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Bat cave vulnerability index (BCVI): A holistic rapid assessment tool to identify priorities for effective cave conservation in the tropics

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ABSTRACT

The identification of important habitats for wildlife is essential in order to plan and promote strategies for long-term effective conservation. Caves and subterranean habitats are frequently overlooked habitats with diverse communities, which are frequently endemic to a region, karst outcrop or even a single cave. These cave species include a wide range of taxa adapted to cave environments. Within cave systems, bats are key providers of energy for other cave-dependent species. However, identifying caves for conservation prioritisation requires an understanding of cave-dwelling species diversity, patterns of endemism, and conservation status, in addition to a standard mechanism to evaluate risk. In this paper, we present the 'Bat Cave Vulnerability Index' (BCVI) as a standard index for evaluating bat caves for conservation prioritisation by determining Biotic Potential (BP) and Biotic Vulnerability (BV) of caves. The Biotic Potential is represented by various species diversity and rarity measurements. The Biotic Vulnerability is represented by the cave geophysical characteristics and human-induced disturbance present. Pilot testing in the southern Philippines has demonstrated that the index is an effective and practicable method to identify bat caves for conservation prioritisation. The biotic potential variables assess the presence of endemic, rare, and threatened bat species and assays the priority level based on an equation. Relative risk and vulnerability were assayed using landscape vulnerability variables, which showed anthropogenic activities were important factors in conservation prioritisation. The application and mechanism of the index potentially provides a valuable, rapid and simple assessment tool in cave conservation with special relevance to bat diversity and vulnerability. Furthermore, the multiple and holistic criteria of the BCVI, and the accessible information for both biotic and landscape features can be adapted to prioritise caves in a wider scale in the tropics, and in other regions with diverse cave ecosystems.

1. Introduction

It is said that we have entered the sixth mass extinction, with an almost unprecedented rate of species loss at an estimated 100 times background rates (Ceballos et al., 2015), and the probable imminent loss of many species (Pievani, 2014; Ceballos et al., 2015). The over-exploitation and degradation of many of the world's biomes call for urgent protection of biologically important regions and habitats for protection (Hoekstra et al., 2005; Clements et al., 2006; Hughes, 2017a, 2017b). To best maintain and protect current biodiversity, the identification of areas which harbour high levels of biodiversity or endemism are essential to develop priorities and strengthen the design of protected areas to optimize resource investment in conservation and thus, affect the most positive conservation outcomes (Myers et al., 2000; Benayas and de la Montaña, 2003; Hughes, 2017a). To evaluate such strategies, it is crucial to identify areas with the highest conservation value, or areas with the highest vulnerability to threats and disturbance.

However, making effective conservation decisions is challenging (Phalan et al., 2011), and due to the limited funding and capacity, the development of effective strategies for the selection of priority areas for conservation are urgently needed (Pullin et al., 2004; Zhang et al., 2014). Surrogate taxa have become a useful shortcut for conservation biologists to assess and address conservation issues, evaluate the effect of human activities, and understand patterns of diversity and endemism for conservation prioritisation (Caro and O'Doherty, 1999; Roberge and

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Angelstam, 2004; Larsen et al., 2007; Rodrigues and Brooks, 2007). Though surrogate taxa have been discussed for a wide variety of ecosystems (Larsen et al., 2007; Sætersdal and Gjerde, 2011), other ecosystems which in many cases may be even more vulnerable are frequently overlooked.

Cave ecosystems are one such example, with high levels of endemism and a lack of consolidated research i.e., up to 90% species are estimated undescribed in Chinese caves (Whitten, 2009). Yet such systems may not only have high levels of endemism due to the poor dispersal ability of many cave-dependent species, but may also be sensitive to environmental changes brought about by either direct destruction or disturbance of the cave, or the immediate surroundings. Caves are vulnerable from various forms of exploitation, and the increasing demand of limestone for cement means that many caves may be destroyed completely for cement production (FFI, 2001; Liew et al., 2016). Other caves may be degraded through tourism or other activities, and even changes in surrounding land cover may drive climatic changes within the cave system (Van Beynen and Townsend, 2005; Boulton, 2005; Clements et al., 2006; Phelps et al., 2016). Southeast Asia and South China has over 800,000 km^2 of karst, but only 13% of the former falls within protected areas (Day and Urich, 2000). In Southeast Asia, it is estimated that around 178 million metric tons of karst limestone are quarried annually (Clements et al., 2006). The current demands for new infrastructure development have exponentially increased the demand for cement mined directly from karsts. China alone used 6.6 gigatonnes of cement between 2011 and 2013, this volume is more than the cement consumption of United States in recorded history (USGS, 2009; Lei et al., 2011). In addition, Thailand (6.8%), Vietnam (3.9%) and India (2.2%) are among the top cement exporters in tropical Asia (http://www.worldstopexports.com/cement-exports-by-country/). While in the Philippines, there is a continuing increase in cement demand across the last decade. In 2015, the total demand had increased to 24.4 million tons from 21.3 million tons in 2014. This figure reflects the 20% public construction growth in 2015 (CEMAP, 2014). Thus, indicators of biotic value and potential risk for cave systems are urgently needed in order to protect areas of high endemism, diversity, and risk.

