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COMMUNICATION

Faunal diversity of an insular crepuscular cave of Goa, India

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Abstract: This study is the first attempt to document troglofaunal diversity of crepuscular cave ecosystem from the state of Goa. Twelve faunal species (seven invertebrates and five vertebrates) have been documented from an insular crepuscular cave which measures 18.62m in floor length and shows a transition of light and hygrothermal profile between its entrance and dead end. Absence of primary producers, thermal constancy, high humidity, poor ventilation, and competitive exclusion due to limited food resources restricts the faunal diversity of this cave; though trophic linkages are interesting yet speculative, as is typical of subterranean ecosystem. Among the macro-invertebrates, cavernicolous Whip Spider is a significant species here; whereas the important vertebrates encountered are the Fungoid frog and the Indian Cricket frog, besides roosts of the Rufous Horseshoe bat. Eco-energetic subsidy, possibly offered by crickets and bats that regularly feed outside this oligotrophic cave ecosystem is discussed. The need to document the unique and vulnerable troglofauna of this sensitive ecosystem from the conservation perspective is highlighted.

Keywords: Crepuscular, eco-energetic subsidy, insular cave, troglofauna.

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Author contribution: PS—Field work, laboratory analysis, computation of data and writing first draft; MRB—Conceptualization and supervision of field & laboratory work, data collation and interpretation, writing final research manuscript and editing; IS—Field work and laboratory analysis; AP—Field work and laboratory analysis.

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INTRODUCTION

Caves are natural or man-made subterranean cavities that may also be formed in the face of a cliff or a hillside. Their speleogenesis is attributed to various geologic processes; inclusive of a combination of chemical processes, erosion by water, tectonic forces, microorganisms, pressure and atmospheric influences (Ford & Williams 2007).

Cave as an ecosystem has its unique features characterized by gradients of darkness, narrow range of temperature differences and high humidity with limited air currents as some of its abiotic factors. These features make the cave ecosystem unique and the study of its biota fascinating (Biswas 2009). Bio-speleology is a relatively nascent area of ecology in India; the dearth of bio-speleological data being on account of the relatively hostile and secluded nature of these ecosystems.

The cave environment creates an ecosystem, which the fauna living in epigean conditions find difficult to adapt to (Biswas 2010). Nonetheless, caves support and sustain a good faunal diversity within the limited geophysical parameters. Organisms attracted to live in caves show high degree of morphological, behavioral, and physiological adaptations necessary to endure and thrive in such an ecosystem (Vandel 1965; Barr 1968; Biswas 1992; Gunn 2004). Species colonise caves for various reasons for at least part of their life cycles for temporary shelter or due to low predation pressure and easy availability of prey (Biswas 2009).

This study is the first attempt at charting out the faunal diversity of crepuscular cave ecosystem of Goa's insular landscape. The term insular is used here to indicate the cave's presence on an island. Divar is the third largest of the seven islands of Goa; roughly triangular in shape and measures an average 5.80km long and about 3.00km wide, with an area of around 17.56km^2. A cursory mention of this cave ecosystem of Divar Island appears in the book "Island Biodiversity Goa" (Sawant & Jadhav 2014).

Present study is particularly intended to obtain data on the troglofaunal diversity inhabiting the cave. In the present case the crepuscular cave investigated is a relatively small subterranean ecosystem with a floor length of 18m and average roof height of 3.4m; as such the environmental variables typical of a classical cave resulting in distinct zonation as proposed by Vermeulen & Whitten (1999) cannot be applied here. Nonetheless, from the cave entrance towards the dead end it is possible to demarcate three zones using variation in hygrothermal profile and diminishing light intensity as zone boundaries. The organic carbon and phosphate content of the soil through the floor length of the cave have been analysed. The data gathered addresses an important gap in our state specific biodiversity of sensitive ecosystems.

