 ±0.12	(7)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.04 ±0.12	(7)
Artocarpus	-0.01	(1)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	-0.01	(1)
Syzygium	–	(–)	0.01 ±0.02	(3)	0.13	(1)	–	(–)	–	(–)	–	(–)	0.04 ±0.06	(4)
Anneslea	–	(–)	-0.01	(1)	–	(–)	–	(–)	–	(–)	–	(–)	-0.01	(1)
Catunaregam	0.02 ±0.00	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.02 ±0.00	(2)
Symplocos	0.24	(1)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.24	(1)
Total	**0.11 ±0.13**	**(31)**	**0.11 ±0.09**	**(33)**	**0.17 ±0.19**	**(12)**	**0.05 ±0.08**	**(3)**	**0.24 ±0.13**	**(4)**	**0.33 ±0.04**	**(2)**	**0.12 ±0.13**	**(85)**

Appendix 3 Cont'd

2011–2014 (pre-logging to post-logging) census.

Genus	DBH class (cm)													
	5–10		10–20		20–30		30–40		40–50		50–60		Total	
Gluta	–	(–)	–	(–)	0.24	(1)	–	(–)	0.38 ±0.22	(2)	–	(–)	0.33 ±0.17	(3)
Xylopia	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Calophyllum	0.48 ±0.13	(3)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.48 ±0.13	(3)
Parinari	0.24 ±0.23	(2)	0.39 ±0.24	(4)	0.34	(1)	0.40	(1)	–	(–)	–	(–)	0.35 ±0.19	(8)
Dipterocarpus	0.10 ±0.17	(14)	0.20 ±0.14	(24)	0.17 ±0.15	(9)	0.06 ±0.08	(2)	–	(–)	–	(–)	0.16 ±0.15	(49)
Memecylon	0.10 ±0.15	(9)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.10 ±0.15	(9)
Artocarpus	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Syzygium	–	(–)	0.15 ±0.06	(3)	0.39	(1)	–	(–)	–	(–)	–	(–)	0.21 ±0.13	(4)
Anneslea	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Catunaregam	0.10 ±0.06	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.10 ±0.06	(2)
Symplocos	–	(–)	0.32	(1)	–	(–)	–	(–)	–	(–)	–	(–)	0.32	(1)
Total	**0.15 ±0.19**	**(30)**	**0.23 ±0.16**	**(32)**	**0.21 ±0.15**	**(12)**	**0.17 ±0.21**	**(3)**	**0.38 ±0.22**	**(2)**	**–**	**(–)**	**0.20 ±0.17**	**(79)**

2003–2014 (first to post-logging) census.

Genus	DBH class (cm)													
	5–10		10–20		20–30		30–40		40–50		50–60		Total	
Gluta	–	(–)	–	(–)	0.22	(1)	–	(–)	0.29 ±0.01	(2)	–	(–)	0.26 ±0.04	(3)
Xylopia	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Calophyllum	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Parinari	0.34 ±0.17	(3)	0.39	(1)	0.48 ±0.21	(2)	–	(–)	–	(–)	–	(–)	0.39 ±0.16	(6)
Dipterocarpus	0.10 ±0.09	(15)	0.14 ±0.08	(23)	0.10 ±0.05	(8)	0.02 ±0.00	(2)	–	(–)	–	(–)	0.12 ±0.08	(48)
Memecylon	0.07 ±0.06	(5)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.07 ±0.06	(5)
Artocarpus	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Syzygium	–	(–)	0.05 ±0.03	(3)	0.20	(1)	–	(–)	–	(–)	–	(–)	0.09 ±0.08	(4)
Anneslea	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)
Catunaregam	0.04 ±0.01	(2)	–	(–)	–	(–)	–	(–)	–	(–)	–	(–)	0.04 ±0.01	(2)
Symplocos	–	(–)	0.26	(1)	–	(–)	–	(–)	–	(–)	–	(–)	0.26	(1)
Total	**0.12 ±0.12**	**(26)**	**0.14 ±0.09**	**(27)**	**0.18 ±0.16**	**(12)**	**0.02 ±0.00**	**(2)**	**0.29 ±0.01**	**(2)**	**–**	**(–)**	**0.14 ±0.12**	**(69)**

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.

Diversity and population dynamics of mosquito vectors of Japanese encephalitis virus in a peri-urban and rural pig farm setting in Cambodia