Bats provide a good candidate as a surrogate (i.e., umbrella, keystone, and indicator taxa) of cave biodiversity and conservation value. Primarily, they may be relatively easier to survey in a standardised and comparable manner than the majority of other cave-dependent species, i.e., majority of the conservation status of cave bats are evaluated and available vs. most invertebrate species in caves (Kunz, 1982; McCracken, 1989; Elliott, 2005; Jones et al., 2009; Cardoso et al., 2011a). While invertebrates like insects often show high endemism many taxa remain undersampled or undescribed, thus their conservation status requires detailed assessment (Picker and Samways, 1996; Cardoso et al., 2011b). In addition, the distribution of described invertebrate species is largely unknown (Cardoso et al., 2011a) and pseudo-endemism may be attributed (Picker and Samways 1996). Furthermore bats are keystone species in cave ecosystems as they bring organic nutrients into the caves primarily in their guano (Culver and Pipan, 2009; Trajano, 2012). Therefore, using bats as umbrella species to evaluate the diversity and conservation needs of caves may provide an index to protect total cave biodiversity. Bats roosting in caves also provide important ecological functions and contribute significantly to the economy through ecosystem service provisions such as pollination, seed dispersal, and insect-pest reduction (Bumrungsri et al., 2013; Wanger et al., 2014; Sritongchuay et al., 2016; Aziz et al., 2017). However, human activities and exploitation threaten many bat caves and karst ecosystems, and the endemic species within these systems (Baker and Genty, 1998; Ball, 2002; Mickleburgh et al., 2002; Clements et al., 2006; Niu et al., 2007; Furey and Racey, 2016; Medellin et al., 2017). Around a quarter of global bat species are under threat largely as a consequence of habitat destruction and modification (Kunz and Racey, 1998). The alteration of cave and karst ecosystems represent major drivers of extinction for diverse cave-dependent species (McCracken, 2011; Medellin et al., 2017), which in turn support a wide-array of macroinvertebrate species dependent on the organic nutrients from bat guano, respiration, and urination (Pape, 2014; Iskali and Zhang, 2015). Thus, developing standardised and comparable methodologies to develop priorities for management and conservation are crucial to effectively protecting cave biodiversity.

McGeoch (2007) emphasized that efficient, concrete and understandable biodiversity indices are important to effectively assess the status of certain ecosystems and populations (Lamb et al., 2009). A grading scheme for cave prioritisation was developed by Furman and Özgül (2002) based on the Eurobats Agreement of Parties (Mitchell-Jones et al., 2000, 2007). This scheme is the only index which has been developed to grade caves based on bat diversity, however, this does not take into account the risk and rarity, and thus fails to provide enough information to develop priorities. Therefore, we present the ‘Bat Cave Vulnerability Index’ (BCVI), which is a new approach in using bats as surrogate taxa in prioritising caves. This index is specifically tailored to rapidly evaluate cave biotic potential and vulnerability based on bat species diversity and presence of human-induced threats. The result of the assessment using the BCVI will present the conservation status of caves as a first step in developing priorities which maximize the effectiveness and efficiency of conservation.

2. Material and methods

2.1. Components of the bat cave vulnerability index (BCVI)

The index integrates the biotic potential and biotic vulnerability of the caves, which is represented mainly by bat species diversity and vulnerability to threats of the caves respectively. The general equation of the index is shown below.

$$\mathbf{BCVI = (BP)\ (BV)} \tag{1}$$

Where:

BCVI = Bat Cave Vulnerability Index
BP = Biotic Potential Index (see Eq. (3))
BV = Biotic Vulnerability Index (see Eq. (5))

The values of Biotic Potential (BP) and Biotic Vulnerability (BV) are obtained in two separate approaches since both have different values and attributes to be assessed.

2.2. Cave biotic potential (BP) index

2.2.1. Species richness (S) and abundance (A)

The cave biotic potential status describes the bat population (i.e., estimated population, individual abundance) and diversity in caves. The first variable in computing the cave Biotic Potential (BP) includes the bat species abundance (A) per cave and it is given in the number of individuals or estimated population. The method of assessing bat populations should be standardised among all cave sites. This may include direct counts of roosting or exiting bats and photographic counts. Different approaches and combined methods should be employed in large caves or caves with multiple entrances where getting realistic exit counts is challenging. The species richness (S) represents the actual number of bat species.

2.2.2. Species relative abundance (Ar)

The relative species abundance (Ar) indicates the information on the status of the population relative to other sites. It is calculated using the equation n/N (where: n is the actual abundance of the species (x) and N is the average abundance of the species from all caves sampled. The values equal to 1.00 are interpreted ‘average’, which represents a site with an average population of the species. This measure was used to balance out hyper-abundant species (which roost in colonies of thousands to millions of individuals) relative to naturally lower populations. By exploring relative abundance for each species, we can assess how each cave performs relative to "global/regional" species average and note caves of particular importance.

