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Bio-ecology of Asian giant honeybee, *Apis dorsata* F. (Hymenoptera: Apidae) at arid, semi-arid and regions of South-Western Karnataka, India

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Abstract

India is one of the honey hubs, where large quantity of multifloral honey comes from the wild colonies of Asian giant honeybee, *Apis dorsata* Fabricius. Being an open nester, *A. dorsata* construct big sized comb and thrive well under diversified ecosystems by extending pollination services to various plant species. However, during its stay at arid, semi-arid and malnad regions, experiencing hardships while availing ecological and biological factors at its nesting site. Reports are scanty and that show less attention compared to domestic species like *A. cerana* and *A. mellifera*. Therefore, investigations were made during 2010-12 by following various standard methods to reveal bio-ecology of *A. dorsata* at various regions of south-western Karnataka, India. Information on colony density, abundance, hive products potential, various nesting parameters, floral source, natural and man-made intereferences on the survival of *A. dorsata* were collected. *A. dorsata* thriving well by nesting single or multiples of variously sized colonies on several tree species including on human built structures at specific elevation with unique comb architecture. To avail continuous floral source during different seasons, *A. dorsata* exhibited ubiquitous nesting behaviour at different regions, but there existed a significant variation and did indicated the region specific nesting activity and hive products potential. Despite its ubiquitous nesting behaviour, predators, enemies, pests and human intrusions have made *A. dorsata* to face problems during its survival at various regions. However, suitable bio-ecological conditions that favour *A. dorsata* to thrive well under arboreal conditions in the wild are discussed to a greater length in this presentation.

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Introduction

In India, Asian giant honeybee, *Apis dorsata* Fabricius (Hymenoptera: Apidae) is one of the major pollinators, producing multifloral honey at various agro-ecosystems. It contributes lion share to the overall honey production in India (Bradbear and Reddy, 1998). In Karnataka, it is locally called 'Hejjenu' and is known as a large feral insect. It establishes big-sized colonies at diversified ecosystems such as farm lands, forests and human inhabited ecosystems (Basavarajappa and Raghunandan, 2013). Although reports are available on *A.dorsata* hive products (ex. Honey and beeswax) at certain regions of Karnataka, information on bio-ecology, human associated disturbances along with pests, predators and enemies problems for hive products are sparse at south-western Karnataka. Further, it is a migratory species, move from one place to another during different seasons to seek suitable habitat. Under such conditions, estimating its hive products potential is rather difficult, but it required for human advantage. Being one of the largest bees in the genus *Apis* (Oldroyd *et al.,* 2000), *A. dorsata* comb aggregations on tree species and human built structures at higher elevations are not properly explored for their proper usage.

In Karnataka honey is harvested from *A. dorsata* colonies by conventional methods (Setty and Bawa, 2002), honey hunters give least importance for hygienic honey production. Further, scientific data on comb parameters are not available. Reports are available on predators, parasites, pests which cause severe damage to *A. dorsata* colonies at different parts of India (Abrol, 2003; Nagaraja and Rajagopal, 2011; Morse and Laigo, 1969). However, there is a lacuna of information on such type of data in this part of the state. Therefore, it is presumed that, bio-ecology of *A. dorsata* is essential to quantify its hive products. This has impelled us to conduct the present study by following multifaceted approach and the results of such investigations are presented in this paper.

Materials and methods

Systematic field survey was conducted during 2008 to 2011 by selecting three districts namely: Chamarajanagar, Mysore and Kodagu, which lies in between 11° 92′ to 12° 52′ N latitude and 72° 22′ to 76° 95′ E longitude at an elevation of more than 867.33 meter above msl. Since, these districts located amidst the vicinity of southern parts of Western Ghats, covered by rich floral source (Kamath, 2001). In each district, one taluk was selected based on the prevailed climate respectively arid, semi-arid and malnad at south-western Karnataka (Fig. 1). The physiographic and meteorological details of the study area are depicted in Table 1. During field study, pre-tested questionnaire was prepared by including various colony parameters namely: normal colonies at various habitats during different seasons, colony density, abundance, colony aggregates, comb morphology, hive products (ex. Honey and beeswax) potential, nest host tree species, nests at human built structures (HBS), nesting elevation, floral source, possible causes stressing on the survival of *A. dorsata* were considered.

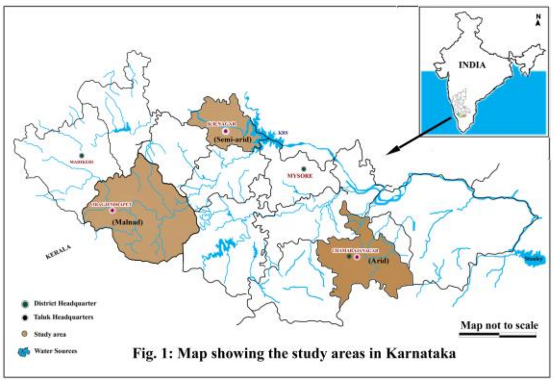

Fig. 1. Map showing the study area in Karnataka.

Table 1. Physiographic and Ecological details of different regions of south-western Karnataka.

Sl. No.	Region	Physiographic details			Ecological factors			Climate	Major crops grown
		Longitude	Latitude	Elevation in ft (Height in above msl)	Temp (^{o} C) (Min – Max)	RH (%) (Min – Max)	Average Rainfall (in mm)		
1.	Arid	$11^{0}\,40^{1}\,22^{11}$ to $12^{0}\,01^{1}\,37^{11}$	$76^{0}\ 43^{1}\,49^{11}$ to $77^{0}\,01^{1}\,99^{11}$	2533	11.5^{o} - 36^{o}	44 – 75.5	731.80	Located in Southern dry zone, experience hot summer and cold and dry winter and considered as drought-prone area (Siddalingamurthy *et al.*, 2012)	Paddy, Ragi, Jower, Bajra, Maize, Gram, Tur, Groundnut, Sun flower, Sugarcane, Tobacco and Cotton
2.	Semi-arid	$12^{0}\,23^{1}\,29.02^{11}$ to $12^{0}\,39^{1}\ 06^{11}$	$76^{0}\,30^{1}\,23^{11}$ to $76^{0}\,30^{1}\,23^{11}$	2648	14.3^{o} –34.8^{o}	29-83	748.70	Semi-Malnad type, Climate is congenial, Cauvery river drain some parts of this region.	Coconut Paddy, Ragi, Maize, Jowar, Pulses, Tobbaco and Sugarcane
3.	Malnad	$12^{0}\,02^{1}\ 44.21^{11}$ to $12^{0}\,25^{1}\ 27.96^{11}$	$75^{0}\,44^{1}\,19.92^{11}$ to $76^{0}\,08^{1}\,00.04^{11}$	3112	10.6^{o} –29.7^{o}	39 – 81	872.8	Malnad type, experiences very high rainfall. Region is with valleys, streams, several tributaries and bestowed with rich forest vegetation.	Coffee, Rubber, Cashew, Coconut, Arecanut, Palm, Ginger, Cardamom, Banana, Orange, Chilly, Paddy and Maize

Source: India Meteorological Station, Bangalore, Google Earth and Kamath (2011).

Colony Density and Abundance

Agricultural ecosystems, human inhabited places were periodically visited during different seasons to collect information on the normal colony density, abundance on different trees and HBS and calculated normal colony density = Total no. of normal colonies recorded/total no. of study sites visited to record the normal colonies. The normal colony abundance = Total no. of normal colonies recorded/ number of study sites where normal colonies observed by using Phillips (1959) formulae.

