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Review: Biodiversity of forests over limestone in Southeast Asia with emphasis on the Philippines

PAUL JOHN S. TOLENTINO[1,♥], JOHN RYAN L. NAVIDAD[1], MARJORIE DELOS ANGELES[2], DESAMARIE ANTONETTE P. FERNANDEZ[3], ELAINE LOREEN C. VILLANUEVA[4], REN DIVIEN R. OBEÑA[1], INOCENCIO E. BUOT, JR.[2]

[1]University Research Associate I of CONserve-KAIGANGAN Program Project 1, Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños. College, Batong Malake, Laguna 4031, Philippines. Tel.: +63-2-536-2807, ♥email: pstolentino2@up.edu.ph
[2]Plant Biology Division, Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños. College, Batong Malake, Laguna 4031, Philippines
[3]Animal Biology Division, Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños. College, Batong Malake, Laguna 4031, Philippines
[4]Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños. College, Batong Malake, Laguna 4031, Philippines

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Abstract. *Tolentino PJS, Navidad JRL, Angeles MD, Fernandez AP, Villanueva ELC, Obena RDR, Buot Jr IE. 2020. Review: Biodiversity of forests over limestone in Southeast Asia with emphasis on the Philippines. Biodiversitas 21: 1597-1613.* A comprehensive review of literature was carried out to determine the status of plant and animal diversity on forests over limestone in Southeast Asia (SEA), particularly in the Philippines. Angiosperm records are available in Peninsular Malaysia (1216 spp.); West Java and Seram Indonesia (101 and 149 spp., respectively); Laos (135 spp.); Thailand and Myanmar (1 sp.); and Limestone areas in Vietnam. Pteridophytes were recorded in Malaysia (32 spp.) while Bryophytes are recorded in Peninsular Malaysia (59 spp.). In the Philippines, there are plant records in: Masbate (61 spp.); Isabela (169 spp. Pteridophytes); Bohol (12 spp.), and Samar forests over limestone (29 spp. palms and 20 spp. orchids). A floral assessment in Samar Island Natural Park (SINP) includes species (212 spp.) that can possibly be found but are not limited to karsts. New Philippine endemic species are also recorded in Cebu, Palawan, and Panay Island. There are animal records in SEA including Vietnam (Bats-36, Bird-1, and Langurs-5 spp.); Malaysia (Sciuridae-1, Bats-28, Birds-129, Reptiles-17, and Invertebrates-74 spp.); Thailand (Murids-12, Reptiles-11, and Amphibian-1 sp.); and Myanmar (Reptiles-15 spp.). Records in the Philippines include: Mammals (Bicol-9, Mt. Irid-24, Mt. Aruyan-1, and Cebu-1 species), and; Birds (Cebu-1 sp.). A terrestrial faunal assessment in SINP includes species (182 spp.) that can possibly be found but are not limited to karsts. Forests over limestone are still largely understudied and the potential of discovering species is high. Further research is critical to establish science-based initiatives and policies that will protect and conserve limestone ecosystem biodiversity while allowing the utilization of its biological resources at a sustainable level.

Keywords: Biodiversity potentials, conservation, flora and fauna, karst, Southeast Asia

INTRODUCTION

Forest over limestone is a type of forest formation that can be found within tropical rainforest regions along with limestone hill areas. Limestone dissolution and abundance of calcium in the soil contributes to strongly irregular geomorphology referred to as "karsts". Limestone landscapes, though generally perceived to be lower in stature than other forest types, are known worldwide as areas of great biological importance (Struebig et al. 2009) because of its rich endemic flora and fauna (Fernando et al. 2008). It is also significant in terms of its mineral and aquifer resources, aesthetic, cultural, and tourism value.

Southeast Asia comprises 11 countries, namely: Myanmar, Vietnam, Laos, Thailand, Cambodia, Malaysia, Singapore, Indonesia, Brunei, Philippines and East Timor (Sodhi et al. 2004). The region has abundant large formations of limestone landscapes, which cover an area of 460,000 square kilometers (km^2) and accounts for about 10% of the total land area in Southeast Asia (Day and Urich 2000) with the most extensive found in Vietnam, Thailand, Indonesia, and Malaysia (Fernando et al. 2008). The Philippines is recorded to also possess extensive forest over limestone landscapes. While 30,000 km^2 of the country's land area are karst landscapes, a large portion of this is still unknown to science because of the low priority and limited research support of the government. Recognizing the importance of limestone ecosystems as a host of unique flora and fauna, a strategic action plan is needed to save and sustainably manage the country's unique ecosystem (BMB-DENR 2019).

The need for research on forest over limestone has been identified as a conservation priority for the sustainability of these forests especially that natural and anthropogenic disturbances are increasing (Sodhi et al. 2010). As an example, unsustainable use of resources can change the soil's quality and dynamics thus altering the forest's productivity and affecting its species composition. Given

the fragile nature of limestone forests, there is a need for practical methods for the extraction of raw materials that are more compatible with the conservation of biodiversity in limestone areas. Research is a crucial factor to consider before doing anything that will cause change to limestone landscapes. Despite the significance and high potential of discovering new scientific breakthroughs, biological data focusing on forest over limestone is still lacking. It is a perfect opportunity to study forests over limestone and gain more knowledge of its biological information. Researches on forest over limestone focusing on its high biological importance should be urgently considered in order to protect its biodiversity. Thus, threats on forest over limestone could be minimized by implementing research-based knowledge on proper management practices, land use plans, and conservation strategies toward a sustainable ecosystem.

This study assessed the status and the biodiversity of forests over limestone in Southeast Asia, with emphasis on the Philippine setting. Based on several literature reviews, it also determined the biodiversity found in forests over limestone and provided an assessment of its potentials. Lastly, this article evaluated the conservation efforts towards forests over limestone in Southeast Asia.

DATA SOURCES

A comprehensive review of several published literature regarding biodiversity, potentials, and conservation efforts in forests over limestone of Southeast Asia was employed and compared with the Philippine setting. Reputable scientific journals were among the sources of information such as Trends in Ecology and Evolution, BioScience, Conservation Biology, Biological Conservation, Biodiversity and Conservation, Cave and Karst Science, Journal of Threatened Taxa, and Acta Carsologica. Several published journal articles about tropical forests over limestone in Southeast Asia were also consulted. Descriptions of the forest over limestone and its composition in the different regions of the Philippines was reviewed from Fernando et al. (2008) and Restificar et al. (2006). The threats which include limestone quarrying, land use change, deforestation, hunting, illegal logging, and habitat degradation of forests over limestone were in reference to the Cave Management, Protection and Conservation Strategy and Action Plan (2019-2028) of BMB-DENR (2019), Woxvold et al. (2009), and Clements et al. (2006). In addition, the guidelines for forest over limestone protection were consulted with the publications from Restificar et al. (2006) and Watson et al. (1997) guidelines for cave and karst protection. The animal species mentioned were verified based on the latest assessments by the International Union for Conservation of Nature (IUCN). Lastly, each listed species of plants was verified through The International Plant Name Index (IPNI).

BIODIVERSITY OF FOREST OVER LIMESTONE LANDSCAPES

Preliminary studies indicate that the Philippine karst landscapes have a total area of 35 000 km² (Figure 1) which is about 11.7% of the country's total land area (BMB-DENR 2019) and about 29% is protected by law (Wagner 2013). However, there are no existing legislation that directly addressed the protection and conservation of karst areas in the country, and its protection is mainly indirect. Significant actions for the protection of karst in the Philippines only address specific aspects, such as the National Caves and Cave Resources Management and Protection Act in 2001 and the inclusion of karst water resources in the country's National Action Plan (NAP) under the United Nations Convention to Combat Desertification (UNCCD) (Restificar et al. 2006). Tourism is one of the driving factors for karst conservation and some portion of karst areas are protected only because it is part of a larger protected landscape such as nature reserves, natural parks, wildlife sanctuary, or protected seascapes. The government shoulders a big responsibility in recognizing the importance of protecting forests over limestone and its components which offer economic, scientific, recreational and aesthetic resources. Given these, they are also potentially highly sensitive so careful protective management is essential (Watson et al. 1997).

