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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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A B S T R A C T

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