MATERIALS AND METHODS

The cave investigated in this study is located at 15.535^{0}N & 73.924^{0}E on Divar Island towards the north of Old Goa, 9.50km from Panaji and surrounded by the Mandovi estuary and its network of tributaries (Image 1a,b). The island is dominated by agricultural landscape and a few aquaculture units (Image 1c).

The cave was physically measured for various speleometric dimensions and a schematic diagram was hand drawn by mapping the layout of the cave and later digitized to add details like measurements and sampling points. Physical parameters such as light (Luxmeter HTC Model LX-103), temperature and humidity (Digital Hygrometer-Thermometer HTC Model 103-CTH) were recorded throughout the cave.

Soil samples from various points within the cave were collected in pre-sterilized zipped plastic pouches using a spatula and analysed for organic carbon (Walkley & Black 1934) and phosphate content (Adelowo et al. 2016). Monthly visits were made for seven months from August 2018 to February 2019 for documentation of troglofauna in relation to three zones of the cave. Only direct evidences were considered to compile an inventory of troglofauna. Most observations were made between 09.00h and 17.00h, but occasional observations were made at night to account for any night cave visitors. Species were photo-documented and collection was avoided to uphold conservation ethics, unless absolutely necessary for taxonomy.

The various troglofaunal species observed and photo-documented in this cave were identified based on taxonomic guides, as also consultations with taxon experts (Chopard 1970; Bastawade 1995; Whitaker 2006; Srinivasulu et al. 2010; Gururaja 2012; Keswani et al. 2012; Baidya & Chindarkar 2015). Notwithstanding that much larger sample sizes instill confidence for detecting small changes between sampling times or sites, in this exercise semi-quantitative ACFOR scale was used for the rapid assessment of abundance of the cave fauna. The utility of ACFOR scale in coarse assessment of abundance, both accurately and quickly, has been proven (Hawkins & Jones 1992).

