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Research Article

Diversity of vespid wasps (Hymenoptera:Vespidae) in agroecosystem and forest ecosystem of Western Ghats region of Goa, India

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ABSTRACT: The present study was aimed to document and compare the diversity of vespid wasps (Hymenoptera:Vespidae) in the forest ecosystem and agroecosystem located in the Western Ghats region of Goa, India. We used moericke traps for sampling and collected a total of 231 individuals belonging to 19 species, 12 genera and 4 subfamilies of Vespidae between January to December 2019. It was found that the forest ecosystem with 125 individuals belonging to 19 species, 12 genera and 4 subfamilies was rich in Vespidae diversity as compared to agroecosystem with 106 individuals belonging to 13 species, 7 genera and 3 subfamilies.

KEY WORDS: Agroecosystem, forest ecosystem,Vespidae

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INTRODUCTION

India is the fastest-growing as well as the second-most populous country in the world after China (Koshy 2020). It is likely to overtake China in the coming years (Gladstone 2015). With the growing population, the demand for resources is also increasing. It has become a challenge for India to meet its increasing demands for resources to sustain its growing population and at the same time to protect its biodiversity. Agriculture has been one of the major threats to global biodiversity loss (Somavilla *et al.* 2016).

Goa is the smallest state in India and it is located on the South West coast of India. Goa has an area of 3702 km^2 and it is part of a biodiversity hotspot – Western Ghats (Chandran 1997). More than 20% geographic area of Goa is under the Western Ghats and it is protected legally by making it a part of the Protected Area network. Being a part of the biodiversity hotspot, Goa is blessed with tremendous biodiversity. Numerous studies have been conducted to study and document arthropod fauna of Goa (Rangnekar and Dharwadkar 2009, Rangnekar *et al.* 2010, Vyjayandi *et al.* 2010, Rangnekar and Naik 2014, Gaude and Janarthanam 2015, Gupta *et al.* 2015, Halali *et al.* 2015, Bowalkar *et al.* 2017, Maruthadurai and Singh 2017, Borkar 2018, Gawas *et al.* 2019, Pandit and Dharwadkar 2020, Baidya and Bagchi 2020).

Vespidae is the cosmopolitan family of predatory wasps. Vespid wasps are a very important group of insects in terms of its ecological as well as economic services they provide. They are pollinators, predators and are excellent biocontrol agents (Das and Gupta 1989). Many species of vespid wasps have been successfully utilized as bio-control agents for agroecosystems in different parts of the world (Gould and Jeanne 1984, Picanco *et al.* 2010). Indian Vespidae fauna is represented by 288 species belonging to 60 genera and 5 subfamilies (Gawas *et al.* 2020), out of which 35 species, 24 genera and 4 subfamilies are known to occur in Goa (Gawas *et al.* (2019, 2020)). Information on diversity and abundance are necessary to understand the environmental changes caused due to anthropogenic or natural factors (Lawton *et al.* 1998). Although taxonomic studies on Indian (Gawas *et al.* 2020, Pannure *et al.* 2016) and Goan Vespidae (Gawas *et al*. 2019) are available, studies to document and compare Vespidae diversity with respect to its habitats in India are scarce. The present study was undertaken to document and compare Vespidae diversity in the forest ecosystem and agroecosystem in the Western Ghats region of Goa, India.

MATERIALS AND METHODS

Ethics statement

Wasps specimens were collected from the tropical deciduous forest of Mollem National Park under the Goa

Forest Department research permit no. 2-66-WL-RESEARCH PROPOSALS-FD-Vol. I/3665 issued on November 5, 2018. Additionally, oral permission was taken from the private landowners for sampling insects in an agroecosystem. Vespid wasps (Hymenoptera:Vespidae) does not come under the Wildlife Protection Act of 1972 and therefore are not legally protected in India.