The karst areas in the country (Figure 2) vary in terms of form and age but most of it formed in Tertiary and Quaternary carbonates (Fernando 2008). According to BMB-DENR (2019), the dominant limestone formations in the Philippines are karst towers and cones. It is also characterized by caves, sinkholes, and aquifers. One of the most extensive recorded is the Calbiga Karst on Samar Island with many other significant karst areas found on other large islands. Important karst areas are also found in Luzon (Cagayan, Kalinga-Apayao, Ilocos and Bicol regions), Visayas (Bohol and Cebu) (Cadiz and Buot 2010, 2011; Lillo et al. 2020), and Mindanao (Negros, Davao and Cotabato) (Restificar et al. 2006). Pinnacle karsts and conspicuous steep-sided karst towers are found in northern Palawan-specifically Coron Island-and Palawan's west coast (Fernando et al. 2008). Bohol island, on the other hand, is dominated by dome-shaped karst hills and numerous sinkholes, dry valleys, karst fields, and caves (Restificar et al. 2006).

Samar Island Natural Park (SINP) covers an area of about 333,300 hectares. The interior natural habitats of Samar Island are dominated by lowland evergreen rainforests and limestone forests (UNDP 2007; Taylor et al. 2015). It was declared as a protected area under the NIPAS Act in 2003. The area is worthy of attention as it holds a significant portion of karst landscapes including the Calbiga karst which is one of the largest limestone areas in the country which covers an area of about 900 km^2. The Calbiga Cave Protected Landscape found within the Calbiga karst contains 12 caves, with the five-kilometer-long Langun-Gobingob System being the largest (Restificar et al. 2006).

Karst landscapes provide protection and safety to numerous species (BMB-DENR 2019; Clements et al. 2006) in which the surface vegetation is often distinctive and supports a wide range of karst-endemic species of plants, vertebrates, and invertebrates (Hamilton-Smith 2001). Southeast Asia's karsts support a very high level of endemic species (Clements et al. 2006; Latinne et al. 2011; Schilthuizen et al. 2005) and is considered as one of the most biologically rich regions in the world (Sodhi et al. 2004). Most karsts are scattered and isolated as small limestone hills (Schilthuizen et al. 2005; Clements et al. 2006; Struebig et al. 2009) and there is a high degree of localized endemism, due at least in part to the diversity of microclimate in karst areas (Hamilton-Smith 2001). Limestone's unique characteristics such as its chemistry, hydrology, geology, and micro-climates, is a driving factor in the evolution of its biological components in order to adapt to their environment including some species of plants (orchids), vertebrates (bats, fish), and invertebrates (snails, beetles) (BirdLife/FFI/IUCN/WWF 2014). The limestone species are adapted with the highly alkaline environment and plants are also able to cope with the extreme water shortage in the soil during drought seasons of the year (FFI 2001). Moreover, many limestone species provide important ecosystem services (BirdLife/FFI/IUCN/WWF 2014).

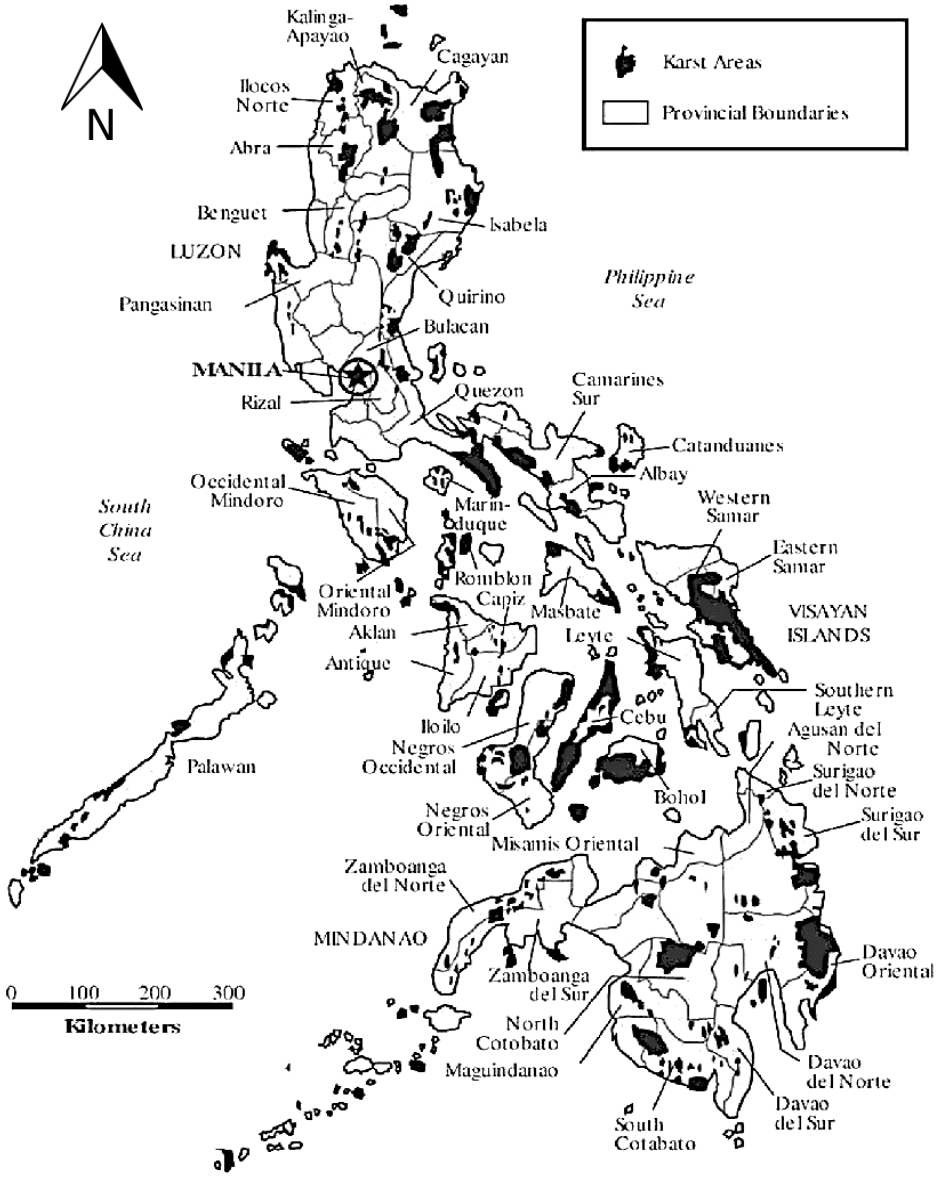

Figure 1. Karst areas in the Philippines shaded in black (based on Balázs 1973; Restificar et al. 2006)