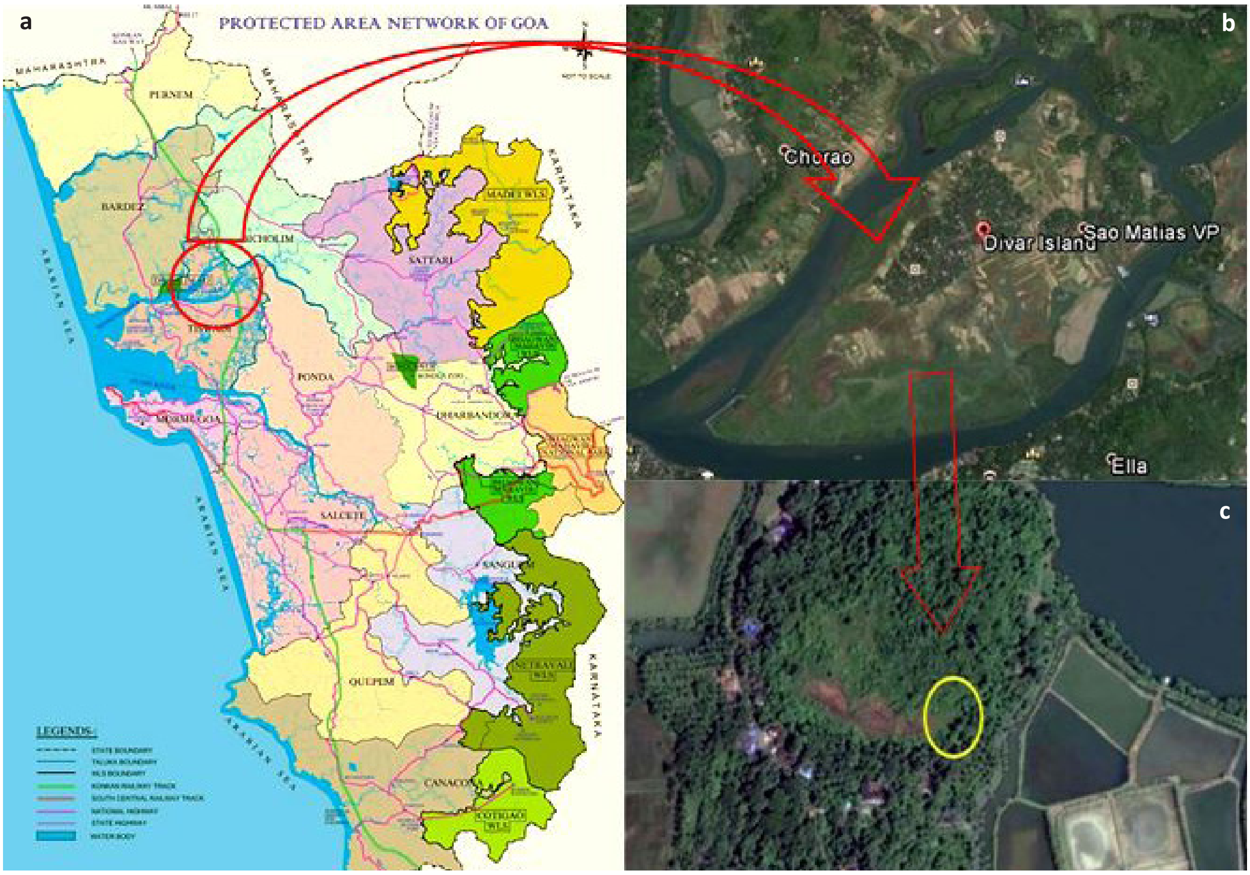

Image 1. Location of the cave on Divar Island of Goa, India.

RESULTS & OBSERVATIONS

The investigated cave on Divar Island in Goa is a natural subterranean vault at the base of a cliff (Image 1). This crepuscular cave is lateritic and damp with progressively diminishing light from the entrance to the end chamber, totaling a floor length of 18.62m (Image 2 & Fig. 2). Schematic diagrams (Fig. 1 & 2) depict the measurements of the cave. The cave entrance is 3.52m wide and opens up horizontally into a chamber typed as the zone A (proximate to the entrance), since it had less light and vegetation than outside and the temperature and humidity were found to be 30.5°C and 80%, respectively (Fig. 2 & 3, sampling point C). The next cave segment with light intensity decreasing further was considered to be the zone B (middle zone) with temperature of 30.4°C and humidity at 97% (Fig. 2 & 3, sampling point D). The zone C (end zone) is characterized by complete darkness with 99% humidity and temperature ranging between 29.1–30.1°C (Fig. 2 & 3, sampling points E & F). The intensity of light decreased with increasing distance from the cave entrance to the end zone, average light of 1782.13 lux and 0 lux being recorded respectively at the two extreme points. The organic carbon and phosphate content of the soil from sampling sites along the three cave zones is shown in Fig. 5 & 6 and correlates well with roost positions of the bats (Fig. 4), values being higher in the zone B and C as compared to zone A.

In the present investigation, 12 faunal species were recorded from various zones of the cave; (See Table 1 and Image 3). Two species of frogs have been encountered in the cave, namely, Fungoid Frog *Hydrophylax malabaricus* and Indian Cricket Frog *Fejervarya limnocharis*; the sightings of the former being more frequent after the rains extending in distribution from the zone A to Zone C, but the latter more confined to zone A. Often called the Paddy Frog, *Fejervarya limnocharis* is a common species of croplands here. Brooke's Gecko *Hemidactylus brookii* occurs from the entrance through the zone A of the cave co-inhabited by Scutigeromorph Centipede *Scutigera coleoptrata,* Woodlouse unidentified species, Daddy Longlegs *Puria dorsalis*, Humped Spider *Zosis geniculata* and Whip Spider *Phrynichus phipsoni*. The

Image 2. a—Cave Entrance | b—Zone A (proximate to the entrance) | c—Zone B (middle zone) | d—Zone C (end zone). © Manoj R. Borkar.

