Composition and nutritional profile of edible insects in a Natural World Heritage Site of India: Implications for food security in the region

Arup Kumar Hazarika Corresp., 1 , **Unmilan Kalita** Corresp., 2 , **Sasanka S Ghosh** 1 , **Suraj Chetri** 1

1 Department of Zoology, Cotton University, Guwahati, India

2 Department of Economics, Cotton University, Guwahati, India

Corresponding Authors: Arup Kumar Hazarika, Unmilan Kalita
Email address: dr.arupkhazarika@gmail.com, unmilan.k@gmail.com

Insects not only play a significant role in the ecological process of nature but since pre-historic times have also formed a part of the human diet. With a still growing population and skewed demographic structures across most societies of the world, their role as nutrient-rich food has been increasingly advocated by researchers and policymakers globally. In this study, we intended to examine the edible insect diversity and entomophagy attitudes of ethnic people in Manas National Park, a UNESCO Natural World Heritage Site, located in South Asia. The study involved a field investigation through which the pattern of entomophagy and the attitude towards insect-eating was studied. Following this, we examined the edible insect diversity and abundance at different sampling points. A total of 22 species of edible insects belonging to fifteen families and nine orders were recorded from different habitat types. Out of these 22 species, Orthopterans showed a maximum number of 8 species followed by Hymenoptera (4), Hemiptera (3), Lepidoptera (2), Blattodea (2) and 1 species each from Coleoptera, Odonata, and Mantodea. Dominance, diversity, and equitability indices were computed along with the relative abundance of the insects concerning four habitat types. Biochemical analyses of the recorded insect species was done to record their nutrient composition to establish their role as crucial nutrient inputs. The economic significance of entomophagy was also observed during the field investigation. To manage insects in the interest of food security, more attention should be given to an environmentally sustainable collection and rearing method, emphasizing their economic, nutritional, and ecological advantages.

Composition and nutritional profile of edible insects in a Natural World Heritage Site of India: Implications for food security in the region

Running title: Edible insects in Manas National Park

Arup Kumar Hazarika[1], Unmilan Kalita[2], Sasanka Sekhar Ghosh[3], Suraj Chetri[4]

[1] Department of Zoology, Cotton University, Guwahati, India
[2] Department of Economics, Cotton University, Guwahati, India
[3] Department of Zoology, Cotton University, Guwahati, India
[4] Department of Zoology, Cotton University, Guwahati, India

Corresponding Authors:
Arup Kumar Hazarika
Department of Zoology, Cotton University, Guwahati, Assam, India
Email address: dr.arupkhazarika@gmail.com
Unmilan Kalita
Department of Economics, Cotton University, Guwahati, India
Email address: unmilan.k@gmail.com

Abstract

Insects not only play a significant role in the ecological process of nature but since pre-historic times have also formed a part of the human diet. With a still growing population and skewed demographic structures across most societies of the world, their role as nutrient-rich food has been increasingly advocated by researchers and policymakers globally. In this study, we intended to examine the edible insect diversity and entomophagy attitudes of ethnic people in Manas National Park, a UNESCO Natural World Heritage Site, located in South Asia. The study involved a field investigation through which the pattern of entomophagy and the attitude towards insect-eating was studied. Following this, we examined the edible insect diversity and abundance at different sampling points. A total of 22 species of edible insects belonging to fifteen families and nine orders were recorded from different habitat types. Out of these 22 species, Orthopterans showed a maximum number of 8 species followed by Hymenoptera (4), Hemiptera (3), Lepidoptera (2), Blattodea (2) and 1 species each from Coleoptera, Odonata, and Mantodea. Dominance, diversity, and equitability indices were computed along with the relative abundance of the insects concerning four habitat types. Biochemical analyses of the recorded insect species was done to record their nutrient composition to establish their role as crucial nutrient inputs.

The economic significance of entomophagy was also observed during the field investigation. To manage insects in the interest of food security, more attention should be given to an environmentally sustainable collection and rearing method, emphasizing their economic, nutritional, and ecological advantages.