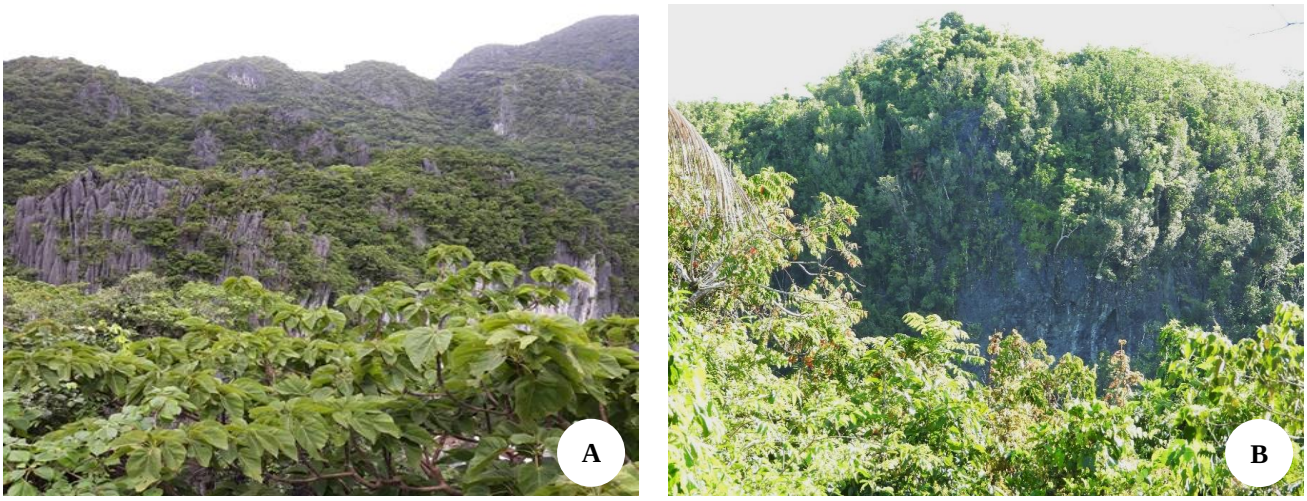

Figure 2. Karst formations in the Philippines: A. Taraw Cliff, El Nido, Palawan (Photograph by J.R. Navidad), and B. Karst near Linao Cave, Guiuan, Eastern Samar (Photograph by P.J. Tolentino)

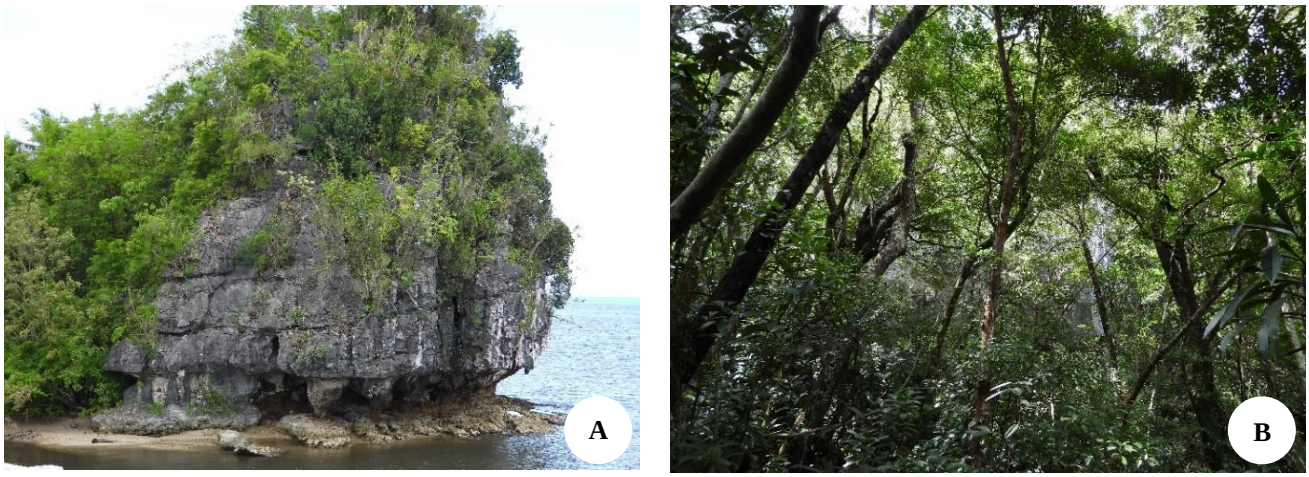

Figure 3. A. Short stunted plants on exposed vertical cliffs; B. Tall trees on gentler areas of Paranas, SINP. Photographs by P.J. Tolentino.

Sadly, karst outcrops are under immense pressure from mining interests, local harvest of animal resources (e.g., guano, bird's nest-used for nido soup), land conversion, illegal hunting/poaching, and over-extraction of timber products (Clements et al. 2006; Struebig et al. 2009). The SEA region is recognized as a biodiversity hotspot because its rich flora and fauna is threatened by activities such as rapid land-use change and other anthropogenic activities, putting much of the biodiversity at risk for extinction.

Flora of forest over limestone

The forest over limestone typically has greatly varying tree heights when compared to other forest types depending on the site and physical habitat, from short stunted trees on exposed vertical cliffs to tall trees (Figure 3) up to 35 meters (m) tall on gentle hills (Fernando et al. 2008). Limestone landscapes are comprised of several diverse plant communities and are floristically unique compared to other forest types. The varied ecological niches and intricate terrains that can be found within the limestone landscapes result in high species diversity of the area (Asanok and Marod 2016; Clements et al. 2006; Saw et al. 2010). The surface rock layer of limestone landscapes has innumerable perforations and hollow areas that allow rainwater to drain fast underground. The upper rock layer, for the most part, holds a thin substrate of soil that cannot provide for a plant's sustenance alone. High temperatures and exposure also require plants to have strategies for surviving acute drought (FFI 2001). For this reason, most of the plant species found on forests over limestone are deciduous which is part of their adaptation to seasonal shortages in water.

The presence of many narrow endemic species or those that only exist in one area can command thousands of dollars per plant when traded on the illegal market; e.g. slipper orchids (*Paphiopedilum* spp.). Notable cycads (primitive, palm-like trees) and fan palms that can recover even after severe wilting are also present in limestone

ecosystems (FFI 2001). The interest in this component of the biota is growing rapidly, partly because a range of particularly exotic and often attractive plants, such as orchids, begonias (Peng et al. 2015, 2017; Phutthai and Hughes 2017) and pitcher plants are included in karst flora (Hamilton-Smith 2001). The unusual soil condition paved the way for the high environmental heterogeneity found within forests over limestone (Pérez-García et al. 2009). The vegetation of a limestone forest is also greatly varied depending on the site's prevailing conditions. Many of these are calcicoles, species which are adapted to grow on limestone soils (Clements et al. 2006).

In a study on the tower karst limestone formation in Selangor, Malaysia (Kiew 2014), a total of 269 species of vascular plants were recorded of which 51 are endemic and 80 are calciphiles. Some of the most common families listed in the study were Orchidaceae (23 species), Apocynaceae (20 species), Rubiaceae (14 species), Araceae (12 species), Gesneriaceae, Moraceae (9 species), and Urticaceae (9 species). Among these families, *Ficus* (Moraceae) comprise the largest genus. In the limestone forest of Seram Island in Indonesia (Ranlund 2011), a total number of 149 species were recorded. The two most abundant species in Seram Island are *Aglaia sapindina* Harms. and *Myristica lancifolia* Poir. Other abundant species include *Alangium javanicum* (Blume) Wangerin., *Gymnacranthera paniculata* Warb., *Celtis philippinensis* Blanco., *Chisocheton ceramicus* Miq., and *Palaquium amboinense* Burck.