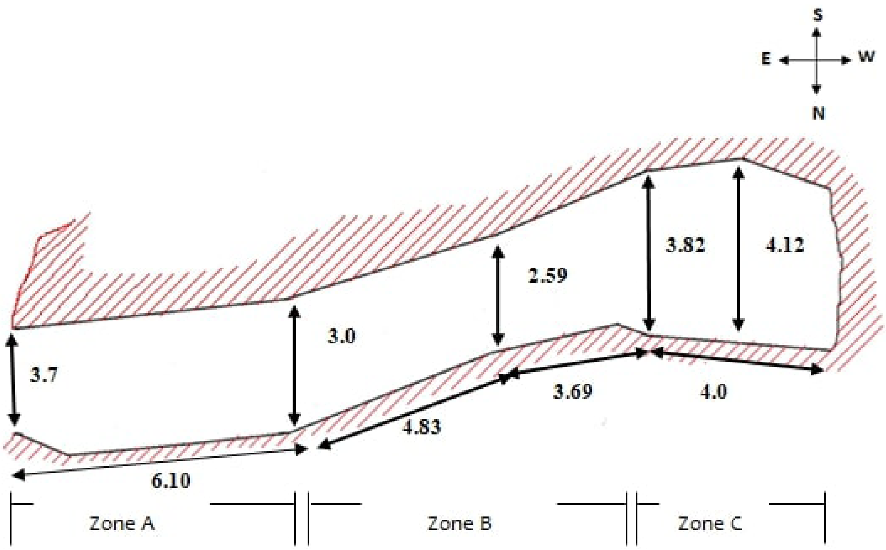

Figure 1. Speleometric data (in meters) in a schematic lateral section of the Divar Cave in Goa.

Cricket *Itaropsis parviceps* and Long-necked Sugar Ant *Camponotus angusticollis* were associated with zone B of the cave. The Whip Spider *Phrynichus phipsoni* population of this cave exhibits site fidelity, with individuals dispersing at night on the cave walls from their hideouts in crevices.

The Rufous Horseshoe Bat *Rhinolophus rouxii* is an important mammalian constituent of troglofauna in this cave, its population and distribution varying seasonally. In the wet months dense bat roosts occupied the zone B and C. In the zone A, five individuals of Rufous Horseshoe Bat were seen clustered on extreme right

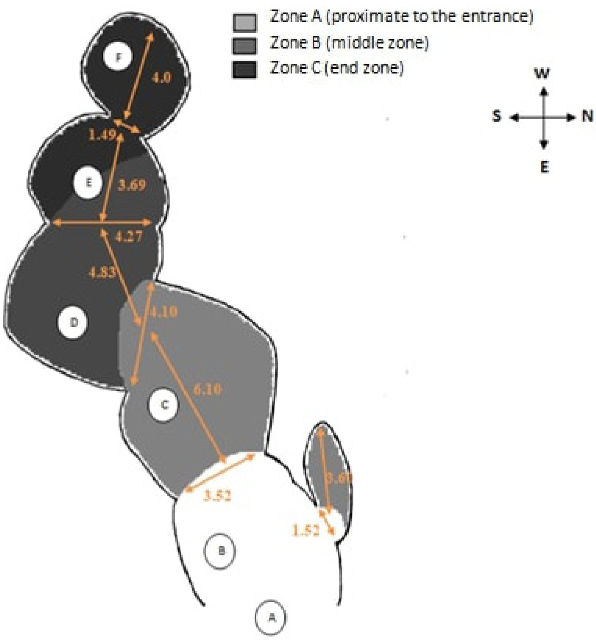

Figure 2 . Cave measurements and zones. (A to F are sampling points in different zones).