Introduction

Insects are the most diverse and abundant forms of life and constitute a primary component of the total faunal biodiversity on Earth. They play vital roles in an ecosystem that includes soil turning and aeration, dung burial, pest control, pollination, and wildlife nutrition (Bernard & Womeni, 2017). Besides providing ecological services, insects are also an important source of protein, fat, carbohydrate, and other nutrients. As per the current scientific literature, there are 1.4 million species of insects worldwide which are an intrinsic part of the Earth's ecosystem (Kulshrestha & Jain, 2016). As such, they influence not only with their immense species richness but also with their species variety and their role in energy flow. An interesting dimension to their existence pertains to the fact that they have formed a part of human diets since prehistoric times. Evidence points to at least 113 countries where insects form a part of human diets in one way or the other. This practice of consuming insects as part of the human diet is referred to as entomophagy. Insect-eating or entomophagy is not a traditional or common practice in most countries, except some in South- and South-East Asia, Latin America, and Africa (Rumpold & Schluter, 2013), where more than 2,000 insect species are consumed (Jongema, 2015). Given the shortfalls of the 'green revolution' and high risk of food insecurity in developing and underdeveloped nations, the use of insects as a potential source of food for the burgeoning human population had been advocated by Meyer-Rochow (1975), a suggestion that has been gaining interest among researchers, entrepreneurs and policy makers worldwide ever since. Insect farming is popular in most Asian nations for food, feed, and other purposes (Zhang et al., 2008). Weaver ants (*Occophylla smaragdina*), whose chemical composition and value as a human food item has been assessed by Chakravorty et al. (2016), are widespread in the Asia-Pacific region and are found from China south into northern Australia and as far west as India. Though edible insects have commercial value in other countries yet, economic and marketing data on edible insects in Asia and the Pacific is scarce (Johnson, 2010). In Thailand, over 150 species from eight insect orders are eaten by its people. Approximately 50 insect species are eaten in the north and about 14 species are eaten by people in southern Thailand (Rattanapan, 2000). The insect-eating habits in various regions may depend on the indigenous populations' cultural practices, religion, or geographical area. But insects used as emergency food during natural calamities or other national contingencies as well as for their organoleptic characteristics also (Dumont, 1987). In central India too, the people of Pithra village of Simdega district (Jharkhand) collect the red ants (*Solenopsis invicta*) and their pupae which are found on the trees for consumption (Srivastava et al., 2009).

The North-Eastern part of India has diverse ethnic groups that have a unique culture of food intake with insect-eating mostly prevalent amongst rural tribal people of the region which have a long-cultured history. In Arunachal Pradesh, 39 coleopteran insect species are used as indigenous food by approximately 50 ethnic tribes of Arunachal Pradesh (Chakravorty et al., 2013). The ethnic Nishi tribe of Arunachal Pradesh consumed more than 50 edible insect species belonging to 45 genera, 38 families, and 11 orders as a part of their diet (Chakravorty, 2009). Further, a total of 81 species are eaten in Arunachal Pradesh by two ethnic tribes namely Galo and Nyishi (Chakravorty et al., 2011). Odonata were consumed the most followed by Orthoptera, Hemiptera, Hymenoptera, and Coleoptera.

Scientific reports indicate insects to be significant sources of proteins and vitamins and possess viability of providing daily requirements of these nutrients in most developing countries (Bukkens, 1997; Elemo et al., 2011). For instance, edible aquatic beetles play an important role in the nutrition and economy of the rural population in Asian, Latin American and African nations (Shantibala et al., 2014; Macadam & Stockan, 2017). It should be noted that the diversity and abundance of insects in different habitat types have an observed correlation with the entomophagy attitude of a particular region. Therefore, research indicates the importance of exploiting insect diversity effectively through insect farming to avoid global problems associated with dependency on a limited number of insect species as experienced with some food animals and crops (Khoury et al., 2014).

In this research article, we have made an effort to study the edible insect diversity of a UNESCO Natural World Heritage Site, located in the Indo-Burmese biodiversity hotspot. Regional entomophagy was studied through a field investigation. Information on the nutrient composition (macro- and micronutrients) of the edible insect species was used to explore the possibility of promoting them as food/feed or as a base for nutritive products. In short, the aims of this study have been to determine the degree to which the ethnic people use insects in their diet and which species they consume. Recording seasonal abundance and availability of edible species as well as evaluating the role that entomophagy could possibly play as a measure of food security in the region, were further aspects of this study.