2.2.3. Endemism (E) and conservation status (cons)

The species attributes comprising the Biotic Potential (BP) includes the species endemism and Red List status of cave bats. The endemism value (E) is based on bat species range distribution and conservation status (*cons*) based on the global population and distribution status and trends of a bat species. The distribution and conservation status of bat species is provided by the latest information from the International Union for the Conservation of Nature (IUCN) Red List (www.iucnredlist.org) and other valid and updated databases. The inclusion of the two species attributes is vital for weighing the value of a certain cave (Mitchell-Jones et al., 2000; Furman and Özgül, 2002). Caves with more endemic and threatened species will have higher values because they contain bat species which have narrow ranges and decreasing populations and therefore, are vulnerable to extinction.

All species attributes are weighted accordingly based on their current RedList status. Widespread and 'Least concern' species are given the lowest score (2) because such species have wide ranges and stable populations. While, species with very narrow distribution ranges and critically endangered species are given the highest scores (5, 6 points respectively) because these species may become extinct in the near future and need urgent conservation action. Species listed as 'Data Deficient' are treated as rare species with low populations and limited distributions and are given score same as endemic and endangered species. Species listed as 'Least concern' but with 'decreasing populations' are given a score of 3 (Table 1).

2.2.4. Species-site commonness index (site)

The Species-site commonness index (*site*) is developed to measure the rarity of the bat species from the caves assessed. This equation is based on the frequency that the species occurred among caves rather than their abundance. The values < 1.00 or near the values of *Ncave* indicate that the species is rare or only occurs in few caves and values equal to 1.00 indicate that the species is common to all caves. It is calculated using the formula shown below.

$$\textbf{site} = \boldsymbol{Ncave/f} \tag{2}$$

Where:
$Ncave$ = Number of caves assessed in a specific locality
f = Frequency of the species occurrence

2.2.5. Computation of the biotic potential (BP)

To compute the individual species scores, the species abundance (A) of each species is multiplied to the respective scores based on species attributes (i.e., *E, cons*, *site*). The final value of the cave Biotic Potential (BP) can be derived by summing individual species scores multiplied by the total species richness (S) per cave (see Eq. (2b)). The Biotic Potential (BP) of the cave can be calculated using the general equation shown below.

Table 1
Scoring of species attributes based on endemicity (E) and conservation status (cons).

Species attributes	Code	Score
Species Endemism	E	Scale
Widespread	NE	2
Regional Endemic (i.e. Southeast Asia)	RE	3
Country Endemic	CE	4
Restricted only to a single or few localities/Faunal region/Data Deficient	RES	5
Conservation Status	cons	Scale
Least concern	LC	2
Least concern (decreasing population)	LCD	3
Near Threatened	NT	3
Vulnerable	VU	4
Endangered	EN	5
Critically Endangered/Near Extinction/Data Deficient	CR	6

$$\mathbf{BP} = \mathbf{\Sigma\ Species\ 1\ [(}\boldsymbol{A*Ar*E*cons*site}\mathbf{)} + \mathbf{Species\ 2\ (}\boldsymbol{A*Ar*E*cons*site}\mathbf{)\ \ldots\ Species\ nth\ (}\boldsymbol{A*Ar*E*cons*site}\mathbf{)]\ (}\boldsymbol{S}\mathbf{)} \tag{3a}$$

Or

$$\mathbf{BP} = \mathbf{\Sigma\ individual\ species\ score\ (}\boldsymbol{S}\mathbf{)} \tag{3b}$$

Where:
BP = Cave Biotic potential index
A = Cave bat species abundance
Ar = Relative species abundance
S = Species richness per cave
E = Species endemicity
$cons$ = Species conservation status
$site$ = Species-Site commonness

The cave status is determined based on the computed scores using the Biotic Potential (BP) equation. Four (4) status (Levels 1–4) represent the most probable status of the cave. The biotic potential values were set based on the bracket scores ranging from below 25, 000 to > 100,000. Consequently, 'Level 1′ caves classified as high in species diversity, while caves classified as 'Level 4' are the least biodiverse caves (Table 2). The cave Biotic Potential (BP) status will be complemented with the cave Biotic Vulnerability (BV) in order to derive the final alphanumeric BCVI value, which will indicate the priority levels of caves.

2.3. Cave biotic vulnerability (BV) index

The second sub-index, Biotic Vulnerability (BV) represents cave geophysical features and anthropogenic threats to the cave. It utilizes information on cave accessibility, cave size, and openings, the effort of exploration, tourism potential, cave use, land-use change activities in cave adjacent areas, and the presence of temples and sacred structures. The selection of landscape features and anthropogenic activities set for BV are based on factors considered to affect cave biota (see Borges et al., 2008; Gabriel et al., 2008; Donato et al., 2014; Tanalgo et al., 2016; Phelps et al., 2016). Landscape features and human-induced activities in each cave influence the score depending on their severity and impact on the cave biota (Table 3). In some areas where some landscape and anthropogenic features are absent or not available to assess, the recalibration of the criteria is crucial to adjust the applicability of the Biotic Vulnerability index.