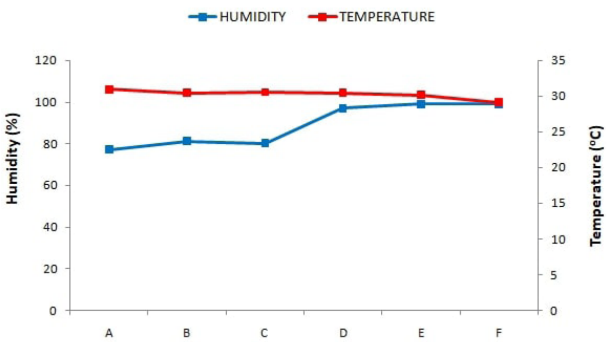

Figure 3. Hygrothermal data recorded at the sampling points of different cave zones as shown in Figure 2.

Figure 4. Roost and individual count of Rufous Horseshoe Bat *Rhinolophus rouxii* across cave zones.

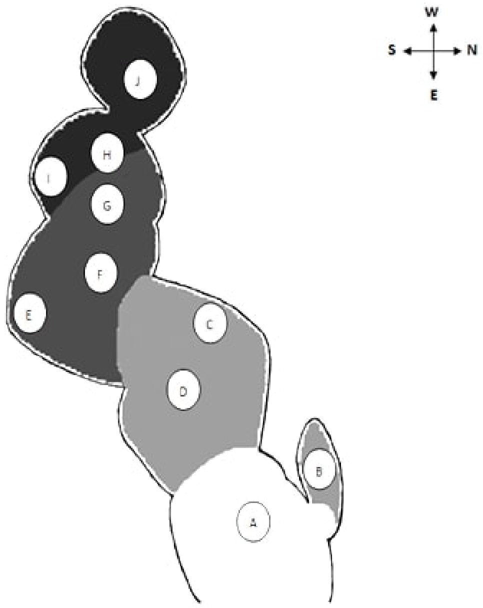

Figure 5. Sampling points for total organic Carbon and Phosphate content of soil in different cave zones.

wall, where light intensity was perceptibly less. Bats preferred to roost on the walls rather than the roof of the cave. In the month of November 2018, the bat density decreased and the roosts were restricted to zone B and C. By February 2019, the numbers dropped further; barring a small cluster of bats in the distal end of the zone B and a roost of predominantly sub-adults was confined to the end part of the cave. Such seasonal shifts in the distribution and number of the bat roosts within this cave (see Fig. 4) accounts for absence of a thick bulky guano deposit in this cave and the guano is loosely scattered on the cave floor.

A single individual of Common Krait *Bungarus caeruleus* documented from this cave during the night survey is most likely to have been a straggler or an opportunistic predator that had been attracted to the cave, after seeing concentrated food supply in form of roosting bats. Such opportunistic predations on cave roosting bats have also been recorded by Tanalgo et al. (2020).

All the species listed in this study are secondary consumers and saprotrophs. The smaller invertebrates help in remineralization of dead organic matter, as also constitute the prey base for lower rungs of secondary consumers such as daddy longlegs, Scutigeromorph Centipede, humped spider, and whip spider. The herpetofauna and bats operate at the next trophic level, whereas the Common Krait could either be a straggler or an opportunistic predator of frogs, lizards, and bats. From the troglofaunal inventory compiled in this study,

Table 1. Zone of occurrence and abundance of faunal diversity of the crepuscular cave in Divar, Goa.

	Common name	Species	Zone of occurrence	Abundance ratings
1	Scutigeromorph Centipede	*Scutigera coleoptrata* Linnaeus, 1758	A	F
2	Woodlouse	Unidentified Isopod	A	F
3	Cricket	*Itaropsis parviceps* Walker, 1869	B	C
4	Long-necked Sugar Ant	*Camponotus angusticollis* Jerdon, 1851	B	C
5	Daddy longlegs	*Puria dorsalis* Roewer, 1914	A	C
6	Humped spider	*Zosis geniculata* Olivier, 1789	A	O
7	Whip spider	*Phrynicus phipsoni* Pocock, 1900	A, B & C	F
8	Fungoid Frog	*Hydrophylax malabaricus* Tschudi, 1838	A, B & C	F
9	Indian Cricket Frog	*Fejervarya limnocharis* Gravenhorst, 1829	A	R
10	Brooke's Gecko	*Hemidactylus brookii* Gray, 1845	A	O
11	Common Krait	*Bungarus caeruleus* Schneider, 1801	A	R
12	Rufous Horseshoe Bat	*Rhinolophus rouxii* Temminck, 1835	B & C	A