In the Philippines, only a few studies focusing on limestone forests have been conducted. The existing studies on plant diversity which includes forest over limestone showed varying results in different regions. In Baladingan, Ticao Island, 61 species in 32 families were recorded, of which 23 species are endemic and approximately half of the 23 species are island endemics (Calumpong 2014). In Palawan near St. Paul's Bay, the common species dominant in the forest over limestone includes *Vitex parviflora* Juss., *Afzelia rhomboidea* Fern.-Vill., *Sindora supa* Merr., *Intsia bijuga* Kuntze., *Albizia acle* Merr., *Wallaceodendron celebicum* Koord., *Pterocarpus indicus* Willd., *Kingiodendron alternifolium* Merr. & Rolfe., *Wrightia pubescens* R.Br. (Fernando et al. 2008). In the case of Dinagat Island, where the forest over limestone is on mountainous topography, tree species like *Terminalia catappa* L., *Barringtonia asiatica* Kurz., *Hernandia nymphaeifolia* (C.Presl) Kubitzki., *Barringtonia racemosa* (L.) Spreng., *Taliparitiliaceum* (L.) Fryxell., and *Millettia pinnata* (L.) Panigrahi. are dominant (Lillo et al. 2019). Many herbs are also documented in the crevices of karst limestone areas of the Philippines including the species belonging to Araceae, Begoniaceae, Gesneriaceae, Orchidaceae (Fernando et al 2008). Fern and fern allies are also found within this forest type of Palanan, Isabela where Barcelona et al. (2006) recorded a total of 169 species. Twelve species of dipterocarps were recorded in the aseasonal southern part of Bohol Island by Fernando et al. (2008). Species belonging to Rubiaceae are also be found in forests over limestone of Eastern Samar, Visayas based on a checklist by Ordas et al. (2018). Lastly, a floral diversity assessment in Samar Island Natural Park by Quimio (2016) recorded a total of 212 timber species where 86% of individual trees were dipterocarps, in 14 species, with *Shorea squamata* Benth. & Hook.f. and *Shorea polysperma* Merr. being the most frequent. SINP is located where the sedimentary formation generally consists of basement rocks, sometimes with overlying clastic rocks or limestone.

The high floral richness that has been recorded on forest over limestone are still underestimated (Clements et al. 2006) and lot of biological data could still be unveiled. Exploring the remote areas of forest over limestone could lead to the discovery of new plant species of economic importance. A table showing the compiled number of species found in forests over limestone of Southeast Asia from different floral studies is shown in Table 1.

Fauna of forest over limestone

The distinctive vegetation together with the often highly dissected terrain of karst leads in turn to an especially attractive environment for unique species of invertebrates, reptiles, birds and mammals. In fact, some species appear to be fully confined to karst regions (Hamilton-Ssmith 2001). By far, lizards under the Family Gekkonidae are the most well-represented taxa among forest over limestone biodiversity studies in Southeast Asia. On a study by Grismer et al. (2018), 12 new karst-adapted gekkonid species under the genus *Cyrtodactylus* were recorded from isolated limestone ecosystems in east-central and southern Myanmar. These geckoes have evolved specialized scansors under their feet that allow them to stick to surfaces such as limestone. Newly discovered species have been and are continuously being described from Laos (Luu et al. 2016ab, 2017; Nazarov et al. 2018; Schneider et al. 2011, 2014), Indonesia (Grismer et al. 2014; Riyanto et al. 2014), Malaysia (Grismer and Onn 2009, 2010; Grismer et al. 2008a,b; Grismer et al. 2013, 2014a,b,c, 2016; Wood et al. 2013), Myanmar (Connette et al. 2017; Grismer et al. 2018a,b), Thailand (Ellis and Pauwels 2012; Grismer et al. 2008, 2014; Panitvong et al. 2012; Pauwels and Sumontha 2014; Wood et al. 2017), and Vietnam (Ngo 2011; Nguyen et al. 2017; Quang et al. 2007; Rösler et al. 2005; Ziegler et al. 2008). A new species of sticky frog, *Kalophrynus calciphilus*, found only in the karst hills and mountains of Melinau Limestone Formation, Malaysian Borneo, has also been recently discovered (Dehling 2011). Another notable species of frog, *Ansonia khaochangensis* sp. Nov., from southern Thailand is the first of its species that prefer to live in a karst ecosystem as compared to all other *Ansonia* species that are adapted to a lotic lifestyle. This emphasizes that aside from promoting evolution of new species, karst ecosystems also play a part in the evolution of remarkably different lifestyles (Grismer et al. 2017).

Table 1. Major plant groups and the number of species found in different forests over limestone of Southeast Asia based from recent floral surveys

Major plant group	No. of species	Location	Notes	Reference
Spermatophytes				
Angiosperms	1216	Peninsular Malaysia limestone flora	21% endemics; 11% calciphiles (strictly confined to karsts)	Adam and Mamat (2005); Chin (1977); Clements (2006); Kiew (2014); Nizam et al. (2012)
	42	Peninsular Malaysia	42 Gesneriaceae species; 28 are endemic and 16 are restricted to a single or adjacent hill.	Rahman and Kiew (2018)
	4	Peninsular Malaysia	*Impatiens* (Balsaminaceae) species; 1 widespread on karst limestone in Kelantan and Pahang; 3 other new species narrowly endemic to Kelantan limestone and are critically endangered.	Kiew (2016)
	6	Peninsular Malaysia	*Microchirita* (Gesneriaceae) restricted to limestone areas.	Rafidah (2017)
	1	Peninsular Malaysia	*Exacum tenue* (Gentianaceae); new record from Malaysia.	Rafidah (2018)
	1	Relai Forest Reserve, Gua Musang, Kelantan and Gua Tanggang, Merapoh, Pahang, Peninsular Malaysia	*Vatica najibiana* (Dipterocarpaceae); new species	Ummul-Nazrah et al. (2018)
	3	Perak, Malaysia	Three new species: *Gymnostachyum kanthanense* Kiew (Acanthaceae), *Meiogyne kanthanensis* (Annonaceae) and *Vatica kanthanensis* (Dipterocarpaceae)	Tan et al. (2014)
	101	West Java, Indonesia	Total of 38 families recorded for both sites.	Satyani and Kusuma (2010)
	149	Lowland limestone forest on Seram Indonesia	-	Ranlund (2011)
	135	Limestone karst vegetation of Vang Vieng District, Vientiane Province, Laos	Orchid species	Kumar et al. (2016)
	1	Thailand and Myanmar	*Begonia tenasserimensis* sp. nov.; Endemic to the hills of the Tenasserim Range.	Phutthai and Hughes (2017)
	6	Limestone areas in northern Vietnam	6 new species of *Begonia* (Begoniaceae)	Peng et al. (2015)
	5	Xuan Son National Park, northern Vietnam	3 restricted to limestone hills and 2 others widely distributed.	Ngo and Holsher (2014)
	20	Ba Be National Park, Vietnam	20 native tree species	Binh et al. (2015)
	29	Ben En National Park, Vietnam	26 most abundant tree species	Nguyen et al. (2015)
	1	Karst regions of China and Vietnam	*Hemiboea crystallina*, a new species of Gesneriaceae	Chen et al. (2018)
	260	Samar Island Natural Park	Sites include but are not limited to forests over limestone.	Quimio (2016)
	61	Baladingan, Ticao Island, Philippines	32 families; 23 endemics, half of which reported endemic only to Ticao; 9 species in 5 families are introduced; 10 species in 7 families are endangered.	Calumpong (2014)
	19	General Philippine limestone	7 dominant leguminous trees; 9 other dominant species; 3 smaller trees.	Fernando (2008)
	9	St Paul's Bay, Palawan, Philippines	5 common species; other 4 frequent on crevices.	
	9	Malapakan Island, Northern Palawan, Philippines	-	
	16	Aseasonal southern part of Bohol Island	-	
	1	Nug-as forest, Alcoy Municipality, southern Cebu	*Lepeostegeres cebuensis* (Loranthaceae); New mistletoe species from Cebu, Philippines.	Pelser et al. (2016); Pelser et al. (2011 onwards)
	1	Cebu, Philippines	*Gymnosiphon philippinensis*, new species of Burmanniaceae	