PENG Borin

មូលន័យសង្ខេប

វីរុសបង្កជំងឺរលាកខួរក្បាលជប៉ុន (Japanese encephalitis virus (JEV)) គឺជាបុព្វហេតុបង្កជំងឺរលាកខួរក្បាលនៅអាស៊ី។ បក្សីទឹកជាច្រើនប្រភេទមានផ្ទុកវីរុសនេះ ចំណែកឯសត្វជ្រូកគឺជាផ្ទួលវីរុស JEV ហើយមូសអង្គាម (*Culex*) ជាភ្នាក់ងារសំខាន់ចម្លងជំងឺនេះ។ ដោយការយល់ដឹងពីអន្តរកម្មរវាងផ្ទួល និង ភ្នាក់ងារចម្លង JEV នៅមានកម្រិតក្នុងបរិបទការរីករាលដាលនៃនគរូបនីយកម្ម យើង បានអង្កេតពីនានាភាព និង បម្រែបម្រួល ប៉ូពុយឡាស្យុងនៃភ្នាក់ងារបង្កជំងឺ JEV នៅកសិដ្ឋានចិញ្ចឹមជ្រូកក្នុងតំបន់ជាយក្រុង និងជន បទក្នុងប្រទេសកម្ពុជា។ មូសត្រូវបានចាប់ក្នុងរយៈពេល១២ខែ គឺចាប់ពីខែកក្កដា ឆ្នាំ២០១៥ ដល់ខែកក្កដា ឆ្នាំ២០១៦ ដោយប្រើអន្ទាក់ច្រើនយប់ជាប់ៗ សរុបមានមូស៨៣.៥៣១ ក្បាលត្រូវបានចាប់។ មូស១៧ប្រភេទត្រូវបានកំណត់ ត្រាពីតំបន់ជាយក្រុង និង ១៥ប្រភេទទៀតពីជនបទ។ *Culex gelidus* ជាប្រភេទចាប់បានច្រើនជាងគេនៅតំ បន់ជាងក្រុង តំណាងឲ្យ៣៦.៧៨% នៃឯកត្តសរុប និងច្រើនបន្ទាប់គឺសមាជិកនៃក្រុមរង *C. vishnui* (២៨%) *C. tritaeniorhynchus* (១៩.៨%) *Culex* sp. (១១.៥%) *Anopheles* sp. (១.៥%) និង *C. quinquefasciatus* (១.៤%)។ សមាជិកនៃក្រុមរង *C. vishnui* (៥១.៦%) គឺជាក្រុមដែលសម្បូរជាងគេនៅទីជនបទ បន្ទាប់មកគឺ *Culex* sp. (១៧%) *C. gelidus* (១៤.៩%) *C. tritaeniorhynchus* (១០.៩%) *C. quinquefasciatus* (១.៨%) និង *Anopheles* sp. (១.៨%)។ ចំនួនមូលដែលបានប្រមូលក្នុងខែនីមួយៗបានកើនឡើងក្នុងខែធ្នូ និង ខែកក្កដា ហើយទំនងជាផ្តល់ផលប៉ះពាល់ដល់សុខភាពសត្វជ្រូក សត្វគោនិងក្របី នៅក្នុងតំបន់សិក្សា (ជាពិសេសនៅ តំបន់ជាយក្រុង) នៅក្នុងកំឡុងពេលនោះ។ នានាភាព និង បម្រែបម្រួលប៉ូពុយឡាស្យុងនៃភ្នាក់ងារបង្កជំងឺ នៅក្នុងប្រទេសកម្ពុជា ពិតណាស់ទាមទារឲ្យមានការសិក្សាបន្ថែមទៀត។

Abstract

Japanese encephalitis virus (JEV) is a leading cause of encephalitis in Asia. Several water bird species are reservoirs for the virus, whereas pigs act as hosts for JEV and several *Culex* mosquitoes are important vectors for its transmission. As understanding of interactions between JEV hosts and vectors remains limited in the context of expanding urbanization, we investigated the diversity and population dynamics of potential JEV vectors in a peri-urban and a rural pig-farming setting in Cambodia. Mosquitoes were sampled for 12 months from July 2015 to July 2016 using consecutive night traps which captured a total of 83,531 mosquitoes. Seventeen mosquito species were recorded in the peri-urban study site and 15 mosquito species in the rural study site. *Culex gelidus* was the most abundant species in the former, representing 36.7% of individuals, followed by members of the *C. vishnui* subgroup (28%), *C. tritaeniorhynchus* (19.8%), *Culex* sp. (11.5%), *Anopheles* sp. (1.5%), and *C. quinquefasciatus* (1.4%). Members of the *C. vishnui* subgroup (51.6%) were most abundant at the latter study site, followed by *Culex* sp. (17%), *C. gelidus* (14.9%), *C. tritaeniorhynchus* (10.9%), *C. quinquefasciatus* (1.8%) and *Anopheles* sp. (1.8%). Numbers of mosquitoes sampled each month increased in December and July and likely impacted pig and/or cattle livestock in the study sites (particularly the peri-urban site) during these periods. The diversity and population dynamics of mosquito vectors in Cambodia warrant further study.

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The current and historical impact of community fisheries on sea turtles in Koh Sdach and Chrouy Svay, southwestern Cambodia