Nesting Parameters

The nesting elevation was measured as per Krishnamurthy (2001). To record the comb aggregates, 25 sampling sites were randomly selected in each region and in each sampling site, various nest host trees located at garden, cultivable land, on either sides of the road and various HBS were observed from a distance of 25 to 50 m (Woyke, 2008). As comb aggregations were confined to few tree limbs, on some parts of HBS, only five square meter imaginary area was considered and photographed. Number of colonies was counted by using adobe software version CS3 and digital video camera with 16X Optical Zoom and recorded noteworthy variations (ex. shape of comb, size, comb length, width, cell depth, cell area and honey storing capacity in honey chamber and brood chamber) from the normal colonies (Vinutha, 1998; Sukla and Upadhya, 2007).

Hive products estimation

The weight of abandoned comb was taken before boiling it in water at 60°C. After boiling, the molten wax was filtered, smeared on silver plate and again the weight of dried wax was taken (Bogdanov, 2004 and Timande and Tembhare, 2010). Similarly, multifloral honey estimation has been carried out as per the standard methods (Basavarajappa and Raghunandan, 2013).

Nest host trees and floral source

Nest host trees were observed at 15 sampling sites both by naked eyes and using a binocular (10 × 50X) by selecting one kilometer length Variable Width Line Transects (VWLTs) (Burnham *et al.,* 1980). The trees were photographed with the help of Canon-Power Shot S21S, 8.0 Mega Pixels Digital Camera with 12X Optical Zoom. Images were identified by using both photographic pictures and with the help of information given by Gamble (1967). The foraging plants were further grouped into various types so as to reveal their percent occurrence (Rao, 1973).

Natural and Man-made interference

The predators or enemies, pests were recorded at the vicinity of *A. dorsata* colonies as per Abrol (2003), Nagaraja and Rajagopal (2011). Total 15 VWLT's were selected, predators and pests were identified by following standard methods as described by Abrol (2003), Nagaraja and Rajagopal (2011), Hepburn and Radloff (2011). As the vegetation distribution was not uniform at different regions of south-western Karnataka, an all out search method (AOSM) was also adopted during the field survey.

The collected data was analyzed with the help of SPSS (ver.12.0, Chicago, Inc. USA) and MS-EXCEL

Result

Normal colony Distribution

Normal colony distribution at arid, semi-arid and malnad regions of south-western Karnataka is predicted in Table 2. Figure 2 shows the per cent occurrence of *A. dorsata* colonies at different regions of south-western Karnataka. In general, *A. dorsata* preferred trees more for its nesting compared on to human built structures. Highest (856) colonies were observed on the tree limbs, whereas, only 104 colonies were seen on human built structures (HBS). Trees of malnad region hosted highest number of colonies (568) compared to semi-arid and arid region. However, arid region recorded highest (80) colonies on HBS compared to semi-arid and malnad regions where, it was less than 20 colonies. Interestingly, there was no significant variation existed between the regions and on the on the nesting sites (Table 2). Figure 3 shows the occurrence of *A. dorsata* colonies on trees and HBS at different regions of Karnataka. Further, distribution of *A. dorsata* normal colonies on the eaves of tree limbs and on HBS during rainy, winter and summer seasons is shown in Table 3. On an average 66.7 ± 48.6 normal colonies were recorded on trees during summer and it was less (8.3 ± 10.2) at HBS. It was followed by rainy season both on tree and HBS respectively 42.7 ± 49.7 and 7.0 ± 7.0 (Table 2). However, normal colonies were comparatively less during winter both on trees and HBS. Figure 2 and 3 shows the per cent occurrence of *A. dorsata* colonies at different regions on trees and HBS. Interestingly, there was no significant variation existed between the seasons and the regions (Table 3).

Table 2. *Apis dorsata* colony distribution at different geographical regions.

Sl. No.	Region	Colonies on Trees	HBS	Total	'F' value
1.	Arid	100	80	180	0.4014
2.	Semi-arid	195	17	212	
3.	Malnad	561	07	568	
	Total	856	104	960	
	Mean ± SD	285.3 ± 243.4	34.7 ± 39.6	-	-
	'F' value	3.099			

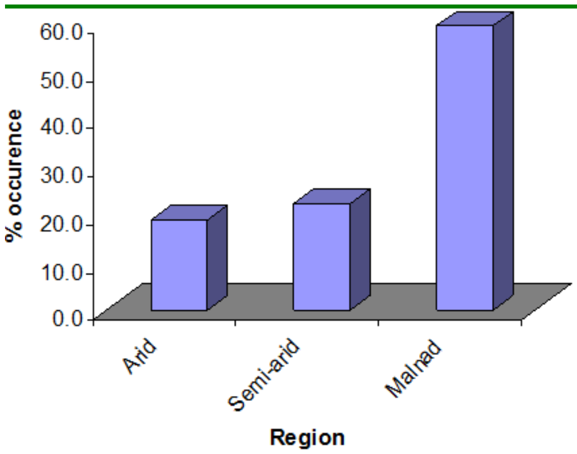

Fig. 2. Occurrence of *Apis dorsata* colonies at different regions.

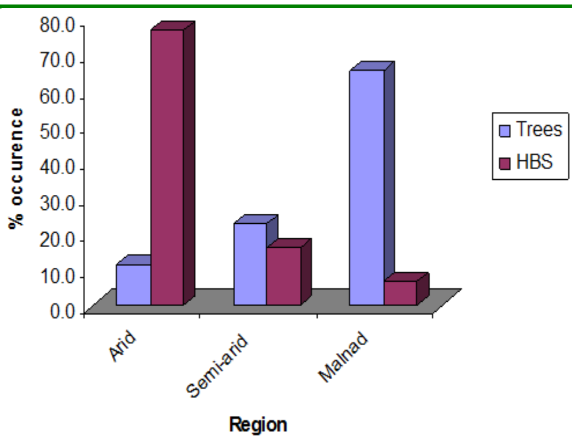

Fig. 3. Occurrence of *Apis dorsata* colonies on Trees and HBS at different regions.

Table 3. Distribution of *Apis dorsata* colonies during different seasons.

Sl. No.	Region	*Apis dorsata* colonies on the eaves of tree limb during: Rainy	Winter	Summer	Human built structures during: Rainy	Winter	Summer
1.	Arid	16	10	25	15	06	20
2.	Semi-arid	100	62	120	02	02	01
3.	Malnad	12	31	55	04	02	04
	Mean ± SD	42.7 ± 49.7	34.3 ± 26.2	66.7 ± 48.6	7.00 ± 7.00	3.00 ± 2.3	8.3 ± 10.2
	'F' value	0.460NS			0.380NS		

Nest host trees and Human built structures

Nest host plants and nests on human built structures are given in Table 4. About eight tree species belong to six families were opted by *A. dorsata* to establish single colony and colony aggregates. Total eight trees which belong to six families have hosted *A.dorsata* colonies. Further, colonies were recorded on seven different Human built structures. Total 856 colonies with a mean 106.12 ± 129.11 on trees and 104 colonies with a mean of 13.12 ± 17.53 on human built structures were recorded and there existed a significant difference (F=4.075; P>0.01) between nesting sites offered by *A. dorsata* in Karnataka (Table 4). Figure 4 shows the per cent occurrence of

A. dorsata colonies on different nesting sites in Karanataka. Consistent with the observations of Sahebzadeh *et al.* (2012), *A. dorsata* solitary nests and aggregations were recorded on specific trees that were later called 'Bee Trees' selected often for nesting. Presumably, *A. dorsata* use certain criteria to select a specific site for nesting that should bear the weight of nest, free from predators/enemies. The single or numerous colonies can settle safely on preferred sites at different elevations which become suitable nesting niche to sustain the colony structure. Similar type of observations was made by Sahebzadeh *et al.* (2012).