	1	Limestone hills near El Nido, Palawan, Philippines	1 new species of *Amorphophallus* (Araceae)	Hetterscheid et al. (2012)
	18	Northeastern Luzon near Palanan, Isabela, Philippines	-	Co et al. (2006); Fernando 2008
	29	Samar Island forests over limestone	14 climbing palm species; 15 erect palm species (2 new species: *Pinanga* (Arecaceae) (Adorador et al. 2020) and *Orania zheae* (Oranieae, Arecoideae, Arecaceae) (Adorador and Fernando 2019)	Adorador and Fernando (2019); Adorador and Fernando (2017); Adorador et al. (2020)
	20	Paranas and Marabut's forest over limestone in Samar Island, Philippines	20 orchid (Orchidaceae) species; 18 in Paranas, 1 in Marabut, and 1 occurring in both.	Meneses et al. (2018); Meneses and Cootes (2019)
	3	Panay Island, Philippines	3 new species of *Begonia* sect. Baryandra	Peng et al. (2017)
	6	Across Visayas in the Philippines	Rare tree species confined to limestone areas.	Peque and Holscher (2014)
Gymnosperms	2	Batu Caves tower karst formation, Malaysia	1 species usually found in limestone.	Kiew (2014)
Pteridophytes (ferns and fern allies)	32	Batu Caves tower karst formation, Malaysia	1 endemic; 7 obligate calciphiles.	Kiew (2014)
	169	Bohol Island, Philippines	63 genera and 27 families; 21 species are Philippine endemics.	Barcelona (2006)
	48	Samar Island Natural Park	Sites include but are not limited to forests over limestone.	Quimio (2016)
	10	Baladingan, Ticao Island, Philippines	-	Calumpong (2014)
	50	Forest over limestone in Cebu Island Key Biodiversity Areas	15 families and 29 genera.	Lillo (2020)
Bryophytes (mosses, liverworts and hornworts)	59	Gunung Senyum Recreational Forest, Peninsular Malaysia	32 genera and 16 families of mosses.	Norhazrina et al. (2019)
	-	Southeast Asia	See Mohamed and Tan (1998); Mohamed et al. (2005)	Mohamed and Tan (1998); Mohamed et al. (2005); Clements (2006)

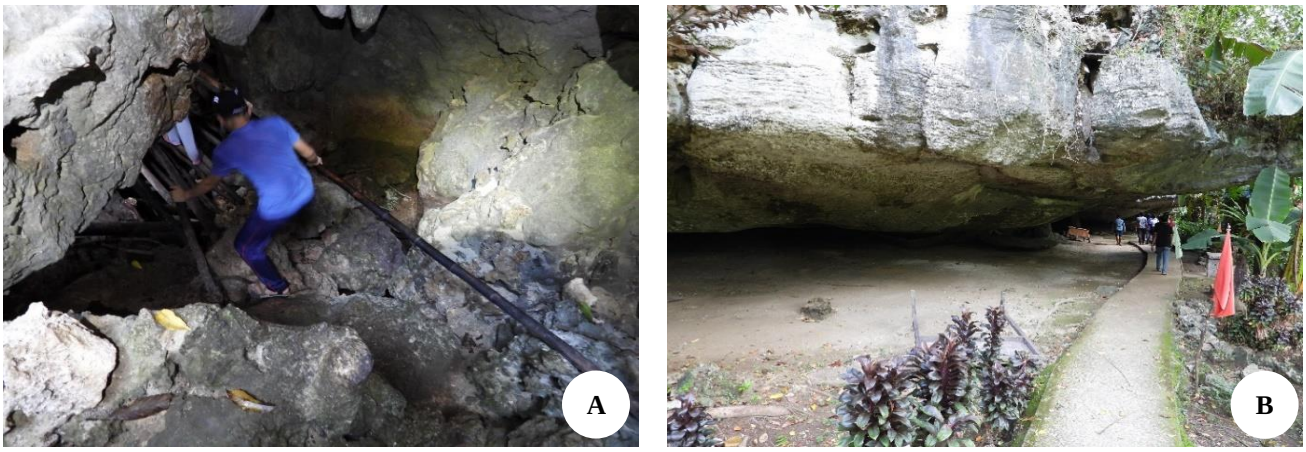

Figure 4. Caves in Samar Island which are possible roosting sites for bats: A. Entrance of Linao Cave in Sulangan, Guiuan, Eastern Samar; B. Saob cave in Basey, Samar. Photographs by P.J. Tolentino

Karst caves and outcrops in forests over limestone harbor a large percentage of bat populations, as these landscapes provide roosting resources and shelter for the vertebrates (Figure 4). This significant feature is often neglected in conservation research (Struebig et al. 2009). In an investigation by Furey et al. (2010) in the limestone karst ecosystem of Vietnam, they recorded a total of 694 bats representing 36 species and five families. This confirms that primary forests in Vietnamese karst are critical for supporting large percentage of bat diversity in

the country. In Indonesian Borneo, a study found 36 species of bats in the Sangkulirang limestone karst formations, including the karst associated *Hipposideros larvatus*, *Rhinolophus creaghi* and *Rhinolophus pusillus* (Suyanto and Struebig 2007).

According to Kingston (2008), bats constitute about 30% of Southeast Asia's mammal species and comprise about half of all mammal species in the tropical rainforest ecosystems, making it a critical component of the region's threatened fauna. Even though there is paucity of data on Southeast Asian karst ecosystems on the comparative studies of bats, Kingston (2008; 2003) pointed out that a considerable number of bat species found only in Asia depend upon intact forests for roosting and foraging. In relation with this, it was also found that bat abundance, species richness, and assemblage composition in Malaysia is negatively affected by forest degradation and fragmentation (Furey et al. 2010; Struebig et al. 2008) which can also be implied to other Southeast Asian countries.

Among avifauna, cave-nesting swiftlets also roost and nest in caves of forests over limestone. A few species of swiftlets (genus *Aerodramus*) make nest from their hardened saliva. The edible saliva is a delicacy and is considered as one of the most expensive animal resources that humans consume (Thorburn 2015). The demand for authentic bird's nest soup is mainly because of its perceived health benefits and not solely due to its taste (Marcone 2005). According to researchers from China and Japan, the hardened saliva contains sialic acid-also found in human milk-which is thought to play a role in developmental advantages for breastfed infants and possibly beneficial for human health (Oda et al. 1998; Thorburn 2015; Wang and Brand-Miller 2003). Other bird species such as the bald-headed bulbul *Pycnonotus hualon* (Woxvold et al. 2009), and the limestone leaf-warbler *Phylloscopus calciatilis* (Alström et al. 2010) have been discovered only recently in Laos and Vietnam.

The limestone karsts of Southeast Asia are also home to many small non-volant or non-flying mammals, particularly rodents of the Family Muridae. In a study of 122 karsts in Thailand, 12 murid species were found including the karst-endemic *Leopoldamys neilli* and the endangered limestone rat *Niviventer hinpoon* (Latinne et al. 2013). The Laotian rock-rat *Laonastes aenigmamus* (Jenkins et al. 2005) and Paulina's limestone rat *Saxatilomys paulinae* (Musser et al. 2005) are murids discovered on the karsts of Laos, with *S. paulinae* being recently found to also occur in Vietnam (Nguyen et al. 2015). The forest cover in limestone hills, while not immune to deforestation, are still more resistant compared to its surrounding areas making it a natural refuge to many species endemic to the area (FFI 2001). The genus *Trachypithecus* is widely distributed in Southeast Asia with 6 species of limestone langurs (*T. francoisi, T. poliocephalus, T. delacouri, T. hatinhensis, T. laotum, T. ebenus*) that occur in separate non-overlapping geographical areas (Liu et al. 2019). Among larger mammals, the Laotian langur or Lao leaf monkey *Trachypithecus laotum* is found only in Laos (Steinmetz et al. 2011), François's langur *Trachypithecus francoisi* in Southwestern China to northeastern Vietnam (Liu et al. 2019), Indochinese black langur *T. ebenus* in Laos and Vietnam, while Delacour's langur *Trachypithecus delacouri*, Hatinh langur *T. hatinhensis*, Cat Ba langur *Trachypithecus poliocephalus poliocephalus*, and the critically endangered Tonkin snub-nosed monkey *Rhinopithecus avunculus* are found only in Vietnam (Dang et al. 2019; Tuyet 2001). These mammals had their natural habitats largely wiped out due to deforestation. However, they have adapted the pads on their hands, feet and rump to enable them to move on the sharp edges of the limestone, making these karst-dependent primates more specialized to living in this unique ecosystem (FFI 2001).