SAN Satya

មូលន័យសង្ខេប

អណ្តើកសមុទ្រ៥ប្រភេទត្រូវបានគេស្គាល់ជាប្រវត្តិសាស្ត្រនៅប្រទេសកម្ពុជា ទោះបីជាមានតែពីរប្រភេទ(អណ្តើកល្មិច *Chelonia mydas*និងអណ្តើកក្រាស់ *Eretmochelys imbricata*) ត្រូវបានគេធ្វើកំណត់ត្រាក្នុងអំឡុង១០ឆ្នាំចុងក្រោយក៏ដោយ។ ប្រភេទខាងដើមត្រូវបានគេចាត់ទុកថាជាប្រភេទរងគ្រោះ ហើយប្រភេទបន្ទាប់ជាប្រភេទរងគ្រោះធ្ងន់ធ្ងរ។ ប៉ុន្តែពុយឡាស្យុងរបស់ប្រភេទទាំងពីរ ត្រូវបានគេជឿជាក់ថាមានការថយចុះដោយសារការជាប់ដោយចៃដន្យនិងងាប់នៅក្នុងឧបករណ៍នេសាទត្រី។ មានការដឹងតិចតួចនៅឡើយពីកម្រិតនៃការងាប់ ព្រោះវាជាការជាប់ដោយចៃដន្យក្នុងដំណើរការនេសាទសមុទ្រ ការសិក្សារបស់ខ្ញុំមានបំណងបង្កើនការយល់ដឹងពីប្រភេទឧបករណ៍នេសាទដែលបានប្រើក្នុងប្រទេសកម្ពុជា និង កម្រិតប៉ះពាល់ផ្សេងៗទៅលើប៉ូពុយឡាស្យុងរបស់អណ្តើកសមុទ្រ។ ទិន្នន័យត្រូវបានប្រមូលតាមរយៈកម្រងសំណួរសម្ភាស៍អ្នកនេសាទចំនួន២២៤នាក់ នៅក្នុងភូមិចំនួន៤ នៅស្រុកកោះស្តេច និងស្រុកជ្រោយស្វាយ ខេត្តកោះកុង ភាគនិរតីនៃប្រទេសកម្ពុជា ពីខែកុម្ភៈដល់ខែមីនា ឆ្នាំ២០១៦។ ទោះជាប្រភេទឧបករណ៍នេសាទដែលបានប្រើមានការផ្លាស់ប្តូរកន្លងមក ហើយអ្នកនេសាទខ្លះប្រើប្រាស់ច្រើនជាងមួយប្រភេទ សំណាញ់បង្គានិងផ្លែសន្ទូចបបែលត្រូវបានគេប្រើប្រាស់ច្រើនជាងគេក្នុងចំណោមឧបករណ៍ដែលបានប្រើដោយអ្នកនេសាទ គឺប្រហែលជា៤៤%និង២៨% តាមលំដាប់។ យោងតាមចម្លើយសម្ភាសន៍ សន្ទូចបបែលផ្តល់ការគំរាមកំហែងដល់អណ្តើកសមុទ្រខ្លាំងជាងគេ ដែលវាមួយមុខចាប់បានអណ្តើកបានចំនួន៤១ក្បាលដោយចៃដន្យ ធៀបនឹងអួនបានចំនួន៩ក្បាល និង តិចជាងនេះចំពោះប្រភេទឧបករណ៍នេសាទផ្សេងទៀត។ លទ្ធផលនៃការសិក្សារបស់ខ្ញុំបានបង្ហាញថា ការតាមដានលើអណ្តើកសមុទ្រដែលចាប់ដោយចៃដន្យតាមរយៈការនេសាទសមុទ្រ និងកាត់បន្ថយកម្រិតនៃការចាប់នេះ គឺជាការងារបន្ទាន់។ ការងារនេះគួររាប់បញ្ចូលទាំងការបង្កើនការត្រួតពិនិត្យការនេសាទខុសច្បាប់។

Abstract

Five species of marine turtle are historically known in Cambodia, although only two—green turtle *Chelonia mydas* and hawksbill turtle *Eretmochelys imbricata*—have been recorded in the last 10 years. The former species is Endangered and the latter Critically Endangered and populations of both are believed to be decreasing due to incidental capture and subsequent mortality in fishing gear. As little is known about the extent of mortality due to by-catch in marine fisheries, my study aimed to improve understanding of the types of fishing gear used in Cambodia and their relative impacts on sea turtle populations. Data were collected through questionnaire-based interviews of 224 fishermen in four villages in the Koh Sdach and Chrouy Svay districts of Koh Kong Province, southwestern Cambodia, in February–March 2016. Though types of fishing gear used have changed over time and some fishermen use more than one type, shrimp gill nets and ray hooks were most common gear types used, being employed by 44% and 28% of fishermen respectively. According to respondents, ray hooks posed the greatest threat to sea turtles with these alone resulting in a by-catch of 41 turtles, compared to nine reported for single trawling and lesser numbers for other types of fishing gear. My results suggest that monitoring of turtle by-catch in marine fisheries, and measures to reduce this are urgently needed. These should include improved control of illegal fishing.

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An assessment of remote sampling methodologies for estimating bear populations in tropical forest