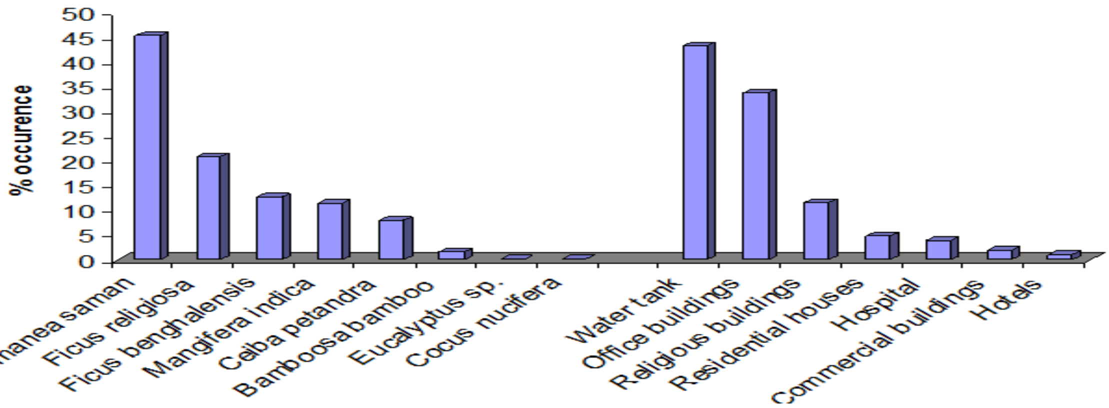

Fig. 4. *Apis dorsata* live colonies recorded at varioustree species and human built structures.

Table 4. *Apis dorsata* colonies recorded on trees and human built structures.

Sl. No.	*Apis dorsata* normal colonies recorded on					
	Trees				Human Built Structures	
	Family	Common Name	Scientific name	No. of colonies	Type of structure	No. of colonies
1.	Mimosaceae	Rain tree	*Samanea saman*	388	Water Tank	45
2.	Moraceae	Aralimara	*Ficus religiosa*	178	Office Buildings	35
		Banyan tree	*Ficus benghalensis*	109	Religious Buildings	12
3.	Anacardiaceae	Mango tree	*Mangifera indica*	98	Residential House	05
4.	Bombaceae	Silk cotton tree	*Ceiba petandra*	68	Hospital	04
					Commercial Building	02
		Bamboo tree	*Bamboosa bamboo*	13	Hotels	01
5.	Myrtaceae	Neelgiri	*Eucalyptus* sp.	01		
6.	Palmaceae	Coconut tree	*Cocus nucifera*	01		
		Total		856	-	104
		Mean ± SD		107.00 ± 129.24	Mean ± SD	13.12 ± 17.53
		'F' value			4.075	

Note: Each value is a total of 25 observations; P-value = 0.06309; Fcrit = 4.60011

Density and Abundance

The colony density on trees and HBS was 9.48 and 1.26 respectively. The colony abundance was 11.23 and 1.59 respectively on trees and HBS and showed considerable variation at different nesting sites in Karnataka (Table 5). Further, the density and abundance were high 18.7 and 21.04 on trees at semi-arid region compared to arid and malnad regions (Table 5). However, arid region showed highest record of colony density and abundance respectively 2.67 and 3.76 on HBS than that of semi-arid and malnad regions of Karnataka (Table 5). In general, colony density was high during summer, winter and rainy at semi-arid regions respectievely 24.1, 19.8 and 12.2 on tree limbs compared to arid and malnad regions (Table 6). However, the colony density was more during rainy, winter and summer seasons on human built structures at arid, semi-arid and malnad regions. Further, the colony abundance showed similar trend during various seasons at different regions of Karanataka. Thus, colony density and abundance fluctuated much during different seasons at arid, semi-arid and malnad regions (Table 6).

Table 5. Density and Abundance of *Apis dorsata* colonies.

Sl. No.	Region	Nest site	Colony		Mean
			Density	Abundance	
1.	Arid	Tree	3.26	4.66	Density on
		HBS	2.67	3.76	i. Tree : 9.48
2.	Semi-arid	Trees	18.7	21.04	ii. HBS : 1.26
		HBS	0.23	0.30	Abundance at
3.	Malnad	Trees	6.50	8.00	i. Trees : 11.23
					ii. HBS : 1.59
		HBS	0.90	0.71	

Table 6. Density and abundance of *Apis dorsata* colonies during different seasons.

Sl. No.	Colony	Region	*Apis dorsata* colonies on					
			The eaves of tree limb during			Human built structures during		
			Rainy	Winter	Summer	Rainy	Winter	Summer
1.	Density	Arid	3.10	2.00	4.70	2.90	1.20	3.90
		Semi-arid	19.80	12.20	24.10	0.30	0.30	0.10
		Malnad	2.30	6.50	10.70	1.70	0.30	0.70
2.	Abundance	Arid	5.15	2.70	6.12	4.83	1.71	4.75
		Semi-arid	19.80	13.20	30.12	0.40	0.38	0.13
		Malnad	3.33	8.12	12.60	1.04	0.38	0.70

Pearson's correlation for ecological factors and distribution of normal colonies of *A. dorsata* is depicted in Table 7. Excepting RH, the temperature and rainfall showed positive correlation with the number of colonies built by *A. dorsata* on the eaves of tree limbs at arid region and semi-arid regions. However, at malnad region, there was no positive correlation established between *A.dorsata* colonies and different ecological factors. Further at HBS, excepting RH at semi-arid region and temperature and rainfall at malnad region, normal colonies showed negative correlation with most of the ecological factors (Table 7). Thus, temperature, relative humidity and rainfall had varied influence on

A. dorsata during its colony establishment on the eaves of trees and human built structures at different regions of Karnataka.

Table 7. Pearson's correlation for ecological factors and *Apis dorsata* normal colonies.

Sl. No.	Region	No. of colonies on		Ecological factor	'r' value	
		Tree	HBS		Tree	HBS
1.	Arid	100	80	11.5 - 36° C. Temp.	0.659	-0.245
				44 – 75.5% RH	-0.177	-0.591
				731.80 mm Rainfall	0.397	-0.869
2.	Semi-arid	195	17	14.3 – 34.8° C. Temp.	0.480	-0.405
				29 – 83% RH	-0.527	0.133
				748.70 mm Rainfall	0.456	-0.206
3.	Malnad	561	07	10.6 – 29.7° C. Temp.	-0.244	0.308
				39 – 81% RH	-0.812	-0.602
				872.8 mm Rainfall	-0.670	0.131

Colony aggregates

Number of colonies per aggregate and their distribution at arid, semi-arid and malnad regions of south-western Karnataka are given in Table 8. In general, colony aggregates were more (147) at semi-arid region compared to arid and malnad regions and there existed a significant variation (F=5.06; P>0.01) between the regions and the colony aggregates. Of all an aggregate with two colonies were more (82) compared to others. Further, aggregates with two, three, four, five, six and > six colonies and their distribution at different regions are shown in Table 8. Per cent occurrence of colony aggregates is shown in Fig. 5.