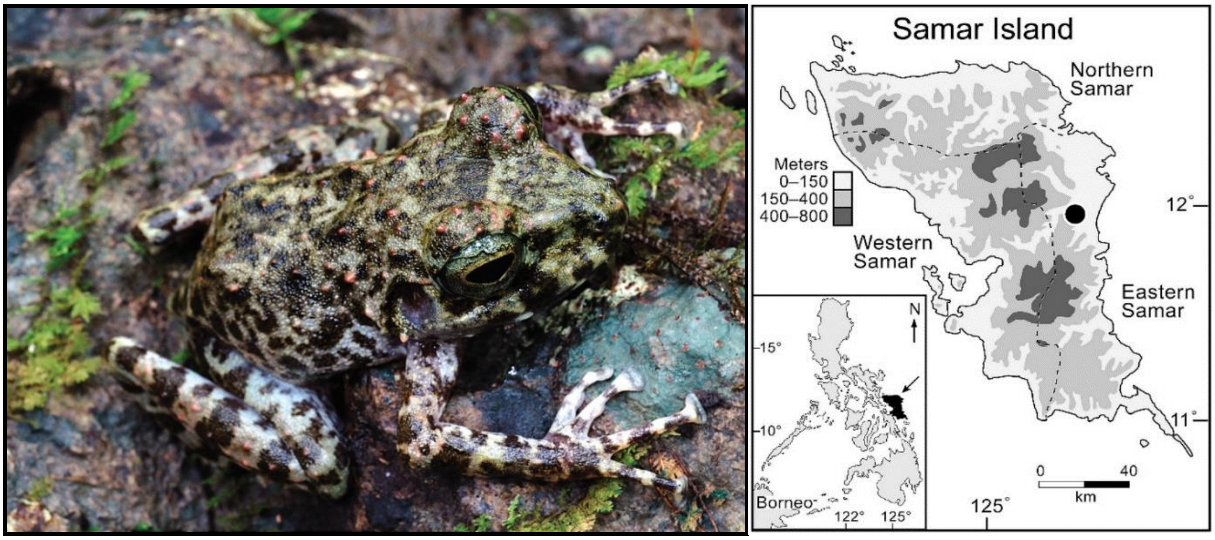

Figure 5. Photograph of *Platymantis bayani* in Taft (photograph by C. Siler) and a map (right) showing its known occurrence in eastern Samar Island, Philippines (black dot). The inset shows the location of the species in Samar Island (colored black) within the Philippines. The three provinces of Samar Island indicated by dashed lines (Siler 2009)

Invertebrates such as snails reach the peak of diversity and abundance in karst ecosystems especially because limestone which is made up of calcium carbonate is an important component of their shells. The limestone outcrops of Sabah, Malaysian Borneo hosts 74 species of land snails (Prosobrasnchia and Pulmonata), and about 80 percent of the country's total land snail fauna is found in karst ecosystems (Schilthuizen 2000; Schilthuizen et al. 2005). On another investigation by Haase and Schilthuizen (2007), new limestone species of *Georissa* (Gastropoda: Neritopsina: Hydrocenidae) were collected from a karstic limestone outcrop in Batu Sanaron, also found in Sabah, Malaysian Borneo. Asian karst ecosystem harbor about 2000 species of snails which can be found only in the region, of which, a single undisturbed karst hill may contain about 60 to 100 different species (FFI 2001).

In the Philippines, there are only a few published studies on the existing biological resources of limestone ecosystems. A survey of Mt. Irid on the Southern Sierra Madre of Luzon Island recorded 8 species of non-volant small mammals and 16 species of bats, including a new island record for the lesser tube-nosed bat, *Murina suilla* (Balete et al. 2013). The island has also been the site of discovery for some karst-obligate frogs such as the data deficient *Platymantis quezoni* from the Quezon Protected Landscape (Brown et al. 2015) and the near-threatened *Platymantis biak* from Biak Na Bato National Park (Siler et al. 2010). Outside of Luzon Island, other karst-obligate frogs include the endangered *Platymantis spelaeus* from Negros Island (Brown and Alcala 1982), the endangered *Platymantis paengi* from Panay Island (Siler et al. 2007), and the critically-endangered *Platymantis insilatus* from South Gigantes Island (Brown and Alcala 1970). In the Romblon Island Group, karst-dwelling lizards such as *Gekko coi* and *Gekko romblon* are known to occur (Siler et al. 2012). In Samar Island Natural Park (SINP), the post-biological assessment of faunal resources by Patindol (2016) recorded 182 species of terrestrial vertebrates, of which, 121 species were birds, 20 were mammals, 18 amphibians and 23 reptiles with overall endemism of 40%. This implies a great opportunity to discover new island records and possibly new species or taxa of wildlife in forests over limestone. A good example is the karst forest frog *Platymantis bayani* (Figure 5) described by Siler et al. (2009) in the Taft Forest Reserve in eastern Samar Island, the Philippines from an elevation of 140 m.

Important information on the distribution and ecology of a wide array of wildlife can be discovered from future researches in the limestone ecosystem. A table showing the compiled number of faunal species found in forests over limestone of Southeast Asia from different studies is shown in Table 2.

Economic development caused the extirpation of many limestone-confined species including small and little-known invertebrates and only a few are included in the IUCN Red List of Threatened Species (FFI 2001). Increasing anthropogenic activities lead to conversion and alteration of natural landscapes that create harsh environment for native species. The decreasing complexity or heterogeneity of the limestone landscapes poses a threat to many animal communities because they are deprived of habitats used for roosting and foraging-such as bats and birds. Hence, it is of high priority to understand how the environmental variables and landscapes in forest over limestone are related to animal activities in order to effectively support efforts for their protection and conservation (Clements et al. 2008; Martin and Blackburn 2010; Dias-Silva et al. 2018). This makes conservation research essential in gathering important biological data that policy makers should take into consideration to effectively put up laws that would benefit not only the economy but concurrently being able to utilize natural resources at a sustainable level while conserving its biodiversity.

POTENTIALS OF FLORA AND FAUNA BIODIVERSITY

Research potential

Forests over limestone are largely understudied and the potential of discovering new flora and fauna species are high. The effect of the unique morphology and features of limestone landscapes such as its caves, sinkholes, and towers contribute to its low accessibility for research, but it has forced the flora and fauna species residing in the area to adapt, resulting to a unique and distinct organism composition. If the difficulty in research can be overcome, the possibility of discovering new endemic species in the area is very high.

The presence or absence of flora and fauna species in forest over limestone could be indicators of the potential for further classifying limestone forests. Unlike dipterocarp forests which usually have dominant flora species throughout the area, forests over limestone have varied species composition (Ranlund 2011). Given the varied nature of species composition, Ranlund (2011) suggested that in order to get an accurate description of limestone forests, it is not enough to select a single area and expect the results to define the whole limestone landscape. To tap the great potential for discovery of new species, methods involving spatial variation within limestone forests are recommended.

Economic potential

In Southeast Asia, the natural occurrence of cave swiftlets provides a major industry in harvesting of nests and at present appears to be ecologically sustainable. However, any such industry should be monitored to ensure that over-harvesting does not occur (Watson et al. 1997). Bats are also economically important as they help in the pollination of numerous tree crops and consume insects that damage agricultural crops. Biodiversity plays an important role in maintaining existing karst landscapes and gives foundation in the process of degraded karst ecosystem recovery (Jiang et al. 2014) which is important for future resource management plans.