Study area

The study was conducted in the Western Ghats region of Goa, India. Two sites, forest ecosystem and agroecosystem were selected as the study area. A one-acre plot was designated at each site for the collection of Vespidae. The natural ecosystem is a tropical deciduous forest with *Terminalia* sp., *Dalbergia* sp. *Xylia* sp. as dominant tree species. It is located at 15°22'47" N and 74°13'57" E with an elevation of 83 meters above mean sea level. It is a part of Western Ghats biodiversity hotspot and falls within Mollem National Park, Dharbandora. The agroecosystem consists of Coconut (*Cocus nucifera*) and Areca nut (*Areca catechu*) plantation. It is located at 15°33'08" N and 74°09'51" E with an elevation of 48 meters above mean sea level. It is a private property in Ambedem village under Nagargao gram panchayat in Goa, India. Goa has a tropical monsoon type of climate with a mean annual rainfall of 110-120 inches, the average annual relative humidity of 72% and annual mean temperature ranges between 28-30°C.

Sampling design

The study was conducted for 12 months between January 2019 and December 2019. The sampling was done for 10 days every month (total 120 days of collection) by laying 50 moericke traps at each site. Moericke traps consist of a yellow colour plastic container with a 20 cm radius and 8 cm height. Moericke traps were filled with water solution mixed with surfactant. Traps were serviced every alternate day; specimens were collected using a sieve and traps were refilled with a fresh water solution. Specimens were preserved in 70% alcohol.

Determination of vespidae species

Collected vespid wasp specimens were either mounted with double mounts or direct pinning method. The specimens were sorted, processed, examined and deposited at the National Insect Museum of ICAR - National Bureau of Agricultural Insect Resources in Bengaluru, India. All the specimens collected are determined up to species level with help of the following keys: Das and Gupta 1989, Carpenter and Nguyen 2003, Kojima *et al.* 2007, Pannure *et al.* 2016 and Gawas *et al.* 2019 using Leica S8APO stereo zoom microscope. Images were taken with a Nikon D7000 camera with Nikkor 105 mm lens.

Statistical analysis

Alpha or species diversity of each site was estimated using the following ecological indices.

• Simpson's Diversity Index (SDI): 1-D

• Simpson's Index (D) = $\Sigma n(n-1) / N(N-1)$

where n = number of a species' individuals and N = total number of all species' individuals. Simpson's Diversity Index is given by subtracting the value of Simpson's index from 1. The index value varies from 0 to 1, with 1 representing infinite diversity and 0 representing no diversity, respectively. SDI is a diversity measure which takes into consideration both the number of species present and the relative abundance of each species (Simpson 1949).

• Shannon-Wiener index (H') =– Σ Pi ln(Pi)

where Pi = S / N; S = number of a species' individuals, N = total number of all species' individuals, ln = logarithm to base e. The greater the value of H', the higher the diversity (Shannon and Wiener 1949).

• Margalef index $\alpha = (S - 1) / \ln (N)$

where S = total number of species, N = total number of all species' individuals (Margalef 1958).

• Pielou's Evenness Index E1 = H' / ln(S)

where H' = Shannon-Wiener diversity index, S = total number of species in the sample (Pielou 1966). As species richness and evenness increase, diversity also increases (Magurran 1988).

Beta diversity measure was used to find out how different (or similar) ranges of habitats are in terms of the variety of species found in them (Magurran 1988). Beta Diversity was calculated using Jaccard Index.

• Jaccard Index (JI) (for two sites) =j / (a+b-j)

where j = species common to both sites A and B, a = species in site A and b = species in site B (Jaccard 1912). All the analysis was conducted in Microsoft Excel (2019).

RESULTS AND DISCUSSION

A total of 231 specimens belonging to 4 subfamilies, 12 genera and 19 were collected during the entire study period. The subfamilies collected were Eumeninae, Polistinae, Stenogastrinae and Vespinae. The subfamily Eumeninae