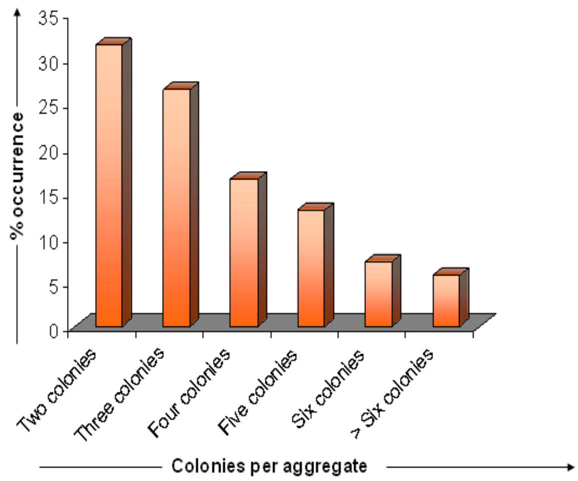

Fig. 5. Occurrence of *Apis dorsata* colony aggregates.

Table 8. *Apis dorsata* colony aggregates found at different regions.

Sl. No.	Aggregates	Region			Total
		Arid	Semi-arid	Malnad	
1.	Two colonies	27	38	17	82
2.	Three colonies	18	33	18	69
3.	Four colonies	8	26	9	43
4.	Five colonies	3	24	7	34
5.	Six colonies	1	13	5	19
6.	> Six colonies	0	13	2	15
	Total	57	147	58	960
	Mean ± SD	9.50 ± 10.82	24.50 ± 10.21	9.67 ± 6.50	-
	'F' value		5.0638S		

Colony Shape

There were five comb shapes namely 'U', 'V', 'Uneven' 'Cone', 'Round' recorded commonly. Among them 'U' shaped comb was most predominant (15.8%) and hence considered as typical comb shape of *A. dorsata* and compared other comb shapes with this. Table 9 shows the normal colony shape at arid, semi-arid and malnad regions of south-western Karnataka. Comparatively, cone and uneven shaped colonies were more almost same (152 to154) in occurrence than that of others. Five distinctly shaped colonies and their distribution varied considerably and indicated a significant variation (F=8.889; P>0.01) between different regions (Table 9). Further per cent occurrence of various comb shapes is shown in Figure 6.

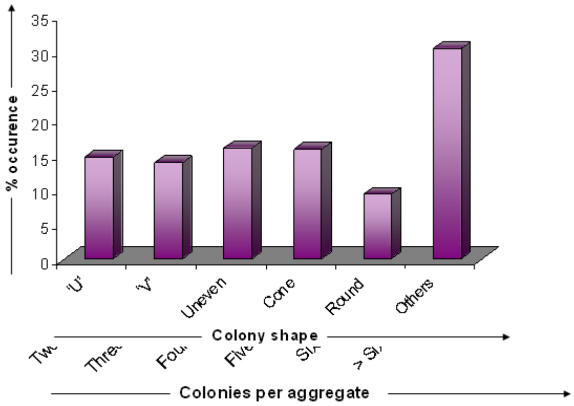

Fig. 6. Occurrence of different shaped *Apis dorsata* colonies.

Table 9. *Apis dorsata* colony shapes recorded at different regions.

Sl. No.	Shape	Region			Total
		Arid	Semi-arid	Malnad	
1.	'U'	27	99	15	141
2.	'V'	22	84	27	133
3.	Uneven	49	73	32	154
4.	Cone	34	103	15	152
5.	Round	9	42	38	89
6.	Others	39	167	85	291
	Total	180	568	212	960
	Mean ± SD	30.00 ± 13.94	94.67 ± 41.66	35.33 ± 26.01	-
	'F' Value		8.889S		

Colony size

A. dorsata built variously sized colonies and they were ranged between 0.5^2 to $>3^2$ ft (Table 10). Distribution of 0.5^2, 0.6 to 1^2, 1.1 to 2^2, 2.1 to 2.9^2, 3^2 and $>3^2$ feet sized colonies at arid, semi-arid and malnad regions indicated a significant variation (F=12.091; P>0.01) between the colony sizes and regions (Table 10 and Fig. 7). Among the colony sizes, 1.1 to 1.9^2 ft sized colonies were more (22.3%) followed by 1^2ft (19.5%) and 2^2 ft (15.5%) and 2.1 to 2.9^2 ft (11.7%). However, 0.5^2, 0.6 to 0.9^2, 3^2 and $>3^2$ ft sized colonies occurred less than 10% (Fig. 7). Thus, normal colonies size was not uniform, but varied significantly between and within arid, semi-arid and malnad regions of south-western Karnataka (Table 10 and Fig. 7).

Table 10. *Apis dorsata* colony size recorded at different regions.

Sl. No.	Size (ft)	Region			Total
		Arid	Semi-arid	Malnad	
1.	0.5^2	12	37	17	66
2.	$0.6 – 0.9^2$	19	52	21	92
3.	1^2	35	104	49	188
4.	$1.1 – 1.9^2$	43	129	42	214
5.	2^2	23	92	34	149
6.	$2.1 – 2.9^2$	25	63	24	112
7.	3^2	9	45	10	64
8.	$>3^2$	14	46	15	75
	Total	180	568	212	960
	Mean ± SD	22.50 ± 11.71	71.00 ± 33.33	26.50 ± 13.80	-
	'F' value		12.091S		

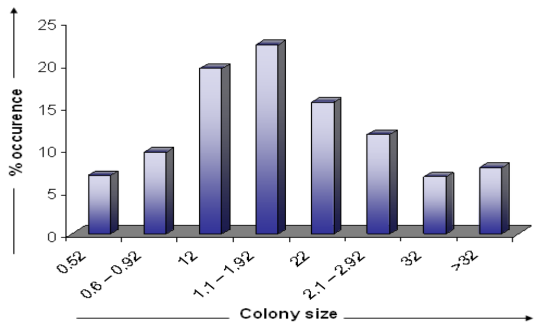

Fig. 7. Occurrence of different sized *Apis dorsata* colonies.

Elevation

Table 11 shows the different elevations selected for colony establishment by *A.dorsata* at arid, semi-arid and malnad regions of south-western Karnataka. Colonies were recorded from 10ft upto 70ft height at arid region whereas, colonies were found at 21ft and upto more than 70ft height at semi-arid region. However in malnad, colonies were seen from 10ft upto more than 70ft height at malnad regions. Further, 31-40ft height was found as an ideal elevation for *A. dorsata*, where highest (335) colonies were recorded. Different sized colonies and their per cent distribution is shown in Figure 8. The distribution of colonies at different elevations varied considerably and there existed a significant variation (F=3.875; P>0.01) between arid, semi-arid and malnad regions (Table 11).

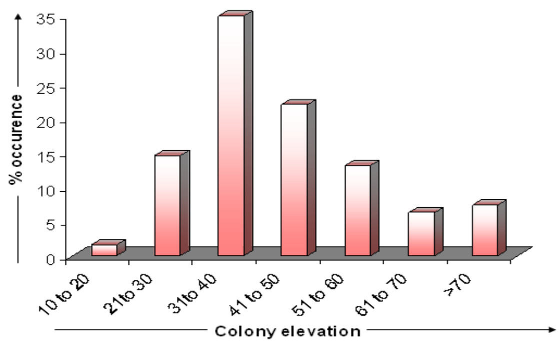

Fig. 8. Occurrence of *Apis dorsata* colonies at different elevations.