To obtain the Biotic Vulnerability (BV) of the cave, the summed scores from the assessed geophysical features and anthropogenic activities are divided by the total number of geophysical features assessed (N) to obtain the average scores of cave sites based on parameters set which will then be interpreted based on range mean scores. The Biotic Vulnerability (BV) value is derived using the equation shown below.

$$\mathbf{BV} = \mathbf{\Sigma}\boldsymbol{N}/\boldsymbol{N}^{\mathbf{o}} \tag{5}$$

Where:
BV = Biotic Vulnerability Index
N = Threats assessed
N^o = *Number of threats assessed/present*

The value computed using the Biotic Vulnerability (BV) index will be translated to a given status describing the importance and risk of the cave biota. The lowest possible value of this index is 1.00 as 'Status A' (highly disturbed and/or prone to disturbance) and the highest value is 4.00 as 'Status D' (pristine caves with no disturbance) (Table 4). The results from both indices, Biotic Potential (BP) and Biotic Vulnerability (BV) are combined to form an alphanumeric value that summarizes the general vulnerability and priority of the cave. When both indices are

Table 2
Priority level for bat caves based on biotic potential.

BP Score	BP Status	Probable scenario
Above 100,000	Level 1	Bat cave/s hold highest numbers of species, relatively with largest populations, with *many* threatened and endemic species, and with *rarest* species also represented.
60,000 to 100,000	Level 2	Bat cave/s are *likely* to have *high* species richness (> 1 number of species), relatively with *large* populations, may contain a number of threatened and endemics with some *rare* species.
20,000 to 59,999	Level 3	Bat cave/s are *likely* to have *few* species, relatively *low* populations, *lesser* threatened and endemic species is present. Most species occur are *common.*
Below 20,000	Level 4	Bat cave/s have the *low* few species, relatively with the *lowest* population and *most* species are least concern, non-endemic species and are *common* in all cave sites

synergistically joint (alphanumeric index), different prioritisation levels are derived.

2.4. BCVI priority settings

In the index, we classified cave sites based on the combined values of BP and BV (Tables 2 and 3). Caves under '1A, 1B, and 2A' (High Priority) are considered as exceedingly vulnerable to population declines and habitat destruction and require urgent conservation interventions to regulate human activities. While, caves classified under '1C', '1D', '2B', '2C,' '2D', '3A','3B', '3C', and '3D' are moderately vulnerable to population declines and species loss due to their low exposure to human activities and disturbance. Conversely, caves classified as '4A', '4B', '4C' and '4D' are less vulnerable (Low Priority) due to the absence of either disturbance or high populations of cave bats (Fig. 1).

Table 4
Scale Index for Biotic Vulnerability (BV).

BV Score	Status	Probable condition
1–1.99	A	Greater accessibility and highly prone to human disturbance and activities.
2–2.99	B	Lesser accessibility but disturbance is/may be present in distance.
3–3.99	C	Less accessibility, less prone to human disturbance.
4.00	D	No disturbance, far from localities and difficult to pass.

2.5. Indices application and testing

To evaluate the effectiveness of the index in assaying biotic value and risk, six caves from south-central Mindanao, Philippines were studied. Bats were sampled using a standardised mist-netting method and

Table 3
Scoring of cave site based from the Biotic Vulnerability (BV).

Geophysical and human activity features	Codes	Score	Scenario
Accessibility to cave sites	Acc	1	Easily accessible with no permit needed. The caves are very near to human settlements; easily accessible by a vehicle, motorcycle or easy walking distance.
		2	No permit needed. Accessible with a motorcycle or two-wheeled vehicle.
		3	Difficult to access, needs permission to enter, far from human settlements, with human trail. Requires trekking for under 8 h from the motorized vehicle accessible area.
		4	Permit enter/explore is needed, no roads, no tracks, and trails, can be reached by trekking at least one day.
Cave openings	Co	1	Main openings are around 2 m tall and a meter wide. Two or more people can enter at the same time.
		2	Anyone can enter, with more than 1 entrance but only one person at a time can pass through squat/crawl.
		3	Difficult to enter, narrow openings but wide on the interior (needs to crawl and clamber).
		4	Very difficult to pass, narrow entrance and narrow inside; needs special equipment to pass cave openings on vertical wall/vertical openings.
Effort of exploration	Eff	1	Easy to explore, no obstacles inside; can be explored by walking.
		2	Easy to explore, with a minimal number of obstacles; crawling in some parts of the cave is needed.
		3	Difficult to explore, many obstacles but no need for special skills. Squeezing and swimming may be needed.
		4	Very difficult to explore, many obstacles need special skills in exploration. May be dangerous to explore; special equipment like rappelling equipment/diving is necessary.
Tourism Activity	Tour	1	Tourism activity is very high. Frequent (at least 4× a month) visitation of large volume of visitors (more than 10 persons per group) per annum.
		2	Intermittent (less than a 4× month) visitation of large volume (more than 10 persons) of tourists per year.
		3	Occasional (less than 4× a month) visitation of small volume of the visitor (less than 10) per year.
		4	Not a potential tourist spot. No visitation at all.
Cave use	CavUS	1	Intense cave use and exploitation. All of these disturbances are present in the cave: regular hunting of bats for bush meat and trade; high volumes of noise occur inside the cave; evidence of lighting or electric cables; mining of minerals; guano collection.
		2	Minimal cave use is present. Two of the listed cave use mentioned above are present.
		3	Only single cave use and activity mentioned above is present in the cave.
		4	All cave use mentioned above is absent.
Land-use change activities within cave vicinity	LandUs	1	All of these land use activities are present near the cave openings; multiple land-use activities are present nearby; monoculture plantations are present; forest conversion and mining/quarrying are also present.
		2	Land-use is minimal; some land has been converted for small-scale agriculture, mining/quarrying is present.
		3	Land-use mentioned above is present but too far; the forest is intercropped with small-scale agriculture; mining is absent.
		4	Land-uses mentioned above are absent. Cave is located in a pristine forest.
Presence of temples and sacred structures	Templ	1	Temples are present but highly used/visited for tourism.
		2	Temples are occasionally used for religious purposes.
		3	Temples are present, high tourism, but entry to temples is prohibited
		4	Temples are present but entry is completely prohibited.