Abundance rating are based on the semi-quantitative visual estimates: A—Abundant | C—Common | F—Frequent | O—Occasional | R—Rare.

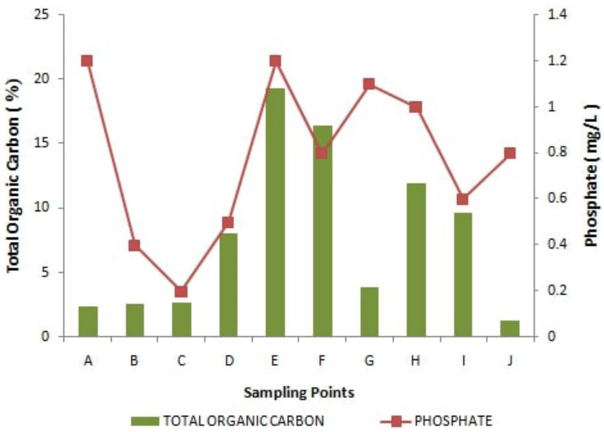

Figure 6. Total organic Carbon and Phosphates in soils from sampling points of different cave zones as in Figure 5.

it is evident that this cave has a truncated biodiversity typified by absence of phototrophic primary producers and presence of fewer apex predators in the food chains operating here.

DISCUSSION

Perusal of literature confirmed a glaring gap in documentation of troglofauna in the state of Goa. Deciphering the composition and dynamics of cave communities has been a key challenge for speleobiologists. The limited organization of a cave ecosystem has been attributed to permanent darkness and competitive exclusion due to resource scarcity (Fernandes et al. 2016). Despite a relatively hostile cavernous environment characterized by diffuse or complete absence of light, constant temperature and high humidity, poor air circulation and severely constrained food supplies; caves do support and sustain a unique assemblage of biota, whose density however is lower than epigean habitats (Mitchell et al. 1977; Parzefall 1983). The relatively poor faunal diversity of this cave ecosystem could also be attributed to the absence of phototrophs; resulting in scarcity of food, reducing the number of predators as well as the overall biodiversity of the cave ecosystem (Gibert & Deharveng 2002). Species might colonise cave environments for reasons such as the need for temporary shelter or in order to escape from persistent adverse environmental conditions on the surface, whereas others may be temporary visitors with limited reliance on the cave environment.

Several researchers have conclusively shown that phenology of species and in particular that of ectotherms, is influenced by air temperature and water availability (Kearny et al. 2013; Amarasekare & Coutinho 2014; Sheldon & Tewskbury 2014) and variations in these features in epigean environments often force animals to search for 'shelter microhabitats' of stable environments such as caves that offer the most suitable and stable conditions (Seebacher & Alfrod 2002; Papaioannou et al. 2015).

Expectedly, the variations in microclimatic attributes across the various cave zones create an environmental gradient, which influences distribution of various faunal elements. Such patterns of macro-invertebrate distribution in a cave ecosystem have also been

Image 3. Faunal diversity of the crepuscular cave in Divar, Goa, India: a—Scutigeromorph Centipede *Scutigera coleoptrata* | b—Woodlice, unidentified isopod | c—Cricket *Itaropsis parviceps* | d—Long-necked Sugar Ant *Camponotus angusticollis* | e—Daddy longlegs *Puria dorsalis* | f—Humped Spider *Zosis geniculata* | g—Whip Spider *Phrynichus phipsoni* | h—Fungoid Frog *Hydrophylax malabaricus* | i—Indian Cricket Frog *Fejervarya limnocharis* | j—Brooke's Gecko *Hemidactylus brookii* | k—Common Krait *Bungarus caeruleus* | l—Rufous Horseshoe Bat *Rhinolophus rouxii*. © Manoj R. Borkar & Andrea Sequeira.