SIM Sovannarun

មូលន័យសង្ខេប

មានខ្លាឃ្មុំពីរប្រភេទនៅប្រទេសកម្ពុជាគឺខ្លាឃ្មុំតូច (*Helarctos malayanus*) និងខ្លាឃ្មុំធំ (*Ursus thibetanus*)។ ពួកវាជាប្រភេទសត្វរស់នៅក្នុងព្រៃ និង ប្រទះឃើញនៅតាមតំបន់ការពារជាច្រើន ទោះបីជាមានការដឹងតិចតួចនៅឡើយអំពីប៉ូពុយឡាស្យុងរបស់វាដែលបាននឹងកំពុងថយចុះដោយសារការបរបាញ់ធ្វើពាណិជ្ជកម្ម ការបាត់បង់ទីជម្រក និង ការបើកសិដ្ឋានចិញ្ចឹមខ្លាឃ្មុំ។ វិធីសាស្ត្រប្រមូលទិន្នន័យ Remote sampling ដូចជាការកត់ត្រាដានឬស្នាម សំណាកសែន និង ម៉ាស៊ីនថតស្វ័យប្រវត្តិ មានសារៈសំខាន់ណាស់សម្រាប់ប៉ាន់ប្រមាណប៉ូពុយឡាស្យុងសត្វព្រៃ ជាពិសេសប្រភេទរងការគំរាមកំហែង ព្រោះវិធីសាស្ត្រនេះមិនតម្រូវឲ្យអ្នកស្រាវជ្រាវចាប់សត្វទេ។ ការសិក្សារបស់ខ្ញុំមានគោលបំណងវាយតម្លៃពីការប្រើប្រាស់វិធីសាស្ត្រនេះ សម្រាប់ប៉ាន់ប្រមាណប៉ូពុយឡាស្យុងខ្លាឃ្មុំក្នុងតំបន់ព្រៃនានា។ ការប្រមូលសំណាកត្រូវបានធ្វើឡើងនៅទីតាំងពីរទិសនិរតីនៃប្រទេសកម្ពុជា ចាប់ពីខែមីនា ដល់ខែឧសភា ឆ្នាំ២០១៦៖ ១) ឧទ្យានជាតិក្រវាញត្បូង ឃុំជីផាង ខេត្តកោះកុង ២) ឧទ្យានជាតិក្រវាញកណ្តាល ស្រុកអូរសោម ខេត្តពោធិ៍សាត់។ ការដាក់ម៉ាស៊ីនថតស្វ័យប្រវត្តិ និង ការប្រមូលសំណាករោម(តាមរយៈឧបករណ៍ទាក់យករោម) សម្រាប់ការវិភាគDNA ត្រូវបានធ្វើឡើងនៅទីតាំងមានដាក់ចំណីនៅតាមទីតាំងទាំងពីរ។ ខ្លាឃ្មុំធំមិនត្រូវបានធ្វើកំណត់ត្រាទេក្នុងអំឡុងពេលសិក្សាទោះបីជាខ្លាឃ្មុំធំមានចំនួនបួនក្បាល បង្ហាញថាខ្លាឃ្មុំតូចមានច្រើនជាងនៅក្នុងតំបន់។ ប្រភេទរងការគំរាមកំហែង និង ប្រឈមការគំរាមកំហែងមួយចំនួនទៀតក៏ត្រូវបានធ្វើកំណត់ត្រាផងដែរ(រាប់បញ្ចូលទាំង ដំរីអាស៊ី ឆ្កែព្រៃ ខ្ទីង រមាំង ខ្លាពពក ខ្លាថ្មីថ្មកែវ និង ខ្លាលឿងមាស) ដែលនេះជាភស្តុតាងដ៏សំខាន់បង្ហាញឲ្យមានការអភិរក្សនៅក្នុងតំបន់។ អត្តសញ្ញាណឯកត្តខ្លាឃ្មុំតូចមិនអាចធ្វើបានឡើយ ពីព្រោះស្នាមនៅលើទ្រូងមិនត្រូវបានថតដោយម៉ាស៊ីនថតស្វ័យប្រវត្តិទេ ហើយសំណាករោមក៏ប្រមូលមិនបានក្នុងអំឡុងពេលសិក្សា។ ករណីរូបថតប្រហែលអាចបណ្តាលមកពីចំណីត្រូវបានស៊ីបឬយកចេញដោយសត្វផ្សេងទៀត ការដាក់ចំណីមិនត្រូវទីតាំងឬសត្វរត់ដោយសារពន្លឺភ្លើងម៉ាស៊ីនថត។ វិធីសាស្ត្រទាំងពីរតម្រូវឲ្យមានការកែលម្អរដើម្បីបង្កើនលទ្ធភាពធ្វើអត្តសញ្ញាណឯកត្ត និង ប៉ាន់ប្រមាណប៉ូពុយឡាស្យុងខ្លាឃ្មុំ។

Abstract

Two bear species occur in Cambodia: sun bear *Helarctos malayanus* and Asiatic black bear *Ursus thibetanus*. Both are forest dwelling and occur in many protected areas. Little is known about their populations, which are decreasing due to commercial hunting, habitat loss and bear farming. Remote sampling methods, such as sign-based surveys, genetic sampling and camera trapping, are useful for estimating populations of wildlife and threatened species in particular because they do not require animal handling. My study aimed to assess the utility of these methods for estimating bear populations in forest areas. Sampling was conducted in two sites in southwestern Cambodia from March to June 2016: 1) Kravanh Khang Tbong National Park, Chi Phat Commune, Koh Kong Province; 2) Central Cardamoms National Park, Ou Saom Commune, Pursat Province. Camera trapping and collection of hair samples (through hair-snag traps) for DNA analysis were undertaken at baited locations at both sites. Asiatic black bear was not recorded during the study, although four sun bears were, suggesting the latter species is more abundant in the region. Several other globally threatened or near-threatened species were also recorded (including Asian elephant, dhole, gaur, sambar, clouded leopard, marbled cat and Asiatic golden cat): proof of their conservation importance. Recognition of individual sun bears was not possible because chest markings were not captured in camera trap images and because hair samples were not obtained during the study. Failure to record the bears' chest markings may have been due to baits being removed by other species, inappropriate positioning of baits or animal movement due to camera flash. Both survey methods require refinement to improve their prospects for facilitating recognition of individual bears and estimation of their populations.