Orientation

Table 12 shows the orientation of *A.dorsata* colonies at different regions of south-western Karnataka. Highest numbers of normal colonies have shown east-west orientation at arid (63), semi-arid (194) and malnad (73) regions and it was followed by north-south orientation (Table 12). However, *A. dorsata* also built its colonies with northeast-southwest and southeast-northwest orientations. About 67 colonies did not show any specific direction and it was difficult to predict their orientation and hence put under others category. In general, east-west orientations were more preferred and it was followed by north-south orientations. Thus, the colony orientation differed significantly (F=5.727; P>0.01) at arid, semi-arid and malnad regions of south-western Karnataka (Table 12). Figure 9 shows the colony orientations and their per cent occurrence.

Table 11. *Apis dorsata* colonies recorded at different elevations.

Sl. No.	Elevation (ft)	Region			Total
		Arid	Semi-arid	Malnad	
1.	10-20	13	-	2	15
2.	21-30	55	58	27	140
3.	31-40	71	184	80	335
4.	41-50	25	126	60	211
5.	51-60	13	92	22	127
6.	61-70	3	50	8	61
7.	>70	-	58	13	71
	Total	180	568	212	960
	Mean	25.71	81.14	30.29	-
	±	±	±	±	
	SD	27.11	59.63	28.95	
	'F' value		3.875S		

Colony morphometrics

Morphometric data of brood comb, honey comb and pollen storing cells and their measurements are predicted in Table 13. In brood chamber, the worker cells with hexagonal shape had 1.73 ± 0.03 cm depth with 2.12 ± 0.07 cm area. The horizontal and vertical length of brood comb was 37.88 ± 8.51 and 23.61 ± 1.95 with 2.99 ± 1.95 comb width. However, the size of drone and queen cell size was slightly bigger than that of worker cells. Further, honey comb cells measured highest depth 2.05 ± 0.31 cm and 2.67 ± 0.05 cm area with 1.19 ± 0.32 ml honey storing capacity. But, the horizontal and vertical length of honey comb was less i.e., 15.41 ± 1.38 and 5.85 ± 1.04 compared to brood comb. Since, brood part of the comb is meant for developing young ones, need lot of space for developing more number of young ones and accordingly more space is confined to brood part. However, honey storing region is restricted to upper part of the comb and with varied thickness and it depends on age and population size in the colony. Perhaps, this may be the reason for lesser size of horizontal and vertical length at honey comb. However, the width was high (4.22 ± 0.13 cm) at honey storing part of the comb. Further, the pollen storing cells had 1.58 ± 0.0.07 cm depths and 2.78 ± 0.29 cm area with good amount 24.89 ± 5.88 gm pollen storage (Table 13).

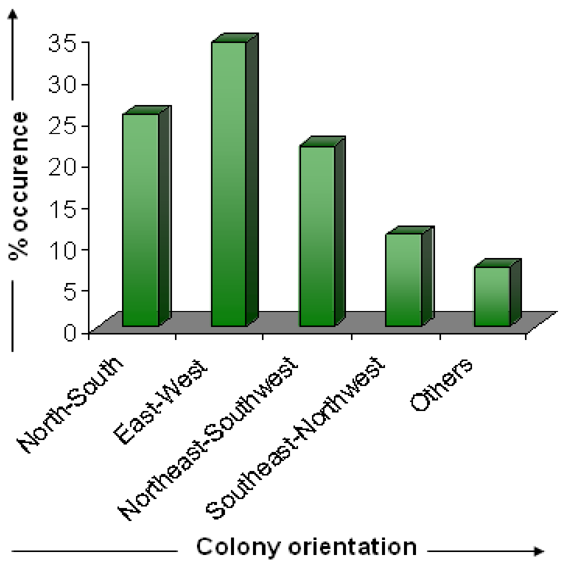

Fig. 9. *Apis dorsata* colony orientation.

Table 12. *Apis dorsata* colony orientation at different regions.

Sl. No.	Orientation	Region			Total
		Arid	Semi-arid	Malnad	
1.	North-South	44	144	58	246
2.	East-West	63	194	73	330
3.	Northeast-Southwest	45	121	44	210
4.	Southeast-Northwest	14	75	18	107
5.	Others	14	34	19	67
	Total	180	568	212	960
	Mean ± SD	36.00 ± 21.46	113.60 ± 61.78	42.40 ± 24.11	-
	'F' value		5.727S		

Table 13. Morphometric data of *Apis dorsata* colonies.

Sl. No.	Parameters	Brood comb			Honey comb	Pollen Storing cell
		Worker (n=100)	Drone (n=30	Queen (n=10)	(n=100)	(n = 100)
1.	Cell Depth (cm)	1.73 ± 0.03	1.85 ± 0.05	2.11 ± 0.31	2.05 ± 0.03	-
2.	Cell Area (cm)	2.12 ± 0.07	2.63 ± 0.04	2.02 ± 0.21	2.67 ± 0.05	-
3.	Horizontal Length (cm)	37.88 ± 8.51	-	0.57 ± 0.11	15.41 ± 1.38	-
4.	Vertical Length (cm)	23.61 ± 1.95	-	1.24 ± 0.31	5.85 ± 1.04	-
5.	Thickness (cm)	2.99 ± 0.10	3.41 ± 0.18	-	4.22 ± 0.13	-
6.	Width of 10 continuous cells (cm)	5.54 ± 0.05	5.82 ± 0.04	-	6.19 ± 0.07	-
7.	No. of cells / inch	24.35 ± 0.49	20.40 ± 0.52	-	-	-
8.	No. of cells / 10g	154.39 ± 0.50	146.9 ± 1.56	-	75.2 ± 6.89	-
9.	Honey storing capacity (ml)	-	-	-	1.19 ± 0.32	-
10.	Pollen storing capacity (g/cell)	-	-	-	-	24.89 ± 5.88
11.	Pollen cell depth (cm)	-	-	-	-	1.588 ± 0.073
12.	Pollen cell area (cm)	-	-	-	-	2.784 ± 0.294
13.	Abandoned comb weight (g)	588 ± 101.5	-	-	-	-
14.	Overall size of the comb (inch)	77.41 ± 20.71	-	-		-

Hive products

The hive products potentials of *A. dorsata* colonies are depicted in Table 14. On an average 2.380 ± 0.516 kg multifloral honey and 123.69 ± 20.810 gm beeswax are produced per colony of *A. dorsata*. Altogether 2,174.868 kg honey and 1,127.257 kg beeswax with a ratio 1:0.123 ± 0.021 was estimated from this part of the State. Further, multifloral honey and beeswax production at arid, semi-arid and malnad regions didn't show much variation and there was no significant difference between the regions (Table 14).

Table 14. Hive products potentials of *Apis dorsata*.