which consists of potter wasps was the most abundant family (n = 1 50, 64%) with 12 species and 8 genera while the subfamily Polistinae which consists of paper wasps was the next most abundant (n = 69, 30%) with 5 species and 2 genera. Subfamily Stenogastrinae (n = 2, 0.8%) and Vespinae (n = 10, 4%) are represented by 1 species each. The genera *Antepipona* de Saussure 1855, *Delta* de Saussure 1855, *Phimenes* Giordani Soika 1992, *Rhynchium* Spinola 1806, *Xenorhynchium* van der Vecht 1963, *Polistes* Latreille 1802, *Ropalidia* Guérin-Méneville 1831 and *Vespa* Linnaeus 1758 were recorded from both the sites and can be considered as the generalists (Table 2). Paper wasp's genus *Ropalidia* Guérin-Méneville 1831 and potter wasp genus *Antepipona* de Saussure 1855 were the most speciose with 4 species each. *Antepipona ceylonica* (de Saussure, 1867) was the most abundant and frequent (n = 53; 22.9%) species in both natural forest and agroecosystem, followed by *Antepipona ovalis* (de Saussure, 1853) (n = 27; 21.6%) in natural forest and *Ropalidia brevita* Das and Gupta, 1989 (n = 17; 16.04%) in agroecosystem.

Out of 231 collected specimens, 125 specimens belonging to 19 species, 12 genera and 4 subfamilies were reported from the forest ecosystem whereas 106 specimens belonging to 13 species, 7 genera and 3 subfamilies were recorded from agroecosystem. 1 subfamily and 6 species (Table 1 and Table 2) were exclusively found in forest ecosystem. Higher species diversity of Vespidae was found in forest ecosystem (H' = 2.31, α = 3.72) than agroecosystem (H' = 2.23, α = 2.57). Vespidae species in an agroecosystem (SDI = 0.88, E1 = 0.87) are more equally abundant and evenly distributed than forest ecosystem (SDI = 0.85, E1 = 0.78). The Jaccard's Index between two sites, Forest ecosystem and agroecosystem was found to be 0.68 (68% similarity between the sites). This is due to 13 species of Vespidae recorded in the agroecosystem were also recorded from the forest ecosystem.

We compared our study with other similar studies (Table 4) from the Western Ghats and its outskirts and found that the Vespid fauna is poorly documented and there has been no serious attempt has been made to study and compare Vespidae diversity across different ecosystems.

The heterogeneous environment of the forest with higher plant diversity has a higher number of niches to encourage the highest number of coexisting species (Latham and Ricklefs 1993, Braganca *et al.* 1998). Similar studies on Vespidae from the other parts of the tropics have also shown that Vespid wasps diversity tend to be lower in agroecosystems as compared to natural vegetation (Silva *et al.* 2013, Souza *et al.* 2011, Santos 1996). Therefore, the high species richness of Vespidae in forest ecosystem could be attributed to the heterogeneous environment which improved resources availability such as food and nesting materials as well as minimum disturbance by humans whereas comparatively lower Vespidae diversity of agroecosystem could be due to its homogenous environment with only 2 crops and human disturbance in the form periodic management practices such as removal of weeds.

This study emphasizes the importance of the forest ecosystem for Vespid wasps as well as the lack of studies on Vespidae documentation across different ecosystem and habitats in the Western Ghats region of India. Further studies should be encouraged in the country to document and improve our knowledge of Vespidae diversity and distribution. More data and information on Vespid wasps will enable us to use Vespidae as an indicator taxon to examine the health of an ecosystem (Hilty and Merenlender 2000) as well as the potential use of Vespid wasps in Integrated Pest Management strategies for agroecosystems (Gould and Jeanne 1984, Picanco *et al.* 2010).

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Table 1. Abundance, richness and relative frequency of vespid wasps (Hymenoptera:Vespidae) species collected in forest and agroecosystem of Goa, India