Table 2. Major animal groups and the number of species found in different forests over limestone of Southeast Asia based from recent faunal surveys

Major animal group	No. of species	Location	Notes	Reference
Birds	121	Samar Island Natural Park, Philippines	Species might be included but are not limited to forests over limestone.	Patindol (2016)
	1	Argao Watershed Reserve, Cebu, Philippines	Black Shama *Copsychus cebuensis* Steere, 1890; Cebu endemic	Malaki et al. (2018)
	129	Bau karsts, Sarawak, Malaysia	40 families	Yong et al. (2004); Clements (2006)
	1	Limestone karst forests of the Sino-Vietnam border	Nonggang Babbler *Stachyris nonggangensis*; rare and newly discovered species that is restricted to limestone karst forest on the Sino-Vietnamese border	Jiang et al. (2019)
Reptiles	23	Samar Island Natural Park, Philippines	Species might be included but are not limited to forests over limestone.	Patindol (2016)
	11	Caves and karsts of Thailand	Bent-toed geckos (genus *Cyrtodactylus*); majority have a very restricted geographical distribution.	Ellis and Pauwels (2012)
	15	Myanmar	New species of *Cyrtodactylus* (Squamata: Gekkonidae)	Grismer et al. (2018a,b)
	3	Malaysia	New species of *Cyrtodactylus* (Squamata: Gekkonidae)	Grismer et al. (2014a,c); Grismer 2016
	14	Malaysia	New species of *Cnemaspis* Strauch 1887 (Squamata: Gekkonidae)	Grismer et al. (2008a,b); Grismer (2009); Grismer (2010); Grismer (2013); Grismer (2014b)
Amphibians	18	Samar Island Natural Park, Philippines	Species might be included but are not limited to forests over limestone.	Patindol (2016)
	1	Panay Island, Philippines	Limestone-forest frog	Siler et al. (2007)
	1	Eastern Samar Island, Philippines	Limestone-forest frog	Siler et al. (2009)
	1	Central Luzon Island, Philippines	Limestone-forest frog	Siler et al. (2010)
	1	Khao Chang karst tower in Phangnga Province, in southern Thailand	Cave dwelling *Ansonia* Stoliczka (Anura: Bufonidae) species with significant departure from lotic lifestyle common to most other species.	Grismer (2017)
Mammals	20	Samar Island Natural Park, Philippines	Species might be included but are not limited to forests over limestone.	Patindol (2016)
	1	Cebu, Philippines	Endangered Philippine tube-nosed fruit bat *Nyctimene rabori*	Alburo (2017)
	1	Mt. Aruyan, Mindoro, Philippines	Status of Tamaraw (*Bubalus mindorensis*)	Matsubayashi et al. (2010)
	24	Mt. Irid, Southern Sierra Madre, Luzon	8 non-volant species and 16 species of bats	Balete et al. (2013)
	9	Bicol Volcanic Belt, Southern Luzon, Philippines	Native species-1 shrew and 5 rodents; exotic species-1 shrew and 2 rodents.	Balete et al. (2013)
	1	Limestone hills of Merapoh, Malaysia	*Petaurista petaurista* (Pallas, 1766) (Mammalia: Rodentia: Sciuridae)	Miard et al. (2020)
	28	Mulu karsts, Sarawak, Malaysia	Bat species	Clements (2006)
	36	Vietnamese limestone karst	5 families of bats	Furey (2010)
	6	Vietnam and Laos	Limestone langurs genus *Trachypithecus*: 1 found only in Laos (Steinmetz et al. 2011), 1 in Southwestern China to northeastern Vietnam, 1 in both Laos and Vietnam, 3 only in Vietnam.	Liu et al. (2019); Steinmetz et al. (2011)
	12	Thailand	Murid species	Latinne et al. (2013)
Invertebrates	1	Barangay Bagong Silang, Basey municipality, Western Samar province, Samar Island, Philippines	First record of the genus *Sacculogalumna* (Acari: Oribatida: Galumnidae) from the Philippines.	Ermilov and Corpuz-Raros (2017)

44	Borneo	All recorded only from karsts.	Vermeulen (1994); Schilthuizen (2004); Clements (2006)
122	Perak, Peninsular Malaysia	34 species unique to one of the surveyed hills; 30 species new to science.	Foon (2017)
78	Peninsular Malaysia	All species restricted to single isolated karsts	Davison (1991)
6	Sarang karst, Borneo	All site endemics	Vermeulen and Witten (1999)
50	Subis Karst, Malaysia	No less than 50 species are endemic to Subis Karst.	
74	Sabah, Malaysian Borneo	Pulmonate and Prosobranch land snails	Schilthuizen (2005)
33	Sukolilo Karst, Java, Indonesia	13 families, 25 genera, 2 subspecies; 1 new record to Java; 4 endemic species	Nurinsiyah (2015).

Ecotourism also takes part in uplifting the limestone landscape's economic potential. Aside from stunning sceneries and landscapes, tourists also visit to experience the unique and wide array of flora and fauna, thereby generating local employment. Biodiversity assessment can uncover new records and new species or taxa of flora and fauna which will strengthen conservation efforts in such areas. For example, species of ornamental plants such as *Hoya* (Apocynaceae) can be uncovered from the vastly unexplored areas of Samar's forests over limestone including *Hoya cutis-porcelana* which is endemic to Samar and Biliran Islands, Philippines (Aurigue et al. 2013). Species of Philippine *Hoyas* described, published as new to science, and collected from their natural habitats are worthy of propagation for conservation and commercialization purposes (Simonsson and Rodda 2009; Aurigue 2012; Aurigue et al. 2013; Kloppenburg et al. 2012; Kloppenburg et al. 2011; Kloppenburg et al. 2010a-d, 2011; Kloppenburg and Siar 2006a-c, 2008, 2009, 2010).

Media in the form of photos, videos, and cinematography can also be a source of income while at the same time promoting the value of protecting the environment to conserve the country's unique biodiversity. The growing ecotourism industry generates a huge amount of money for economies around the world. In Malaysia, millions of dollars were invested for the majestic view of karst preserved as aesthetic backdrop for resort township that provided opportunities for local residents to generate income (Clements et al. 2006). In the Philippines, the stunning Taraw Cliff, an enormous limestone karst overlooking the town of El Nido, Palawan, serves as one of the most popular ecotourism destinations in the country which attracts a lot of local and foreign tourists. However, tourism should still be carefully regulated as a study in the karst area of Bantimurung Bulusaraung National Park, Indonesia, which showed that there is a decrease presence of birds in crowded tourist areas (Putri et al. 2019).

Forests over limestone offer utilization of biological resources and the chance of discovering new medicinal plant species. The extensive range of flora that can be found on forest over limestone offers a large window of opportunity which can unveil plants of significant health and economic importance such as plant-based drugs and medicine. For instance, in an ethnobotanical survey by Pinarok et al. (2015) on SINP, all 62 species of plants (of which 6 are Philippine endemics) mostly represented by families Rubiaceae, Zingiberaceae, and Asteraceae have medicinal uses. Aside from medicine, plants are also used as raw materials for manufacturing food and other local products that can be unique in that place only. While utilizing this potential is beneficial to communities, it is equally important, or even more so, that conservation efforts are done. Balancing the protection, resource utilization, livelihood, and tourism in limestone landscapes is essential for the socio-economic well-being of local communities and sustainability of the area (Chechina et al. 2018).

CONSERVATION OF FOREST OVER LIMESTONE

Threats to limestone landscapes

Several factors contribute to creating drastic impacts on forests over limestone, affecting it in a negative way either directly, indirectly, or both. Many of which are large-scale events that endanger the very integrity or even survival of the karst itself (Hamilton-Smith 2001). In Southeast Asian karsts, threats include limestone quarrying, land-use change (Figure 6), deforestation, hunting, illegal logging (Gillieson 2005; Lillo et al. 2019; Van Der Ploeg et al. 2011), and habitat degradation by process such as grazing of domesticated animals and wood collection for fuel (Clements et al. 2006; Woxvold et al. 2009). Environmental Impact Assessments (EIA) should be done to know the possible extent of ecosystem biodiversity loss from proposed projects that would alter natural habitats and what can be done for it to be ecologically feasible (Bullecer 2014). The steady increase in human population also endangers the fragile ecosystem because of the increase in consumption of natural resources. All of these factors pose a threat to the natural landscape and biodiversity of forest over limestone. Caves are given the most attention when it comes to protection of karst features, making other limestone landscapes of less consideration when it comes to sustainable management and protection of the karst areas as a whole land unit (Watson et al. 1997). All other human uses of karst resources should be planned and monitored in order to minimize undesirable impacts and to provide information for future decision-making.