Sl. No.	Region	Honey Yield / colony (Kg)	Total Honey production (Kg)	Wax Yield / colony (g)	Total Wax production in (Kg)	Ratio (H : BW)
1.	Arid	2.974	535.32	116.97	21.056	1:0.116
2.	Semi-arid	2.043	433.116	107.08	22.700	1:0.107
3.	Malnad	2.124	1206.432	147.02	83.507	1: 0.147
	Total	7.141	2174.868	371.07	127.257	1 : 0.123
	Mean ± SD	2.380 ± 0.516	724.956 ± 420.090	123.69 ± 20.810	42.419 ± 35.591	± 0.021
	'F' value	1.799NS	-	2.668NS	-	-

Note: H= Honey; BW = Beeswax

Total 240 flowering plants which belong to 78 familes have extended foraging source to *A. dorsata* (Table 15). Among them, trees contributed highest (47.6%) and it was followed by shrubs and herbs (23% each). The climbers also extended floral source, but their per cent contribution was less (5.2) (Fig.10). Further, the existed forage source was further classified into economically important plants, medicinal plants, ornamental plants, fruit yielding plants and vegetables and their percent contribution is depicted in Fig 11. Classifying available flowering plants into various types is a common practice to understand the nectar and pollen potential (Fig. 12), this could help predict pollen calendar (Fig. 12) (Basavarajappa *et al.*, 2010). Since, *A. dorsata* is a voracious forager, visits several flowering plants to collect nectar and pollen. Altogether, 240 plants could bloom with characteristic apicultural values in terms of nectar, pollen and both nectar and pollen supply during different seasons and extended continuous flora source to *A. dorsata* at arid, semi-arid and malnad regions of south-western Karnataka. Similar type of observations was made by Rao (1973), Basavarajappa *et al.* (2010) at different habitats of Karnataka. The results agree with the explanation given by the aforementioned authors.

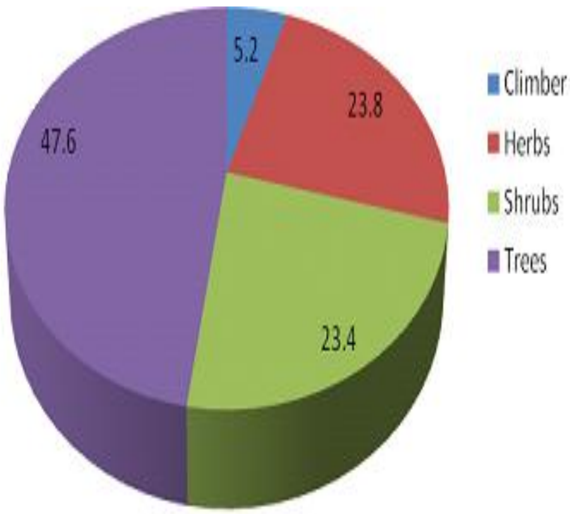

Fig. 10. *Apis dorsata* floral type.

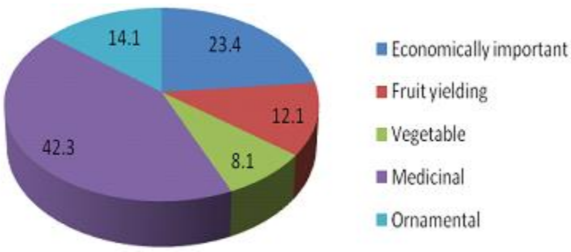

Fig. 11. Contribution of different flora to *Apis dorsata* population.

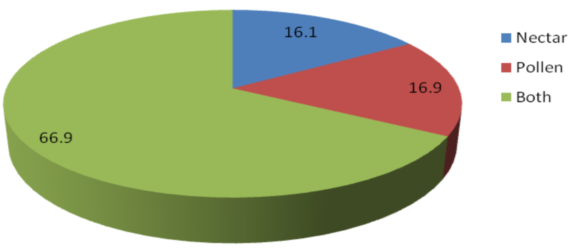

Fig. 12. Occurrence of Nectar and Pollen producing plants.

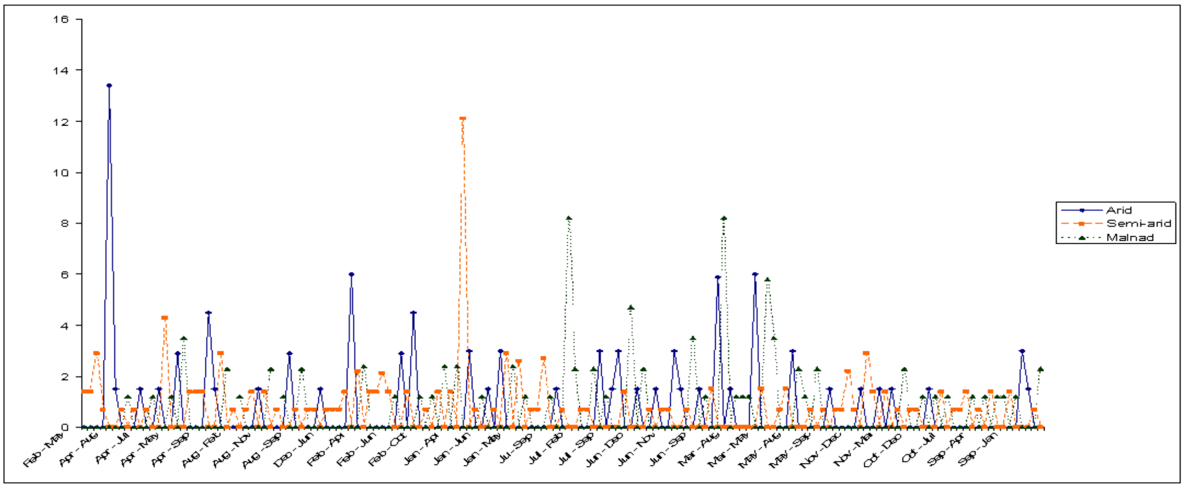

Fig. 13. Occurrence of bee forage for *Apis dorsata.*

Table 15. Foraging source to *Apis dorsata.*

Sl. No.	Family	Species	Per cent	Total Families	Per cent
1.	Alangiaceae, Basellaceae, Cacataceae, Caprifoliaceae Caricaceae, Casuarinaceae, Cleomaceae, Compositae, Datiscaceae, Dilleniaceae, Droseraceae, Elaeocarpaceae, Elatinaceae, Hydrocotylaceae, Icacinaceae, Lauraceae, Lecythidaceae, Leeaceae, Lophopetalaceae, Loranthaceae, Magnoliaceae, Melastonataceae, Menispermaceae, Molluginaceae, Musaceae, Nyctanthaceae, Ongraceae, Oxallidaceae, Palmae, Piperacae, Santalaceae, Smilaceae, Ulmaceae and Zingiberaceae	1 each	0.4	34	43.6
2.	Annonaceae, Bombaceae, Brassicaceae, Burseraceae, Celasteraceae, Ebenaceae, Lythraceae, Periplopace, Poaceae, Portulaceae, Sapindaceae, Sapotaceae, Scrophulariaceae, Violaceae and Vitaceae	2 each	0.8	15	19.2
3.	Araceae, Balsaminaceae, Clusiaceae, Covoluvulceae, Dipterocarpacae, Flacourtiaceae, Nycteginaceae and Sterculaceae	3 each	1.3	8	10.3
4.	Acanthaceae, Amaranthaceae, Bignoniaceae, Combretaceae and Lamiaceae	4 each	1.7	5	6.4
5.	Meliaceae, Papilionaceae, Rubiaceae and Solanaceae	5 each	2.1	4	5.1
6.	Anacardiaceae	6 each	2.5	1	1.3
7.	Myrtaceae and Verbenaceae	7 each	2.9	2	2.6
8.	Asteraceae	8 each	3.3	1	1.3
9.	Malvaceae, Moraceae and Fabaceae	9 each	3.8	3	3.8
10.	Cucurbitaceae and Euphorbiaceae	10 each	4.2	2	2.6
11.	Caesalpinaceae and Rutaceae	11 each	4.6	2	2.6
12.	Mimosaceae	15	6.3	1	1.2
	Total families :78	240	33.9	78	100

Table 16. Man-made interferences on *Apis dorsata* colonies.