Sr. No.	Species	Forest ecosystem		Agroecosystem		Total	
		Abundance	Relative Frequency (%)	Abundance	Relative Frequency (%)	Abundance	Relative Frequency (%)
1	*Allorhynchium argentatum* (Fabricius, 1804)	2	1.6	0	0.00	2	0.87
2	*Antepipona ceylonica* (de Saussure, 1867)	35	28	18	16.98	53	22.94
3	*Antepipona ovalis* (de Saussure, 1853)	27	21.6	13	12.26	40	17.32
4	*Antepipona pruthii* Giordani Soika, 1882	4	3.2	0	0.00	4	1.73
5	*Antepipona sibilans* (Cameron, 1903)	13	10.4	16	15.09	29	12.55
6	*Delta conoideum* (Gmelin, 1790)	1	0.8	1	0.94	2	0.87
7	*Delta pyriforme* (Fabricius, 1775)	1	0.8	1	0.94	2	0.87
8	*Knemodynerus coriaceus* (Giordani Soika, 1970)	3	2.4	0	0.00	3	1.30
9	*Labus pusillus* van der Vecht, 1963	4	3.2	0	0.00	4	1.73
10	*Phimenes flavopictus* (Blanchard, 1845)	2	1.6	3	2.83	5	2.16
11	*Rhynchium brunneum* (Fabricius, 1793)	1	0.8	3	2.83	4	1.73
12	*Xenorhynchium nitidulum* (Fabricius, 1798)	1	0.8	1	0.94	2	0.87
13	*Polistes* (*Polistella*) *stigma tamulus* (Fabricius, 1798)	8	6.4	12	11.32	20	8.66
14	*Ropalidia stigma* (Smith, 1858)	4	3.2	0	0.00	4	1.73
15	*Ropalidia jacobsoni* (du Buysson, 1908)	1	0.8	5	4.72	6	2.60
16	*Ropalidia brevita* Das & Gupta, 1989	5	4	17	16.04	22	9.52
17	*Ropalidia cyathiformis* (Fabricius, 1804)	5	4	12	11.32	17	7.36
18	*Eustenogaster eximia eximioides* (Dover & Rao, 1922)	2	1.6	0	0.00	2	0.87
19	*Vespa tropica* (Linnaeus, 1758)	6	4.8	4	3.77	10	4.33
	Total individuals	**125**		**106**		**231**	
	Species richness	**19**		**13**		**19**	

Table 2. Binary (presence/absence) data of Vespidae collected in forest and agroecosystem of Goa, India

Sr. No.	Insect			Sites	
	Family	Subfamily	Species	Forest ecosystem	Agroecosystem
1	Vespidae	Eumeninae	*Allorhynchium argentatum* (Fabricius, 1804)	+	-
2			*Antepipona ceylonica* (de Saussure, 1867)	+	+
3			*Antepipona ovalis* (de Saussure, 1853)	+	+
4			*Antepipona pruthii* Giordani Soika, 1882	+	-
5			*Antepipona sibilans* (Cameron, 1903)	+	+
6			*Delta conoideum* (Gmelin, 1790)	+	+
7			*Delta pyriforme* (Fabricius, 1775)	+	+
8			*Knemodynerus coriaceus* (Giordani Soika, 1970)	+	-
9			*Labus pusillus* van der Vecht, 1963	+	-
10			*Phimenes flavopictus* (Blanchard, 1845)	+	+
11			*Rhynchium brunneum* (Fabricius, 1793)	+	+
12			*Xenorhynchium nitidulum* (Fabricius, 1798)	+	+
13		Polistinae	*Polistes* (*Polistella*) *stigma tamulus* (Fabricius, 1798)	+	+
14			*Ropalidia stigma* (Smith, 1858)	+	-
15			*Ropalidia jacobsoni* (du Buysson, 1908)	+	+
16			*Ropalidia brevita* Das & Gupta, 1989	+	+
17			*Ropalidia cyathiformis* (Fabricius, 1804)	+	+
18		Stenogastrinae	*Eustenogaster eximia eximioides* (Dover & Rao, 1922)	+	-
19		Vespinae	*Vespa tropica* (Linnaeus, 1758)	+	+

Table 3. Alpha diversity indices for Vespidae recorded from forest and agroecosystems of Goa, India

Site	S	N	SDI	H'	α	E1
Forest ecosystem	19	125	0.85	2.31	3.72	0.78
Agroecosystem	13	106	0.88	2.23	2.57	0.87

S = Total number of species richness; N = Total number of individuals, SDI = Simpson's Index of Diversity; H' = Shannon Weiner Index; α = Margalef Index; E1 = Pielou's Evenness Index.