Citation: Sim S. (2017) An assessment of remote sampling methodologies for estimating bear populations in tropical forest. *Cambodian Journal of Natural History*, **2017**, 130.

Estimating Asian elephant *Elephas maximus* distribution patterns during the dry season in Prey Lang Wildlife Sanctuary, Cambodia: implications for conservation and future recovery

SOUN Visal

មូលន័យសង្ខេប

ដែនជម្រកសត្វព្រៃព្រៃឡង់ គឺជាតំបន់ព្រៃស្រោងទំនាបដែលនៅសេសសល់ចុងក្រោយ ស្ថិតក្នុងទីតាំងជីវៈចម្រុះខ្ពស់ឥណ្ឌូភូមា (Indo-Burma hotspot) ហើយថ្មីៗនេះវាកាន់តែរងកំណើនការដាច់ជាបំណែកៗ ដោយសារការថយចុះនៃគម្របព្រៃ។ មានការសិក្សាស្រាវជ្រាវមួយចំនួនតូចទាក់ទងនឹងជីវៈចម្រុះនៅតំបន់ ដែលពេលវេលានិងវិសាលភាពការងារស្រាវជ្រាវទាំងនោះសុទ្ធតែនៅមានកម្រិត។ ការសិក្សារបស់ខ្ញុំបានប្រើប្រាស់ការវិភាគតាមបែប Remote sensing ក្នុងការតាមដានរបាយដំរីអាស៊ី (*Elephas maximus*) ក្នុងរដូវប្រាំងនៅតំបន់ព្រៃឡង់ ដោយមានគោលបំណងកំណត់ទីតាំងចាំបាច់សម្រាប់ការអភិរក្ស និងស្តារចំនួនដំរីឡើងវិញក្នុងតំបន់។ ដោយផ្អែកលើដំណើរការព្យាករណ៍តាម ArcMap ស្រទាប់ទិន្នន័យតំបន់ភូមិសាស្ត្រចំនួន៣ និង ទិន្នន័យបរិស្ថានចំនួន៤ ត្រូវបានដាក់បញ្ចូលគ្នានៅក្នុងកម្មវិធី Maximum Entropy(MaxEnt) ដែលតម្លៃព្យាករណ៍របស់វា (replicated runs) ជាមធ្យម គឺជាង១៥ដង។ ជាធម្មតា អថេរណាមួយចូលរួមចំណែកកាន់តែខ្លាំងនៅក្នុងម៉ូដែល ជាអថេរដែលមានឥទ្ធិពលខ្លាំងចំពោះការព្យាករណ៍ពីវត្តមាននៃដំរីអាស៊ីក្នុងតំបន់នោះ។ កម្រិតទឹកភ្លៀងក្នុងអំឡុងពេលត្រជាក់បំផុតនៃត្រីមាសប្រចាំឆ្នាំ បានចូលរួមការព្យាករណ៍ល្អជាងគេគឺរហូតដល់៤៤.៥% ក្នុងនោះដែរ ប្រភពទឹករួមចំណែក៤១.៨%នៅក្នុងម៉ូដែល ហើយអថេរផ្សេងៗទៀតបានចូលរួមចំណែកតិចជាង២០%។ ម៉ូដែលមានតម្លៃ ACU ០.៨៥៤ បង្ហាញថាការព្យាករមានភាពត្រឹមត្រូវ។ ដោយប្រើលទ្ធផលទាំងនេះ ស្រទាប់raster ត្រូវបានបម្លែងនៅក្នុងកម្មវិធី ArcMap ដើម្បីបង្កើតផែនទីជម្រកសមស្របនិងតំបន់អភិរក្សសំខាន់។ លទ្ធផលការសិក្សារបស់ខ្ញុំបង្ហាញពីភាពចាំបាច់ក្នុងការកំណត់ការរំខានដោយសកម្មភាពមនុស្សទៅថ្ងៃអនាគតនៅដែនជម្រកសត្វព្រៃព្រៃឡង់ និង បង្ហាញពីតួនាទីសំខាន់ នៃលក្ខខ័ណ្ឌអាកាសធាតុ ប្រភពទឹក និង គម្របព្រៃ សម្រាប់ការរស់រានមានជីវិត និង កើនឡើងវិញនៃចំនួនដំរីអាស៊ីនៅតំបន់នេះ។