Sl. No.	Human intrusions	% occurrence
1.	Trimming of tree limbs	6.5
2.	Normal colonies hunting	3.5
3.	Normal colonies burning	2.5
4.	Clearing / clearing of garden in croplands	1.2
5.	Clearing of colonies	2.3
	Total	15.0

Natural and man-made intereferences

Although, combs of *A. dorsata* in the wild are free for frequent hunting, various biological agents and man-made activities interfere with its normal survival. Possible causes stressing on the survival of *A. dorsata* population are depicted in Tables 16, 17 and 18. The commonly occurring constraints of *A. dorsata* are pests (33.3%), predators/enemies (7.7%) and human intrusion (3%) (Fig.14). The commonly occurring man-made activities namely trimming of tree limbs (6.5%), colony hunting (3.5%), colonies burning (2.5%) and clearing of tree limbs, fronds, weeding in croplands (1.2%) and clearing of colonies (2.3%) have affected the population of *A. dorsata* at its habitat (Table 16). Further, intereferences of predators such as insects (*Ropalidia* sp. and *Vespa cincta*), birds (*Merops orientalis*, *Columba livia*, *Dicrurus adsimilis*, *Acridotheres tristis*, *A. fuscus*, *Muscicapa para*, *Corvus splendens* and *Ocyceros birostris*) and mammals (*Ratufa* sp. and *Pteropus* sp.) have enhanced created sever stress at nesting habitats (Table 17) and caused declined 7.7% of *A. dorsata* colonies (Fig. 15). Perhaps, this might stimulate the considerable decline of *A. dorsata* colonies in this part of the state. Since, these predators are major trouble shooters, their frequent appearance at/or nearby the colonies would interfere with the working efficiency of foraging worker bees and become nuisance to the colony members. This could alter the working efficiency of forager bees and hive bees and finally results disintegration of the colony. The greater wax moth, *G. mellonella* commonly infests weak colonies found on the tree limbs and HBS. Occurrences of wax moth, *G. mellonella* infestation during different seasons and at various regions are predicted in Table 18. Further, *A. dorsata* cover larger area (ex. 102 km) to gather good amount of nectar and pollen to supplement its huge colony population. During foraging, various several hundreds of forager bees become victims to predators. Moreover, hive bees along with developing brood also become victim to certain birds and mammals (Table 17) and ultimately this could cause colony decline (Bright *et al.*, 1998).

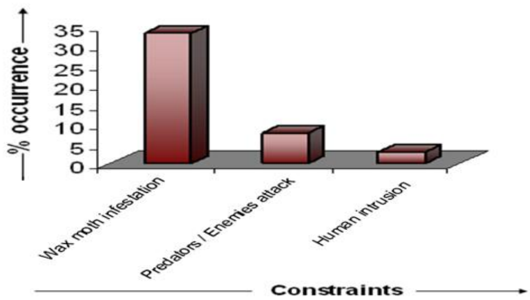

Fig. 14. Natural and Man-made interferences on the survival of *Apis dorsata*.

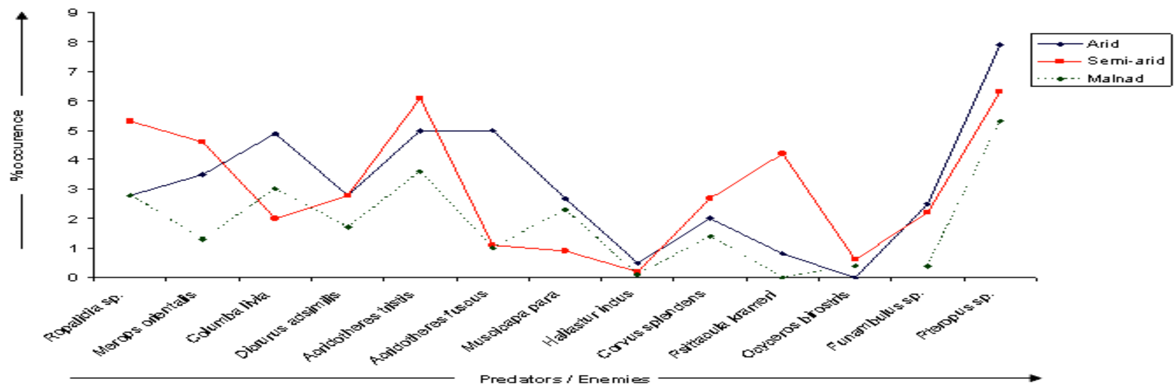

Fig. 15. Per cent occurrence of predators and enemies on *Apis dorsata* colonies at different regions.

Table 17. Interference of predators and enemies on *Apis dorsata* colonies.

Animal Group		Predators / Enemies				Region		
						Arid	Semi arid	Malnad
		Order	Family	Common Name	Scientific Name			
Insect	1.	Hymenoptera	Vespidae	Mud Wasp	*Ropalidia* sp.	44	84	45
Bird	2.	Coraciformes	Meropidae	Green Bee eater	*Merops orientalis*	55	72	21
	3.	Columbiformes	Columbidae	Blue rock pigeon	*Columba livia*	78	31	5
	4.	Passeriformes	Dicruridae	Black Drango	*Dicrurus adsimilis*	44	45	27
	5.	Passeriformes	Sturnidae	Common Myna	*Acridotheres tristis*	79	96	57
	6.	Passeriformes	Sturnidae	Jungle Myna	*Acridotheres fuscus*	79	18	16
	7.	Passeriformes	Musicapidae	Fly Catcher	*Muscicapa para*	43	14	36
	8.	Accipitriformes	Accipitridae	Honey Buzzard	*Halistus indus*	7	3	2
	9.	Passeriformes	Corvidae	Common Crow	*Corvus splendens*	31	42	22
	10.	Psittaciformes	Psittacidae	Parrot	*Psittacula krameri*	12	66	0
	11.	Coraciformes	Bucerotidae	Grey hornbill	*Ocyceros birostris*	0	9	6
Mammal	12.	Rodentia	Sciuridae	Squirrel	*Ratufa* sp.	40	34	6
	13.	Chiroptera	Pteropdidae	Flying Fox	*Pteropus* sp.	126	101	84
			Total			638	615	327
			Mean ± SD			53.17 ± 33.06	47.31 ± 33.56	27.25 ± 24.73
			'F' value			2.34NS		

Table 18. Wax moth infestation to *Apis dorsata* colonies during different seasons.

Sl. No.	Region	Season			'F' value
		Rainy	Winter	Summer	
1.	Arid	20	12	32	
2.	Semi-arid	73	48	96	8.700S
3.	Malnad	9	22	37	
	Total	102	82	165	
	Mean ± SD	34 ± 34.22	27.33 ± 18.58	55 ± 35.59	-
	'F' value	0.675NS			

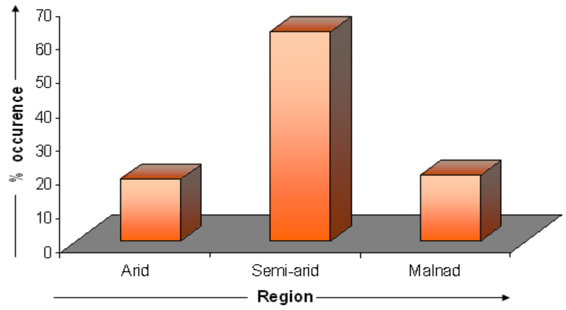

Fig. 16. Occurrence of Wax moth infestation to *Apis dorsata* colonies.