Table 4. Comparison between the total number of species in this study (*) with other similar surveys from Western Ghats region

Researches	No. of species
Mathew and Mohandas 2001(Shola forest)	1
Mathew *et al.* 2005 (Forest)	1
Aland *et al.* 2010 (Tropical semi evergreen forest)	4
Hiremath and Ganesh 2016 (University Campus)	6
Balachandran *et al.* 2017 (Agroecosystem)	3
Jadhav *et al.* 2017 (Forest)	9
Chakraborti and Venkataraman 2018 (Dry deciduous scrub)	3
Veena *et al.* 2018 (University campus)	5
Gurule *et al.* 2020 (College Campus)	6
*Present study (Agroecosystem)	13
*Present study (Deciduous Forest)	19

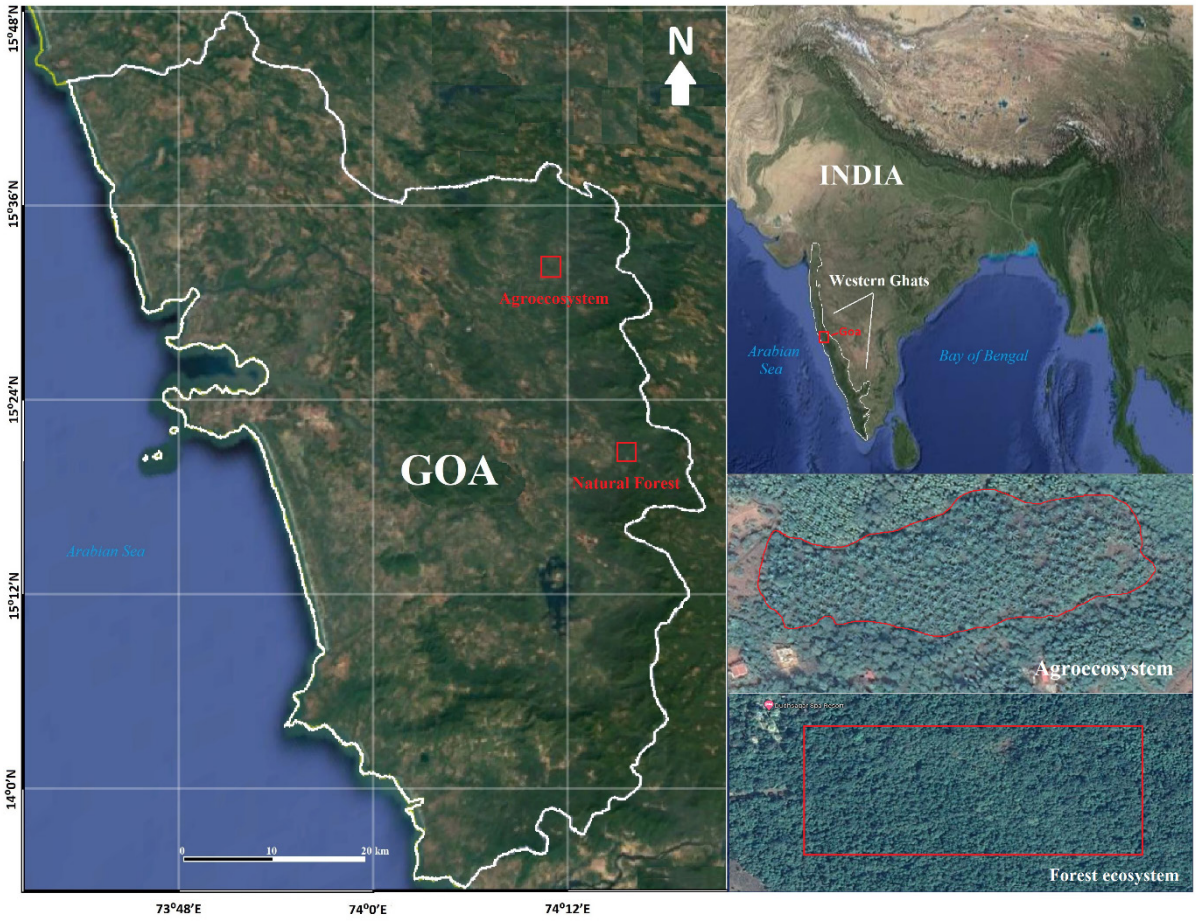

Fig. 1. Map showing locations of study sites 1) Agroecosystem and 2) Forest Ecosystem.