Abstract

Prey Lang Wildlife Sanctuary is one of the last remaining areas of lowland evergreen forest in the Indo-Burma hotspot and has become increasingly isolated with reduced forest cover in recent years. Relatively few biodiversity surveys have been conducted at the site and these were limited in duration and scope. My study employed remote sensing analysis to investigate the distribution patterns of Asian elephant *Elephas maximus* during the dry season in Prey Lang and aimed to identify areas required to conserve and recover remaining populations of the species there. Following a projection process performed in ArcMap, three geographical and four environmental data layers were combined in a Maximum Entropy (MaxEnt) software model whose predictive values were averaged over 15 replicated runs. Not surprisingly, the more a variable contributed to the model, the greater the impact it had in predicting the occurrence of *E. maximus* at the site. Precipitation during the coldest yearly quarter made the greatest predictive contribution of 44.5%, whereas water sources contributed 41.8% to the model, and the remaining variables collectively contributed <20%. The model had an ACU value of 0.854, implying that it was robust. Using these results, a raster layer was converted in ArcMap to produce a map of habitat suitability and conservation hotspots at the site. The results of my study highlight the necessity of limiting future anthropogenic disturbance at Prey Lang Wildlife Sanctuary and indicate the important roles played by climatic conditions, availability of water and forest cover for survival and recovery of Asian elephant populations at the site.

Citation: Soun V. (2017) Estimating Asian elephant (*Elephas maximus*) distribution patterns during the dry season in Prey Lang Wildlife Sanctuary, Cambodia: implications for conservation and future recovery. *Cambodian Journal of Natural History*, **2017**, 131.

Comparative density of green leafhopper *Nephotettix virescens* and brown planthopper *Nilaparvata lugens* in rice fields around the Tonle Sap Lake, Cambodia

SUOR Kimhuor

មូលន័យសង្ខេប

សត្វមមាចត្នោត(*Nilaparvata lugens*)និងមមាចបៃតង(*Nephotettix virescens*) គឺជាសត្វចង្រៃដ៏ចម្បងលើដំណាំស្រូវនៅតំបន់អាស៊ីអាគ្នេយ៍ ដែលធ្វើឲ្យស្រូវលូតលាស់យឺតដូចជា ផ្ទៃកកម្ពស់ ផ្ទៃស្លឹក កម្រិតនៃការធ្វើរស្មីសំយោគនិងអាសូត។ មមាចត្នោតជាអ្នកបញ្ជូនវីរុសបង្កជំងឺតឿរួញស្លឹក(Ragged Stunt Virus)និងវីរុសជំងឺតឿទុំស្លឹក(rice grassy stunt virus) ហើយមមាចបៃតងគឺជាភ្នាក់ងារចម្លងវីរុសរួមមានវីរុសធ្វើអោយលូតលាស់យឺត(tungro virus) វីរុសជំងឺតឿលឿង(yellow dwarf virus) វីរុសជំងឺលឿងទុំស្លឹក(yellow-orange leaf virus) និងវីរុសជំងឺលឿងមិនជាប់លាប់(transitory yellowing virus)។ ការសិក្សារបស់ខ្ញុំមានគោលបំណងប្រៀបធៀបដង់ស៊ីតេនៃ*N. lugens* និង *N. virescens* នៅក្នុងស្រែ និង កំណត់កត្តាដែលអាចមានឥទ្ធិពលដល់ដង់ស៊ីតេរបស់វា។ ការប្រមូលទិន្នន័យត្រូវបានធ្វើឡើងនៅ៥០ទីតាំង ក្នុងស្រុកចំនួនពីរនៃខេត្តពោធិ៍សាត់ និងស្រុកចំនួនពីរនៃខេត្តបាត់ដំបង គឺចាប់ពីថ្ងៃទី៦ ដល់ ២៥ ខែវិច្ឆិកា ឆ្នាំ២០១៥។ ក្នុងទីតាំងនីមួយៗ សំណាកសត្វត្រូវបានប្រមូលពីក្នុងប្លង់ត្រង់(បណ្តោយ១០០ម និង ទទឹង២ម) ចំនួន៣ខ្សែ ដោយប្រើកន្ត្រងស្បៃវាត់ចាប់ និង ម៉ាស៊ីនបូមចាប់សត្វល្អិត ហើយកសិករក៏ត្រូវបានសម្ភាសផងដែរនៅទីតាំងទាំងនោះ។ ជាលទ្ធផល ដង់ស៊ីតេនៃមមាចបៃតងនិងមមាចត្នោតមានលក្ខណៈស្រដៀងគ្នារវាងស្រែក្នុងខេត្តទាំងពីរ ទោះ*N. virescens* ហាក់មានដង់ស៊ីតេខ្ពស់ជាងក្នុងខេត្តទាំងពីរ។ កត្តាមួយចំនួនដូចជាសីតុណ្ហភាពសំណើម ដំណាក់កាលលូតលាស់និងកម្ពស់ស្រូវ មិនមានឥទ្ធិពលដល់ដង់ស៊ីតេរបស់វាទាំងពីរទេ។ ទោះជាបែបនេះក្តី វាអាចបណ្តាលមកពីរយៈពេលប្រមូលទិន្នន័យខ្លី ដោយសីតុណ្ហភាពនិងសំណើមមានភាពខុសគ្នាតិចតួចក្នុងអំឡុងពេលសិក្សា។ លទ្ធផលនេះបានធ្វើអោយឃើញនូវភាពចំបាច់នៃការប្រមូលសំណាក ដោយប្រើប្រាស់វិធីសាស្ត្រលើសពីមួយ និង មានរយៈពេលស្រាវជ្រាវយូរ ដើម្បីកំណត់កត្តាដែលជះឥទ្ធិពលដល់ដង់ស៊ីតេនៃសត្វល្អិតបំផ្លាញស្រូវនៅកម្ពុជា។