Discussion

A. dorsata normal colonies were recorded highest (568) in malnad region followed by semi-arid and arid regions respectively 212 and 180 colonies (Table 2). The colony distribution didn't show significant variation between various seasons (Table 3). Further, *A. dorsata* selected eight tree species, seven human built structures to build 856 and 104 colonies respectively at various regions of south-western Karnataka (Table 4). *A. dorsata* use certain strategies while nesting, select suitable site that should bear the weight, provide good source of physical factors (ex. Sun light, moderate air flow and good flight path) and it should be free from predators and enemies attack. Perhaps, all the eight tree species and seven HBS might have provided suitable nesting niche to establish single or numerous colonies on the eaves of tree limbs and different faces of HBS at various elevations. The results agree with the explanation given by Sahebzadeh *et al.* (2012). The colony density and abundance varied considerably among these regions and seasons (Tables 5 and 6). In general, summer scored highest colonies followed by rainy (807) and winter seasons (Table 3). During summer, the climate is characterized by moderate temperature and humidity with good floral source at many cultivable lands in arid, semi-arid and malnad regions. However, during rainy and winter seasons, the temperature and relative humidity varied considerably along with variable rainfall and this might have discouraged the even distribution of foraging source. Perhaps during these seasons, *A. dorsata* might have undergone migration in search of suitable nest sites and forage. Hence, colonies were less during rainy and winter seasons. Further, Pearson's correlation revealed the influence of ecological factors on the distribution of *A. dorsata* colonies (Table 7). Further, semi-arid region experiences moderate climate and normal floral source due to good water source available at many cultivable lands along with tall ramified trees for nesting. While arid region experiences dry climate, water ways are scanty and accordingly floral source was not good. However, malnad region possess good forest coverage with congenial climate and many streams, canals and rivers provide good water source for the luxuriant growth of diversified flowering plants during major part of the year. Despite all these congenial conditions, tall and long branched tree limbs are not ideal for nesting due to thickly covered epiphytic vegetation during most of the seasons at malnad. Perhaps, these features might have interfered with the even distribution of *A. dorsata* colonies at various regions of south-western Karnataka. Our observations are in conformity with the observations of Dyer and Seeley (1994), Thapa *et al.* (2000) and Shrestha *et al.* (2002).

A. dorsata established its colonies on the eaves of trees and HBS during different seasons (Table 6). Solitary colonies and colony aggregates are common on many tall trees with broad limbs and on HBS amidst various regions (Table 8). Because, they possess dry and wet conditions amidst cultivable lands, where tall trees scattered at irrigated and rain fed fields. Further, certain multistoried buildings at human inhabitated places supported the *A. dorsata* population (Table 4). Similar type of observations was made by Sahebzadeh *et al.* (2012) at Malaysia.

Further, the nesting parameters such as colony shape, size, elevation and orientations revealed significant variations between different regions of south-western Karnataka (Tables 9, 10, 11 and 12). The comb morphometric data revealed interesting results (Table 13). The brood, honey comb size and shape of colony indicated considerable variations. Moreover, the horizontal and vertical length of brood comb, honey comb cells measured highest depth 2.03 ± 0.03 cm and 2.70 ± 0.14 cm area with 1.03 ± 0.84 ml honey storing capacity. But, the horizontal and vertical length of honey comb was less compared to brood comb. As brood part of the comb is meant for developing young ones, the width is normal when compared to honey storing area. Accordingly, cells at honey storing part of comb had very high (14.66 ± 0.51cm) width (Table 13). Altogether 2,174.868kg multifloral honey and 1,127.257kg of beeswax are produced from *A. dorsata* colonies from three to four months of flowering during Kharif and Rabi seasons at different regions of south-western Karnataka (Table 14). However, the hive products potentials were not differed much and didn't show any significant variation between various regions of south-western Karnataka. This shows the importance of these regions for multifloral honey production during different seasons in Karnataka.

Total 240 flowering plants which belong to 78 familes, and classified them into economically important, fruit yielding, vegetables medicinal and ornamental plants based on their usage for pollen and nectar collection by *A. dorsata* (Table 15). It is a voracious forager, visits various flowering plants which posses characteristic apicultural values during different seasons. Different flowering plant species (Figures 10 and 11) extended continuous and consistent supply of pollen and nectar source to *A. dorsata* at arid, semi-arid and malnad regions (Fig. 12). Understanding the nectar and pollen plants and their distribution during different seasons could help estimate the honey flow and inturn support the local honeybee population (Basavarajappa *et al.,* 2010). Similar type of observations was reported by Rao (1973), Basavarajappa *et al.* (2010) at different habitats of south-western Karnataka.

Various man-made activities (Table 16) and predators' interference (Table 17) have caused serious loss to *A. dorsata* population and initiate the process of its colony decline. Predators usually dismantle the hives to feed on honey, pollen, brood and adult bees (Jadczak, 1986). Caron (1978), Seeley *et al.* (1982), Jadczak (1986), Novogrodzki (1990), Abrol (2003), Kastberger and Sharma (2000), Thapa *et al.* (2000), Thapa and Wongsiri (2003) and Nagaraja and Rajagopal (2011) have reported the vertebrates predation on honeybee colonies. The Drango (*Dicrurus* sp.), bee-eater (*Merops* sp.), common crow (*Corvus* sp.), oriental honey buzzard (*Pernis* sp) feed on honey, brood, pollen and hive bees. Mammals are major enemies of honeybee colonies (Jadczak, 1986). Thus, predators menace is more common at natural colonies of *A. dorsata* during their honey flow seasons. They create nuisance in the hive and frequent movement at/or nearby colonies may interfere with the normal activities of hive bees. This might alter the working efficiency of forager bees and hive bees, finally influence the disintegration among the colony members (Basavarajappa and Raghunandan, 2013). Perhaps, it could weaken the colony population and such colonies become prone to predators or pests. In this way all these predators becomes troublesome to hive bees and their brood and stored hive products. Such troublesome activities perhaps weaken the colony gradually and finally initiate the process of colony desertification. Thus, the observations are agree with the earlier reports of Seeley *et al.* (1982), Jadczak (1986), Novogrodzki (1990), Abrol and Kakroo (2000), Kastberger and Sharma (2000), Thapa *et al.* (2000), Thapa and Wongsiri (2003), Nagaraja and Rajagopal (2011), Basavarajappa and Raghunandan (2013). Therefore, it is necessary to understand the bio-ecological agents and in turn it is possible to earmark the precautionary measures to restore the existing *A. dorsata* population and to conserve regional biodiversity.

Conclusion

A. dorsata selected eight tree species, seven human built structures to build 960 normal colonies during different seasons at various regions of south-western Karnataka. The prevailed ecological conditions namely temperature, relative humidity and rainfall did indicated their influence on the distribution of regional vegetation and inturn occurrence of *A. dorsata* colonies at arid, semi-arid and malnad regions of south-western Karnataka. *A. dorsata* constructed solitary colonies and aggregates with two to more than six colonies per 5^2 m area found at different elevations. The colony parameters were significantly varied between different regions. However, honey and wax production potential per colony per season didn't vary significantly between the regions. Various man-made activities and predators interfered with the normal activities of *A. dorsata* colony and encouraged the process of colony decline. Altogether, 13 animal species were interfered with the developing brood, honey, worker bees and hive bees, which could alter the live colony integrity and influenced the process of colony decline. Thus, multifaceted approach in the present investigations could help assess the bio-ecology of *A. dorsata,* which is under threatened state require conservation measures to restore its natural population in its abode.

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