Fig. 2. Collection of vespid wasps using Moericke traps: Agroecosystem (left) and Forest ecosystem (right).

REFERENCES

Aland SR, Mamlayya AB, Gaikwad SM, Bharmal DL, and Bhawane GP. 2010. Diversity of insects with special reference to order hymenoptera in Amba reserved forest of Kolhapur district, Western ghats, Maharashtra, India. *Biological Forum-An International Journal*. **2**(2):59–64.

Baidya P, and Bagchi S. 2020. A new species of Protanilla Taylor 1990 (Hymenoptera:Formicidae:Leptanillinae) from India. *Halteres*. **11**:19–24. http://doi.org/10.5281/zenodo.3941686

Balachandran C, Chandran MS, Vinay S., Shrikant N, and Ranachandra, TV. 2017. Pollinator diversity and foraging dynamics on monsoon crop of cucurbits in a traditional landscape of South Indian West Coast. *Biotropia*. **24**(1):16–27. https://doi.org/10.11598/btb.2017.24.1.480

Borkar MR. 2018. First definitive record of a whip scorpion Labochirus tauricornis (Pocock, 1900) from Goa, India: with notes on its morphometry and pedipalp micro-morphology. *J. Threat. Taxa*. **10**(7):11955–11962. http://doi.org/10.11609/jott.4084.10.7.11955-11962

Bowalkar D, Michael NAG, Gaude K, and Pai IK. 2017. A checklist of butterflies (Insecta:Lepidoptera) from Taleigao plateau, Goa, India. *J. Threat. Taxa*. **9**(8):10626–10630. http://doi.org/10.11609/jott.2687.9.8.10626-10630

Bragança MA, Zanuncio J, Picanço M, and Laranjeiro AJ. 1998. Effects of environmental heterogeneity on Lepidoptera and Hymenoptera populations in Eucalyptus plantations in Brazil. *For. Ecol. Manag*. **103**(2-3):287–292. https://doi.org/10.1016/S0378-1127(97)00226-0

Carpenter JM, and Nguyen LPT. 2003. Keys to the genera of social wasps of South East Asia (Hymenoptera:Vespidae). *Entomol. Sci.* **6**(3):183–192. https://doi.org/10.1046/j.1343-8786.2003.00016.x

Chakraborti S, and Venkataraman R. 2018. Linking insect diversity with habitat health at the ecologically restored sites of the Lokkere Reserve Forest, Bandipur Tiger Reserve, Karnataka. (JS-Insects-001). *JungleScapes.* 10.13140/RG.2.2.25359.02721

Chandran MS. 1997. On the ecological history of the Western Ghats. ***Curr. Sci.*** **73**(2):146–155.

Das BP, and Gupta VK. 1989. The social wasps of India and the adjacent countries (Hymenoptera:Vespidae). *Oriental Insects Monograph*. **11**:1–292. https://doi.org/10.1080/00305316.1989.11835532

Gaude K, and Janarthanam MK. 2015. The butterfly (Insecta:Lepidoptera) diversity of four sacred groves of Goa, India. *J. Threat. Taxa.* **7**(12):7927–7932. https://doi.org/10.11609/JoTT.o4228.7927-32

Gawas SM, Girish Kumar P, Gupta A, and Sureshan PM. 2019. Checklist of vespid wasps (Hymenoptera:Vespidae) of Goa, India, with new records and a key to species. *Zootaxa*. **4585**(2):269–294. PMid: 31716168. https://doi.org/10.11646/zootaxa.4585.2.3

Gawas SM, Girish Kumar P, Pannure A, Gupta A, and Carpenter JM. 2020. An annotated distributional checklist of Vespidae (Hymenoptera:Vespoidea) of India. *Zootaxa*. **4784**(1):1–87. PMid: 33056505. https://doi.org/10.11646/zootaxa.4784.1.1

Gladstone R. 2015. India will be most populous country sooner than thought, U.N. says. The New York Times. Retrieved from https://www.nytimes.com/2015/07/30/world/asia/india-will-be-most-populous-country-sooner-than-thought-un-says.html