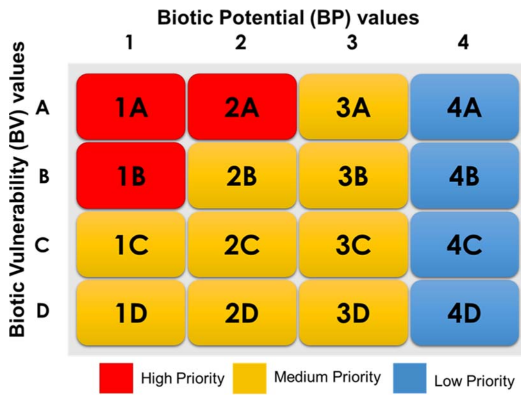

Fig. 1. The Bat Cave Vulnerability Index (BCVI) Prioritisation Scale. This scale is based on the integration of both biotic potential and vulnerability sub-indices. This scale indicates that areas with diverse bat population and high vulnerability as Highest Priority (see Tables 2, 4, and 8 for prioritisation description).

direct counting from the colonies. Captured bats were identified morphologically according to Ingle and Heaney (1992). The population and species diversity of cave bats were assessed based on the abundance and population estimates in caves. We employed BCVI and the Cave Grading Scheme developed by Furman and Özgül (2002) based on the third session of the meeting of Eurobats Agreement Parties (Mitchell-Jones et al., 2000; also see Mitchell-Jones et al., 2007), to compare the capability of both indices to identify priorities for cave sites.

The previously developed cave grading scheme is based on the abundance and conservation status of cave bats similar to the biotic component of BCVI. In the grading scheme, the species abundance is multiplied by the points based on conservation status. Species considered as threatened were given four points, and species at lower risk were given two points. The sum of species contributions from all species is used to prioritise cave sites. There are four priority settings used to grade the sites based on their scores: Level 1 caves are the most important underground sites, supporting high populations with threatened species present (10,000 or more points); Level 2 caves are also important underground sites with large population and more bat species (1000 ≤ score < 10,000); Level 3 sites are the lowest priority areas, which are occupied by smaller population of bats with no threatened species (100 ≤ score < 1000); and Level 4 caves are lowest priority sites occupied by only few bat individuals (score ≤ 100) (Furman and Özgül, 2002, 2004).

3. Results

3.1. Cave biotic potential (BP): bat species diversity

All cave sites assessed contained multiple bat species (Table 5). In terms of species richness, Lupe and Usok were the most diverse caves with 11 and 12 species respectively, and both contain threatened and endemic species. Cathedral and Shortcut caves showed lower species richness ($S = 9$), and Carmen cave had the lowest species richness ($S = 3$), and no endemic or threatened species. The cave bat biodiversity information was utilized to calculate the cave Biotic Potential (BP). The Cathedral cave was classified as 'Level 1', while three cave sites are classified as 'Level 3' (Lupe, Avenue, and Usok) and two caves were 'Level 4' (Shortcut and Carmen) (Table 6).

3.2. Cave biotic vulnerability (BV): landscape features and human impacts in caves

In general, the majority of the caves ecosystems are vulnerable to tourism, bat hunting, unregulated entry, and small-scale agriculture at the cave exterior. Notably, hunting of frugivorous bats (e.g., *Rousettus amplexicaudatus* and *Eonycteris spelaea*) and large insectivorous bats (e.g., *Hipposideros diadema*) occurred in large caves such as Cathedral and Lupe. While, unregulated tourism and habitat destruction are prevalent at all cave sites (see Tanalgo et al., 2016). The information on cave physical characteristics and presence of anthropogenic threats was then used to evaluate the Biotic Vulnerability (BV) of caves. Our assessment showed that three (50%) caves sites (Lupe, Cathedral, and Carmen) have higher accessibility to human activities and significant threats and therefore considered as 'Status A' cave. While, two (33%) caves (Avenue and Usok) were classified 'Status B', which is minimally threatened and little disturbance is present. A single cave (Shortcut) was listed as 'Status C' with least presence of disturbance and located very far from anthropogenic activities (Table 7).