Abstract

The brown planthopper *Nilaparvata lugens* and green leafhopper *Nephotettix virescens* are major pests of rice crops in Southeast Asia, stunting their growth, height, leaf area, photosynthetic rate and nitrogen content. Brown planthopper transmits the ragged stunt virus and rice grassy stunt virus, whereas green leafhopper is a vector for rice diseases including tungro virus, yellow dwarf virus, yellow-orange leaf virus and transitory yellowing virus. My study aimed to compare the density of *N. lugens* and *N. virescens* in rice fields and identify possible factors influencing this. Fieldwork was undertaken at 50 sites in two districts in Pursat Province and two districts in Battambang Province from 6–25 November 2015. At each site, samples were collected from three transect lines (each measuring 100 m in length and 2 m in width) using sweep nets and a vacuum aspirator. Farmers were also interviewed at each site. My results suggest that densities of *N. virescens* and *N. lugens* are similar between the rice fields of the two provinces and that *N. virescens* appears to occur at higher densities in both. Factors such as temperature, humidity and the growth stage and height of rice plants did not influence the density of either species. However, this may have been due to the relatively short sampling duration, as temperature and humidity varied little during the study period. My results highlight the importance of using more than one sampling method and sampling for longer periods in research aiming to identify factors influencing the density of rice insect pests in Cambodia.

Citation: Sour K. (2017) Comparative density of green leafhopper *Nephotettix virescens* and brown planthopper *Nilaparvata lugens* in rice fields around the Tonle Sap Lake, Cambodia. *Cambodian Journal of Natural History*, **2017**, 132.

Density estimation of green peafowl *Pavo muticus* in Srepok Wildlife Sanctuary, Cambodia

TAK Chandara

មូលន័យសង្ខេប

ប៉ូពុយឡាស្យុងរបស់សត្វក្ងោកបៃតង ដែលជាសត្វទទួលរងគ្រោះជិតផុតពូជនៅលើពិភពលោក ត្រូវបានថយចុះទូទាំងតំបន់អាស៊ីអាគ្នេយ៍ ដោយសារតែការបាត់បង់ទីជម្រក និង ការបរបាញ់។ តំបន់ភាគឦសាននៃប្រទេសកម្ពុជា ជាកន្លែងដែលទ្រទ្រង់ប៉ូពុយឡាស្យុងប្រភេទនេះធំជាងគេ ដែលធ្វើអោយវាក្លាយជាតំបន់អាទិភាពបម្រាប់ការអភិរក្ស។ គោលបំណងនៃការសិក្សានេះគឺដើម្បីប៉ាន់ប្រមាណដង់ស៊ីតេនៃប៉ូពុយឡាស្យុងសត្វក្ងោកបៃតងនៅដែនជម្រកសត្វព្រៃស្រែពក។ ការសិក្សាបានធ្វើឡើងនៅក្នុងតំបន់ស្នូល (ផ្ទៃក្រឡា ១.៣៩៨ គម^២) និងតំបន់ជុំវិញតំបន់ស្នូល (ផ្ទៃក្រឡា ១.៩៦៧ គម^២) នៃដែនជម្រក ពីខែធ្នូ ឆ្នាំ២០១៥ ដល់ ខែឧសភា ឆ្នាំ២០១៦។ ការប៉ាន់ប្រមាណដង់ស៊ីតេសត្វក្ងោកគឺ តាមរយៈការរាប់សំឡេងយំនៅតាមចំណុចស្តាប់ទាំង៨០ទីតាំងនៅក្នុងតំបន់ ដែល៤៨ទីតាំងស្ថិតក្នុងតំបន់ស្នូល និង ៣២ទីតាំងស្ថិតនៅជុំវិញតំបន់ស្នូល។ ក្នុងទីតាំងនីមួយៗ មានចំណុចស្តាប់ចំនួនពីរ ដែលចំណុចមួយស្តាប់នៅពេលព្រឹក និង ចំនុចមួយទៀតស្តាប់នៅពេលល្ងាច។ សំឡេងរបស់សត្វក្ងោកឈ្មោលចំនួន៦៥ក្បាលត្រូវបានឮនៅក្នុងតំបន់ស្នូល និង ៧១នៅជុំវិញតំបន់ស្នូល ជាការប៉ាន់ស្មានដង់ស៊ីតេគឺ មានក្ងោកឈ្មោលចំនួន ០,៥៥ ក្បាល/គម^២ ស្មើនឹង៧៦៨ក្បាលក្នុងតំបន់ស្នូល និងនៅជុំវិញតំបន់ស្នូលមានដង់ស៊ីតេ១,០៧ក្បាល/គម^២ ដែលស្មើនឹង២.១០៤ក្បាល។ ដង់ស៊ីតេរួមនៃតំបន់ទាំងពីរចូលគ្នាគឺ០,៧៧ក្បាល/គម^២ ដែលស្មើនឹង២៥៩១ក្បាល ដែលបង្ហាញថាព្រៃនៅតំបន់ភាគឦសាននៃប្រទេសកម្ពុជា ជាតំបន់ដែលមានសារៈសំខាន់ខ្លាំងដល់ប្រភេទសត្វក្ងោកបៃតង។ នៅជុំវិញតំបន់ស្នូលនៃដែនជម្រកសត្វព្រៃស្រែពកមានដង់ស៊ីតេសត្វក្ងោកបៃតងខ្ពស់ អាចដោយសារតែមានការរំខានពីមនុស្សខ្លាំងនៅក្នុងតំបន់ស្នូល។ មានកត្តាចំនួនពីរដែលមានឥទ្ធិពលដល់កម្រិតនៃការកំណត់វត្តមានរបស់ក្ងោក៖ ១) ចម្ងាយពីទន្លេ ២) ចម្ងាយពីភូមិនានា។ ទាក់ទងនឹងកត្តាទី១ គេអាចស្មានពីវត្តមាននៃសត្វក្ងោកបានដោយសារវាចូលចិត្តនៅក្បែរកន្លែងមានទឹកជាអចិន្ត្រៃយ៍។ ក្នុងសកម្មភាពអភិរក្សសត្វប្រភេទនេះ គួរឲ្យអាទិភាពលើការចូលរួមពីសហគមន៍ដែលមានប្រជាជនច្រើន ដើម្បីលើកកម្ពស់ការរស់ដោយសន្តិភាពជាមួយគ្នារវាងមនុស្សនិងសត្វព្រៃ ដែលអាចទទួលបានតាមរយៈការអប់រំ យុទ្ធនាការបង្កើនការយល់ដឹង និង ការលើកទឹកចិត្តផ្នែកសេដ្ឋកិច្ចដូចជាការទេស្សនាសត្វស្លាប និង ទម្រង់ផ្សេងៗទៀតនៃអេកូទេសចរណ៍។