Gould WP, and Jeanne RL. 1984. Polistes wasps (Hymenoptera:Vespidae) as control agents for lepidopterus cabbage pests. *Environ. Entomol.* **13**(1):150–156. https://doi.org/10.1093/ee/13.1.150

Gupta A, Gawas SM, and Bhambure R. 2015. On the parasitoid complex of butterflies with descriptions of two new species of parasitic wasps (Hymenoptera:Eulophidae) from Goa, India. *Syst. Parasitol.* **92**:223–240. PMid: 26446545. https://doi.org/10.1007/s11230-015-9596-6

Gurule SA, Jadhav TA, and Gangurde JH. 2020. Hymenopteran fauna inhabiting K.T.H.M. College Campus, Nashik, Maharashtra. *Flora and Fauna.* **26**(1):149–155. https://doi.org/10.33451/florafauna.v26i1pp149-155

Halali S, Halali D, and Rangnekar P. 2015. Range extension of Microgomphus souteri Fraser, 1924 (Insecta:Odonata:Gomphidae) to northern Western Ghats, India*. J. Threat. Taxa.*. **7**(8):7480–7483. http://dx.doi.org/10.11609/JoTT.o4259.7480-3

Hilty J, and Merenlender A. 2000. Faunal indicator taxa selection for monitoring ecosystem health. *Biol. Conserv*., **92**(2):185–197. https://doi.org/10.1016/S0006-3207(99)00052-X

Hiremath R, and Ganesh CB. 2016. A preliminary study on hymenopteran diversity in University of Agricultural Sciences campus Dharwad. *J. Entomol. Zool. Stud.* **4**(4):1271–1274.

Jaccard P. 1912. The distribution of the flora in the alpine zone. *New Phytol*., **11**:37–50. https://doi.org/10.1111/j.1469-8137.1912.tb05611.x

Jadhav M, Sharma RM, and Gaikwad SM. 2017. Insecta: Hymenoptera:Vespidae. *Fauna of Phansad Wildlife Sanctuary, Consevation Area Series*, **59**:141–151.

Kojima JI, Lambert K, Nguyen LT, and Saito F. 2007. Taxonomic notes on the paper wasps of the genus Ropalidia in the Indian subcontinent (Hymenoptera:Vespidae). *Entomol. Sci.* **10**(4):373–393. PMid: 32834727 PMCid: PMC7163502. https://doi.org/10.1111/j.1479-8298.2007.00237.x

Koshy J. 2020, July 16. India's population may peak by 2047. *The Hindu*. Retrieved from https://www.thehindu.com/news/national/lancet-study-predicts-earlier-peak-for-indian-population/article32095120.ece

Latham RE, and Ricklefs RE. 1993. Global patterns of tree species richness in moist forests: Energy-diversity theory does not account for variation in species richness. *Oikos*. **67**:325–333. https://doi.org/10.2307/3545479

Lawton JH, Bignell DE, Bolton B, Bloemers GF, Eggleton P, Hammond PM, Hodda M, Holt RD, Larsen TB, Mawdsley NA, Stork NE, Srivastava DS, and Watt AD. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature*. **391**(6662):72–76. https://doi.org/10.1038/34166

Magurran EA. 1988. Ecological diversity and its measurement. Croom Helm, Australia, 215 pp. https://doi.org/10.1007/978-94-015-7358-0

Margalef R. 1958. Temporal succession and spatial heterogeneity in phytoplankton, pp. 323-347. In: *Perspectives in Marine Biology*. University of California Press, Berkeley. https://doi.org/10.1525/9780520350281-024

Maruthadurai R, and Singh NP. 2017. A report on occurrence of aphidophagous predators of *Aphis odinae* (van der Goot) (Hemiptera:Aphididae) in cashew ecosystem from Goa, India. *J. Threat. Taxa.* **9**(2):9858–9861. http://doi.org/10.11609/jott.2435.9.2.9858-9861

Mathew G, and Mohanadas K. 2001. Insect fauna of the Shola forests of Munnar and Wynad. (KFRI Research Report No. 206). Kerala Forest Research Institute. http://docs.kfri.res.in/kfri-rr/kfri-rr206.pdf