Table 5
Species abundance of cave bats from south-central Mindanao, Philippines used as a model scenario to test the application of the BCVI.

Species Name	Cave Site					
	Lupe	Avenue	Usok	Cathedral	Shortcut	Carmen
Cynopterus brachyotis	41	80	26	40		
Emballonura alecto		17	16		7	
Eonycteris spelaea	60	12	17	100		21
Hipposideros ater	2					
Hipposideros diadema	41	12	15	29	9	
Hipposideros pygmaeus		4	2		2	
Megaerops wetmorei	1		2			
Miniopterus australis		7	7		1	
Miniopterus tristis			7	1	3	
Myotis horsfieldii	5	4	6	1	4	
Pipistrellus javanicus		6				
Ptenochirus jagori	4		10			
Rhinolophus arcuatus	7	6	5	6	12	
Rousettus amplexicaudatus	78	32	44	150		14
Eonycteris robusta	23			78	14	
Rhinolophus rufus	31			38	34	
Abundance	293	180	157	443	86	35
Species richness	11	10	12	9	9	3
No of endemic spp.	4	1	3	2	3	0
No of threatened spp.	3	0	1	2	2	0

Table 6
The Biotic Potential (BP) of cave sites assessed from south-central Mindanao, Philippines (Est. Pop (Estimated population; Sp. Div. (Species Diversity), *values in (,) indicates number of endemic and threatened species).

Caves	Est. Pop	Sp. Div.	BP score	BP Index	Description
Lupe	293	11 (4,3)	49,002.39	3	Medium Diversity
Avenue	180	10 (1,0)	30,621.33	3	Medium Diversity
Usok	159	12 (3,1)	29,392.02	3	Medium Diversity
Cathedral	443	9 (2,2)	152,155.80	1	High Diversity
Shortcut	86	9 (3,2)	18,476.12	4	Low Diversity
Carmen	35	2 (0,0)	587.05	4	Low Diversity

Table 7
Assessed Biotic Vulnerability (BV) of cave sites using cave geophysical and human disturbance parameters.

Cave Sites	Geophysical Features						BV Score	BV Index
	Acc	Co	Tour	Eff	CavUs	LandUs		
Lupe	2	1	1	2	1	2	1.8	A
Avenue	3	2	1	2	1	3	2.4	B
Usok	3	1	1	1	1	3	2	B
Cathedral	2	1	1	1	1	2	1.6	A
Shortcut	3	3	2	3	1	3	3	C
Carmen	1	1	1	2	2	2	1.8	A

Table 8
Priority level of six cave models using Bat Cave Vulnerability Index and Cave Grading Scheme indicating the suggested conservation needed.

Cave Site	Bat Cave Vulnerability Index						Cave Grading Scheme		
	BP Score (*100)	BP Index (Level)	Biotic Vulnerability (BV) Scores	BV Index (Status)	BCVI	Priority/Suggested action needed	CGS Score	Level	Priority
Lupe	490	Level 3	1.8	A	3A	Medium– Relatively high population, high diversity of species. Highly accessible and prone to disturbance.	7032	2	Very important habitat; large population is present.
Avenue	306	Level 3	2.4	B	3B	Medium–Low population, high site accessibility.	3600	2	Very important habitat; large population is present.
Usok	294	Level 3	2	B	3B	Medium–Low Population, high site accessibility.	4082	2	Very important habitat; large population is present.
Cathedral	1521	Level 1	1.6	A	1A	High–High population is present; high site accessibility; highly disturbed.	7974	2	Very important habitat; large population is present.
Shortcut	184	Level 4	3	Status C	4C	Low–Very low population and species diversity; lower site accessibility and less prone to disturbance.	1548	2	Very important habitat; large population is present.
Carmen	5.9	Level 4	1.8	Status A	4A	Low–Very low population and species diversity; high accessibility; highly disturbed.	210	3	Lower priority; low population is present.

3.3. Cave priority status

The priority settings of caves were compared using the BCVI and the Cave Grading Scheme developed by Furman and Özgül (2002). The prioritisation of caves based on BCVI integrates both the Biotic Potential (BP) and Biotic Vulnerability (BV), while the Cave Grading Scheme is based on population and conservation status of bats. Using BCVI equation, results showed that three caves were classified as 'Medium Priority' (Lupe, Avenue, and Usok), two caves (Shortcut and Carmen) as 'Low Priority' sites, and a single cave Cathedral was designated as a 'High Priority' site (Table 8).

The comparison of the BCVI to the other indices showed the disparity in prioritisation levels in terms of the biotic level. The 'highest priority' cave site (Cathedral) classified in BCVI was determined as 'medium priority' using the Cave Grading Scheme. The lowest priority site (Carmen) appeared equally as 'lowest priority' in both indices used (Table 8).