Abstract

Populations of the globally Endangered green peafowl have declined across Southeast Asia due to habitat loss and hunting. Northeast Cambodia likely supports the largest remaining populations of the species, making it a priority area for its conservation. The aim of my study was to estimate the population density of green peafowl in Srepok Wildlife Sanctuary. The study was conducted in the core zone (1,398 km^2) and outer zone (1,967 km^2) of the sanctuary between December 2015 and May 2016. Density estimates were derived from point counts at 80 locations at the site, 48 of which were situated in the core zone and 32 within the outer zone. Two point counts were conducted at each location, one in the morning and one in the evening. Sixty-five calling males were detected in the core zone and 71 in the outer zone, providing a density estimate of 0.55 calling males / km^2 and a total estimate of 768 calling males in the former, and 1.07 calling males / km^2 and 2,104 calling males in the latter. These provided a combined estimate of 0.77 calling males / km^2 and 2,591 calling males for the site, which supports the notion that forests in northeastern Cambodia are an important stronghold for the species. The higher density of birds recorded in the outer zone of Srepok Wildlife Sanctuary may be due to greater human disturbance within the core zone. Two factors were found to affect detection rate: 1) distance from rivers; 2) distance from villages. The former was expected because the green peafowl is thought to prefer areas near permanent water. Conservation actions for the species should prioritize community engagement where larger human populations occur to promote the peaceful coexistence of people and wildlife. This could include education, awareness campaigns and economic incentives such as bird-watching and other forms of ecotourism.

Citation: Tak C. (2017) Density estimation of green peafowl *Pavo muticus* in Srepok Wildlife Sanctuary, Cambodia. *Cambodian Journal of Natural History*, **2017**, 133.

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/

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Tanaka S. & Ohtaka A. (2010) Freshwater Cladocera (Crustacea, Branchiopoda) in Lake Tonle Sap and its adjacent waters in Cambodia. *Limnology,* **11,** 171–178.

Books and chapters:

Khou E.H. (2010) *A Field Guide to the Rattans of Cambodia.* WWF Greater Mekong Cambodia Country Programme, Phnom Penh, Cambodia.

MacArthur, R.H. & Wilson, E.O. (1967) *The Theory of Island Biogeography*. Princeton University Press, Princeton, USA.

Rawson, B. (2010) The status of Cambodia's primates. In *Conservation of Primates in Indochina* (eds T. Nadler, B. Rawson & Van N.T.), pp. 17–25. Frankfurt Zoological Society, Frankfurt, Germany, and Conservation International, Hanoi, Vietnam.

Reports:

Lic V., Sun H., Hing C. & Dioli, M. (1995) *A Brief Field Visit to Mondolkiri Province to Collect Data on Kouprey* (Bos sauveli), *Rare Wildlife and for Field Training.* Unpublished report to Canada Fund and IUCN, Phnom Penh, Cambodia.

Theses:

Yeang D. (2010) *Tenure rights and benefit sharing arrangements for REDD: a case study of two REDD pilot projects in Cambodia*. MSc thesis, Wageningen University, Wageningen, The Netherlands.

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IUCN (2010) 2*010 IUCN Red List of Threatened Species.* Http://www.redlist.org [accessed 1 December 2010].

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Cambodian Journal of Natural History

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