Mathew G, Shamsudeen RSM, and Chandran R. 2005 Insect fauna of Peechi-vazhani wild life sanctuary, Kerala, India. *Zoos Print J.* **20**(8):1955–1960. https://doi.org/10.11609/JoTT.ZPJ.1280.1955-60

Pandit R, and Dharwadkar M. 2020. Preliminary checklist of spider fauna (Araneae:Arachnida) of Chandranath Hill, Goa, India. *J. Threat. Taxa*. **12**(11):16597–16606. https://doi.org/10.11609/jott.6096.12.11.16597-16606

Pannure A, Belavadi VV, and Carpenter JM. 2016. Taxonomic studies on potter wasps (Hymenoptera:Vespidae:Eum eninae) of south India. *Zootaxa*. **4171**(1):1–50. PMid: 27701247. https://doi.org/10.11646/zootaxa.4171.1.1

Picanco MC, de Oliveira IR, Rosado JF, da Silva FM, da Costa Gontijo P, and da Silva RS. 2010. Natural biological control of Ascia monuste by the Social Wasp Polybia ignobilis (Hymenoptera:Vespidae). *Sociobiology*. **56**(1):67–76.

Pielou EC. 1966. The measurement of diversity in different types of biological collections. *J. Theor. Biol.* **13**:131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Rangnekar P, and Dharwadkar O. 2009. Three additions to the known butterfly (Lepidoptera:Rhopalocera and Grypocera) fauna of Goa, India. *J. Threat. Taxa.* **1**(5):298–299. https://doi.org/10.11609/JoTT.o2140.298-9

Rangnekar P, and Naik R. 2014. Further additions to the Odonata (Insecta) fauna of Goa, India. *J. Threat. Taxa*. **6**(3):5585–5589. https://doi.org/10.11609/JoTT.o3641.5585-9

Rangnekar P, Borkar M, and Dharwadkar O. 2010. Additions to the Odonata (Insecta) of Goa. *J. Threat. Taxa*. **2**(4):805–814. https://doi.org/10.11609/JoTT.o2286.805-14

Santos BD. 1996. Ocorrência de vespídeos sociais (Hymenoptera:Vespidae) em pomar em Goiânia, Goiás, Brasil. *Agrárias*. **15**(1):43–46.

Shannon CE, and W Wiener. 1949. The Mathematical Theory of Communication. Urbana, University of Illinois Press, 177 pp.

Silva NJ, Morais TA, Santos-Prezoto HH, and Prezoto F. 2013. Inventário Rápido de Vespas Sociais em Três Ambientes com Diferentes Vegetações. *EntomoBrasilis.* **6**(2):146–149. https://doi.org/10.12741/ebrasilis.v6i2.303

Simpson EH. 1949. Measurement of species diversity. *Nature*. **163:**688. https://doi.org/10.1038/163688a0

Somavilla A, Schoeninger K, Castro DGD, Oliveira ML, and Krug C. 2016. Diversity of wasps (Hymenoptera:Vespidae) in conventional and organic

guarana (*Paullinia cupana* var. sorbilis) crops in the Brazilian Amazon. *Sociobiology*. **63**(4):1051–1057. https://doi.org/10.13102/sociobiology.v63i4.1178

Souza AR, Venâncio DFA, Zanuncio JC, and Prezoto F. 2011. Sampling methods for assessing social wasps species diversity in a eucalyptus plantation. *J. Econ. Entomol.* **104**(3):1120–1123. PMid: 21735938. https://doi.org/10.1603/EC11060

Veena MN, Shwetha S, Raju L, Vaibhav PU, Dheeraj KV, and Biradar PM. 2018. Survey of hymenopteran diversity in Karnatak University Campus, Dharwad (Karnataka) India. *J. Entomol. Zool. Stud.* **6**(5):1011–1014.

Vyjayandi MC, Rajeesh RS, Sajin John P, and Dhanasree MM. 2010. On a collection of praying mantids (Insecta:Mantodea) from Goa, India, with new distribution records. *J. Threat. Taxa*. 2(12):1325–1329. https://doi.org/10.11609/JoTT.o2188.1325-9