4. Discussion

4.1. Integrating bat species diversity and human impacts on cave priorities

The Bat Cave Vulnerability Index is a holistic tool based on cave bat species diversity and human impacts present at any given site, which has been developed to assist conservation management and prioritisation by determining caves most in need of protection (Fig. 2). Using BCVI in our test model bat caves, it demonstrated that the index was effective and practicable in cave prioritisation. Cave sites with high species diversity became vulnerable when anthropogenic activities are intensely present (e.g. Cathedral cave, BCVI = 1A). Conversely, some caves may be lower priority despite human pressures due to low species diversity (e.g. Carmen cave, BCVI = 4A). Based on the mechanism of the BCVI, cave sites that show high biotic potential but are not threatened by human activities (low vulnerability) may not urgently require rapid conservation intervention, but constant monitoring is still necessary, and further disturbance at these sites should be prevented. Given that caves currently rated as least vulnerable (healthy caves) may become vulnerable under inappropriate cave management, or if site access increases. Meanwhile, potential ecotourism activities could be conducted in the low priority caves, which have the lowest bat diversity (e.g. Carmen cave, BCVI = 4A).

A 'Cave Grading Scheme' for cave conservation (Furman and Özgül, 2002; Mitchell-Jones et al., 2000; Mitchell-Jones et al., 2007) to identify cave sites with the highest populations and assign priority solely based on bat population sizes was previously developed. This scheme was applied in cave bat studies in Europe (see Furman and Özgül, 2002; Furman and Özgül, 2004) and Asia (see Niu et al., 2007), as part of the preliminary prioritisation process. That being so, this index was used to compare our developed index using the same dataset from the Philippines (Table 8). Both indices were useful for identifying important bat cave areas. However, the Cave Grading Scheme overlooks the vulnerability of the caves to human activities and disturbance.

The strength of the integrated approach of BCVI enables it to reasonably select priority caves with considerations of the landscape threats present. Within the BCVI, the human-induced threats and disturbance observable from the cave interior and exterior are measured within the Biotic Vulnerability index (BV), which allows a more nuanced approach to generating conservation priorities than schemes such as Cave Grading Scheme, and is responsible for the different priorities generated by each index. This inclusion provides key information for framing holistic conservation strategies at a landscape level. Donato et al. (2014) and Silva et al. (2015) emphasized that effective cave conservation should encompass the information from biological, geological, and anthropogenic pressures. Threats and disturbances are essential considerations in cave prioritisation since it occurs both inside and outside caves and frequent disturbances will

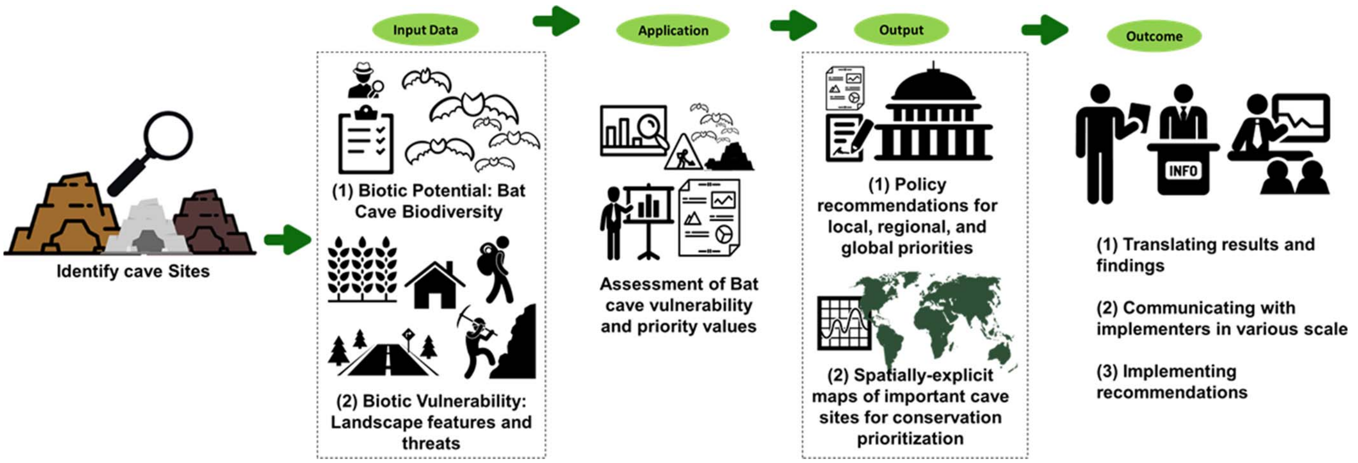

Fig. 2. The schematic diagram of the application of the Bat Cave Vulnerability Index in prioritising bat caves for conservation. The process starts with the identification of cave areas to assess cave priorities. The input data necessary for the holistic process includes the bat cave diversity and threats present in caves that represent the cave biological potential (BP) and vulnerability (BV) respectively. The application of BCVI concept will follow to identify the cave priority settings, which will be transformed into spatial maps of important areas and policy recommendations, which may be adapted and implemented in a regional, national, or global scales.

result in alterations of abiotic structure, habitat loss, and population declines of many cave-dependent species (Sedlock et al., 2014; Furey et al., 2011; Phelps et al., 2016).