Figure 6. Land conversion into an agricultural area in SINP which poses a threat to karst landscapes. Photograph by P.J. Tolentino

Quarrying is one of the most destructive threats that need immediate action. In Peninsular Malaysia, at least 18 karst-dependent plant species have been reported to have gone extinct due to quarrying (Kiew 1991). Limestone is so valuable for creating cement, that governments from developing countries are willing to overlook sustainable limestone quarrying policies just to improve their economy (Bambang and Utomo 2003; Galindon et al. 2018; Liew et al. 2016). Land-use planning that considers the welfare of poorer communities must be highlighted to address this. Another problem at present is that there is lack of information about how limestone forests fully support such biodiversity. Thus, thorough research is required to implement conservation strategies that will influence the use of such resources at a sustainable level. Understanding the present-day situation through research will help develop rational strategies with particular reference to karst such as appropriate land management, sustainable land use planning, and expansion and maintenance of protected areas (Day 2010). The high endemicity and fragile nature of flora and fauna in forest over limestone are important in determining proper conservation techniques. This high endemicity and high chance of discovering new species is an opportunity for researchers to explore limestone landscapes.

Conservation of limestone landscapes

In relation with biodiversity research, recent studies, related to but not specifically, about the forest over limestone of the Philippines were done in Samar Island Natural Park by Patindol (2016) and Quimio (2016) entitled *Post Biological Assessment of Faunal Resources in the Samar Island Natural Park (SINP),* and *Floral Composition and Timber Stock of Forest in the Samar Island Natural Park*, respectively. The first study surveyed 5 priority watersheds of SINP namely Taft, Can-avid, Basey, Suribao and Catubig for its faunal resources. The second study, on the other hand, assessed characteristics of the floral diversity status in SINP and provided recommendations on how such sources can be better managed and protected against destruction (Quimio 2016). Thus, the program "Assessment and Conservation of Forest over Limestone Ecosystem Biodiversity in Selected Municipalities of Samar Island, Philippines (CONserve-KAIGANGAN)" was started in January of year 2019. It is a 3-year research program funded by the Department of Science and Technology-Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) that aims to assess and conserve the plant, animal and microbial diversity in forests over limestone, "kaigangan" in Samar local dialect, towards its sustainable management in Samar Island, Philippines.

Specific government initiatives for the protection of karst biodiversity are attainable such as declaration of National Parks (NPs) and other Protected Areas (PAs), and public education. Declaration of NPs and other PAs have the best potential of protecting the total environment systems such as a karst ecosystem (Hamilton-Smith 2001), but aside from declaring it as parks and inviting people to visit, it must be noted that providing adequate and appropriate support for the management and protection of such areas should not be neglected (Vimal et al. 2018). Increase in expenditure by the government on the protection and research of these resources is essential for the acquisition of knowledge and professional education for the community and land managers. Local community participation is also important for management to ensure the integrity of NPs and PAs (Andrade and Rhodes 2012). In the South China Karst landscapes, for example, a monitoring index (Table 3) for measuring state of conservation has been established. The monitoring index is made for the nominated karst areas of South China but it can also be applicable to other karst areas especially in other Southeast Asian countries where tropical karst areas are found.

About 29% of the total karst landscape in the Philippines is protected. There is no existing legislation that directly addressed its protection and conservation in the country; however, there is other legislation that indirectly protects karst landscapes (Table 4). Tourism is one of the main reasons for karst conservation while other karst landscapes are indirectly protected only because portions of it are covered within a larger protected area such as nature reserves, natural parks, wildlife sanctuary, or protected seascapes (Restificar et al. 2006). Holistic research of the limestone areas is critical to be able to establish scientific and knowledge-based initiatives and laws that will conserve the Philippine forests over limestone biodiversity while at the same time being able to utilize it at a sustainable level.

Table 3. Monitoring index for conservation of South China Karst landscapes implemented by the government (Jiang et al. 2014)

Parameter	Resolution
Karst monitoring processes	Solution rate, dynamic hydrology and elements of surface and underground water
Ecological processes and biodiversity monitoring	Monitoring on vegetations, observation of animals, changes of animal species, vegetation meteorological phenomena, quality of species and cave animals species, monitoring on exotic species
Environmental monitoring	Observation of atmosphere, waters, noise and environmental health
Land using monitoring	Cropland, construction, water, mining, logging, afforestation and transportation facilities
Visitors administering monitoring	Number of visitors, tourism items, scenic spot, quality and quantity of tourism facilities
Natural disasters monitoring	Meteorologic disasters, fire, drought and flood, mud-rock flow, ground sinking, earthquakes, etc.

Table 4. Legislations that indirectly protect limestone landscapes in the Philippines (Restificar et al. 2006)

Legislation	Objective
Republic Act 9147 or the "Wildlife Resources Conservation and Protection Act"	Aims to conserve the country's wildlife resources and their habitats, and can be used to protect wildlife resources in specific karst areas
Republic Act 7942 or the "Mining Act"	Contains provisions relating to areas closed to mining operations. These include all areas under NIPAS, which includes several karst areas
DENR-DOT Memorandum Circular 98-02 (Guidelines for Ecotourism Development in the Philippines) and Executive Order No. 11 (Establishing the Guidelines for Ecotourism Development in the Philippines)	Provide guidelines for the management of caves used for ecotourism activities
Republic Act 4846 or the "Cultural Properties Preservation and Protection Act"	May be invoked to protect cave resources of cultural significance

The importance of public education can never be neglected. The decisions of the public upon the legitimization of government actions is important for the development of effective forest over limestone protection. It is necessary to educate park managers, tourists, and the community with gathered scientific knowledge so they will have better understanding and make appropriate decisions. Public education can also be done through interpretation at parks, journalism, electronic media and popular books for all ages (Hamilton-Smith 2001). Community forestry, when applicable, has proven to be an effective and sustainable means of limestone forest conservation. Community Forestry in Thailand is legally recognized as the participation of a community with forestry officers in forest management activities under laws and regulations (Laosuksri and Qi 2014). The community maintains their culture and other traditions, and they are free to utilize the forest to sustain their needs while simultaneously focusing on conservation and development. The cooperation of the community on reforestation creates a sense of involvement in forest conservation among the villagers.

CONCLUDING REMARKS

Forests over limestone are geomorphologically unique but fragile landscapes. They contain a high degree and extensive range of biodiversity and remains mostly unexplored. In the Philippines, many karst areas are indirectly protected mainly because it is included in wider areas specified for protection. Unfortunately, there are no legislation that directly address the conservation of forests over limestone. Although the whole karst landscapes are not assigned as protected areas, land managers should continually try to establish well-planned and knowledge-based conservation procedures for its protection. There is an opportunity and a need to study limestone forests further. The combination of unique species, valuable resources in the form of forest products, limestone and water, and its fragility makes its conservation of utmost importance. The first step is to increase research efforts in forests over limestone. This is important since the current baseline information on biodiversity is not sufficient in most areas to create proper management strategies in forest over limestone. Conducting regular monitoring and evaluation activities for biodiversity on forest over limestone areas is crucial to know the integration of species, ecosystems, and the landscape itself. Aside from resource protection knowledge, there is also a demand for the unity of local communities and the government in order to effectively conserve the environment. If people are equipped with knowledge that these further studies will provide, communities will be able to know more of what forests over limestone can offer, and thus implement proper forest management strategies for its protection and conservation while at the same time being able to utilize its biological resources at a sustainable level.

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