confirmed by Mazebedi & Hesselberg (2020). The basic tenet of eco-energetics requires linkages between biodiversity and the abiotic components; and the species richness is limited by productivity (Ricklefs & Schluter 1993). As is also the case with the cave investigated here, macro-invertebrates usually play a critical role in cave ecosystem functions because of their relatively high diversity compared to the vertebrate biota. Such an opinion has also been corroborated by Lavoie et al. (2007) and Moseley (2009). Crickets and bats subsidise the consumer community dynamics of this oligotrophic cave ecosystem. The crickets are known to take regular nocturnal feeding sorties on vegetation outside the cave (Benoit et al. 2004) and the bats offer guano subsidy by feeding in epigean habitats (Iskali & Zhang 2015). In the present case too, both these species offer a definite trophic connect to the cavernicoles of this cave, with the epigean resources.

Epigean populations of *Phrynichus phipsoni* have been reported from Goa earlier by Borkar et al. (2006). As documented from this cave; whip spiders also inhabit the crevices and cracks in the subterranean ecosystems that commensurate well with their dorso-ventrally flattened body contour (Chapin 2015). Their site fidelity and homing behavior as has been observed in this investigation, has been well documented (Hebets 2002).

Herepetofaunal constituents of this cave are two species of frogs, one species of gekkonid lizard belonging to the *Hemidactylus* clade complex of *brookii* group (Bauer et al. 2010a,b) and the Common Krait. The association of the Fungoid Frog with subterranean caves of Western Ghats is well established (Chari 1962) and has also been observed in the caves of Kanger Valley National Park, Chattisgharh (Biswas 2010; Biswas & Shotriya 2011). Caves are known to accumulate heat and create a microclimate favouring macrofaunal poikilotherms such as the amphibians and reptiles, and the abundant invertebrate species here remove limitations of food for these opportunistic predators (Turbanov et al. 2019). A single observation of Common Krait in this cave presumably for opportunistic feeding is corroborated by Sinha (1999), who has also reported Banded Kraits preying on Bats from Siju caves in Meghalaya.

The presence and roosting habits of Rufous Horseshoe Bat in caves of the Western Ghats have been previously reported by Korad et al. (2007). The variations in numbers and size of the bat roosts observed in this study is speculated to be driven by the species-specific social structure and foraging behaviour (Kunz & Lumsden 2005). The relatively sparse and scattered guano in this cave correlates well with shifting positions and density of the bat roosts. Similar observations have also been reported by Biswas & Shrotriya (2011). Bat guano may support guanophile communities that in turn could attract predators of these guanophages to the cave (Encinares 2019). Perhaps in a small subterranean cave like the one investigated here the species diversity may seem small, because all micro crustaceans and cavernicolous guanophiles have not been included.

CONCLUSION

On Divar Island where this cave is located, locals have consciously resisted urbanization thus far; but the place is a popular location for Bollywood film shoots. Tourists have been steadily pouring in to relish the rustic countryside. Influx of tourists will open up the hitherto inviolate areas for exploration and exploitation. Ecological studies of cave ecosystems and charting out their troglofauna are a prerequisite for management and conservation of sensitive and fragile subterranean ecosystems (Schneider & Culver 2004). Conservation of cave ecosystems is vital not only because they shelter unique and vulnerable biodiversity (Mammola 2019), but more so because their stable environments provide natural laboratories for testing doctrinal evolutionary concepts of adaptation and speciation (Culver & Pipan 2019). Also, collection and collation of a standardised data for a long term referral purpose is crucial for species conservation assessment (Lunghi et al. 2020).

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