4.2. Insufficiency of species richness to measure cave prioritisation

In cave ecosystems, there are several indices developed and applied, which solely use species richness of different taxa to measure cave priorities. For example, Elliott (2005) introduced an index to prioritise caves in the United States based on species richness and state-wide endemism of troglobites (obligate cave-dwelling species), including stygobites, or aquatic troglobites. However, the numerous taxonomic groups utilized in this index requires significant effort, time, and expert skill and is therefore challenging for rapid-assessment of caves. Furthermore, in Elliot's index assessment threats and cave vulnerability is not included. Similarly, Borges et al. (2008) developed an 'Importance Value for Conservation' (IV-C) based on the arthropod diversity and cave physical characteristics and management system. It was later modified by Gabriel et al. (2008) using bryophyte diversity and rarity. Both indices provide useful assessment tools in identifying cave conservation value but are not able to indicate the vulnerability of cave to human disturbance and other threats in most instances.

An index similar to BCVI was developed using cave invertebrate species diversity and landscape threats to identify cave vulnerability. Donato et al. (2014) developed the Cave Conservation Index (CCI) and integrated this to the rapid assessment protocol (RAP-cr) to assess the vulnerability of cave for conservation prioritisation. This index assesses both the cave biotic characteristics and landscape features but is only based on partial observations of the presence of cave biotic components (i.e., bats are present [score = 2, 3, or 4] or absent [score = 0]). Correspondingly, Silva et al. (2015) developed cave conservation priority index (CCPi) associating troglobiotic and troglophilic richness and human disturbance. However, approaches using obligate cave fauna is challenging. First, cave-limited fauna is difficult to sample because of their limited and unclear knowledge on their distribution (Christman et al., 2016). Secondly, the taxonomy of most cave invertebrates remains largely undocumented thus it is difficult to rapidly assess the conservation value (Culver and Pipan, 2009; Whitten, 2009; Cardoso et al., 2011a, 2011b).

In this paper, we propose that cave species richness should not be the sole basis of prioritisation. It is important to take note that richness alone is not sufficient enough because it is only based on the counts or estimates of the species (Hill, 1973; Boulinier et al., 1998; Jennings et al., 2008; Magurran, 2013). Using this as a measure of conservation prioritisation may overlook other facets of biodiversity patterns i.e., conservation status and endemism or distributional range of an individual species within a community or site (Orme et al., 2005; Chao, 2006; Veach et al., 2017). In our study, using the Biotic Potential index (BP), caves with high species richness did not directly result to the highest priority but the inclusion of endemism, conservation status, and rarity altered the priority setting of those areas with relatively medium diversity sites (Usok and Lupe vs. Cathedral cave).

Furthermore, even though there are few, or no endemic and threatened species in some caves; the presence of large population sizes of more generalist and common species (e.g., *Rousettus amplexicaudatus*) also increases the priority. Hence, using species richness alone for cave conservation decisions may leave other caves under-protected.

4.3. Challenges and future perspectives

Globally very few territories have specified legislation to protect and conserve karst and cave ecosystems, and if there is, it lacks reinforcement and monitoring (Whitten, 2009; Restificar et al., 2006; Van-Beynen, 2011). In the Philippines, for instance, although the National Cave Management Act exists to protect caves, many caves remain undersurveyed and unprotected in the country (PAWB-DENR, 2008; Ingle et al., 2011; BCI, 2013). The 'Bat Cave Vulnerability Index' was developed to address the absence of a standard process that will allow comparative measures to identify important bat caves in the tropics. In Southeast Asia and other tropical regions, for example, where high bat endemism is present yet the area is still experiencing high levels of disturbances. Hence, effective and easy-to-use prioritisation tools are essential to ensure biodiversity is conserved into the future.

The index will serve as a guide to conservationists in the selection of caves for fund allocation, research, restoration, and public use. Though the components of the index can be easily accessed, the prioritisation process requires a robust information on both species diversity (e.g., bat species, conservation status, and endemism) and habitat features to make this index adaptable to a wide range of cave landscapes in the tropics, as well as to other regions with diverse bat caves. While the application of this index to caves with hibernating or migrating population remains a challenge, where species diversity varies spatiotemporally. Furthermore, the index should be refined and calibrated using other factors and datasets (i.e., cave scenario) in order to successfully apply the index to other regions.

5. Conclusion

Our index illustrates a more comprehensive assessment than pre-existing cave indices, which are based on species richness alone. The inclusion of population, endemism, rarity, and the assessment of vulnerability provides a holistic cave prioritisation mechanism for conservation management action. Given that resources are limited, such conservation prioritisation is critical.

Caves and karst ecosystems around the world are vulnerable to various human activities coupled with incessant environmental changes, which represent a significant threat to endemic cave diversity (Hughes, 2017a). These habitats are essential to a host of endemic species, many of which provide essential ecosystem services. The conservation index that we propose in this paper presents an easy and rapid, yet effective, way of prioritising areas for conservation and management based on both diversity and threat. By highlighting bats as umbrella species in caves, we synergistically incorporate significant elements of species diversity with habitat features to produce an inclusive habitat conservation strategy, which provides a mechanism to frame conservation decisions and effectively protect cave diversity into the future.

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