Materials & Methods

Study Area

The Manas National Park (MNP), located at 26.6594° N, 91.0011° E, was declared a UNESCO Natural World Heritage Site (WHS) in 1985 (Figure 1). Renowned for its array of rich, rare, and endangered wildlife not found anywhere else in the world, the faunal diversity of MNP includes the Pygmy Hog, Golden Langur, Hispid Hare, Assam roofed turtle and so on. Located at the Himalayan foothills of India, MNP is shares land territory with Bhutan where it is known as the Royal Manas National Park. The park is composed majorly of grassland and a forest biome. It is covered by the Brahmaputra Valley semi-evergreen forest vegetation along with the Himalayan subtropical broadleaf forests and the Assam Valley semi-evergreen alluvial grassland vegetation. This renders MNP a region of rich and abundant biodiversity. Major trees include the *Bombax ceibar, Gmelina arborea, Bauhini purpurea, Syzygium cumin, Aphanamixis polystachya, Oroxylum indcum,* etc. The climate is sub-tropical with a warm and humid summer, followed by a cool and dry winter. Temperature ranges from 10^0C to 32^0C.

The park has more than 58 fringe villages directly or indirectly dependent upon it, distributed across three ranges: Bansibari, Bhuiyaparaa and Panbari. The village Agrang lies at MNP's core while most are located in its buffer zone. Spread over the State of Assam's Barpeta and Bongaigaon districts, the tribal population in its fringe areas predominantly include Bodos and Rabhas among which the practice of insect eating and rearing are widespread (Rabha, 2016; Das & Hazarika, 2019).

Insect sampling

Insects were collected using entomological nets, beating tray, water traps, or through digging and handpicking. The local people of the study area helped in the collection process. Insects were usually collected during the early hours of the day (0500-0900 hours).

The flying insects were collected via entomological nets at a time when they were active (mid-morning/late afternoon). Sweep net was used for collecting grasshoppers and other insects which naturally hid in low grass- or herb-dominated vegetation or in small shrubs. Netting was normally carried out during daytime as it required good vision, thus causing some limitation to its wider applicability as we could not collect nocturnal taxa. In order to catch nocturnal species, we used light traps. Nocturnal arthropods like species of moths and beetles are easily attracted towards artificial light sources. Light traps have therefore been widely used in nocturnal insect sampling for a long time. A high-power CFL bulb was arranged behind a white cloth for trapping nocturnal insects. Generally, a bowl filled with water was placed under the light sources in the evening, after rainfall, to attract termites. The light attracted the reproductive termites which came out for nuptial flights and were trapped in the water or collected by hand from the water to prevent them from escaping. Light trapping was used widely in case of agricultural habitat type and open field habitat type.

Beating trays were used to collect insects such as Lepidoptera and Hymenoptera. Shrubs and small trees were sampled through commonly used beating tray sample method. Moreover, the red weaver ants were harvested by plucking the nest from the tree and dropping them in a bucket of water before being sorted out for consumption. The soil dwelling edible insects were collected by digging with the help of spades. Further, insects were hand-picked according to a method described by Musundire et al. (2014). Large insects such as grasshoppers and beetles were collected by hand which were caught early in the morning or in evening when they were less mobile due to their low body temperature. The mole cricket and field crickets were dug out of holes.

We used the hand-netting technique to collect the aquatic insects along with other local traditional equipment like *Jakoi*, *Saloni,* etc. Long handled aquatic net was used to collect insects that live on the water surface. Many adult insects living on the surface were predators, so they were removed from the net using forceps directly into a collection container. The kick-net method which is a process where insects are collected by dislodging insects from the substrate (habitat) was also used. The organisms that were dislodged by the disturbance were collected on the net.

For preservation of specimens, both dry and wet preservation methods were followed. For dry preservation, the specimens were preserved using pins in insect cabinet box and were mainly sun-dried. Soft-bodied insects were preserved using 70% ethyl alcohol. Besides, some hard-bodied edible insects were preserved using 2-3% formaldehyde. Some edible insect specimens were also preserved using standard methods (Ghosh & Sengupta, 1982). Identification was done later by comparison with other specimens. Some were identified in the Zoological Survey of India, Shillong, India.

Sampling was done from 20 chosen sites located in and around MNP. The sampling was done during the period 2018 (June)-2019 (June). The permission for conducting the field study was obtained from Office of the Principal Chief Conservator of Forests (Wildlife) and Chief Wildlife Warden, Government of Assam, India vide No. WL/FG31/ResearchStudyPermission/19th Meeting/2019. The remaining methodology of the study is outlined in Figure 2.

Edible insect density, diversity and abundance

Studying the diversity required us to divide each sampling point into four different habitat types, namely, open field habitat (OFH), forest/backyard forest habitat (FBH), swampy area habitat (SAH), and agricultural field habitat (AFH). The entire sampling area amounted to approximately 842 km^2. Insects were recorded within quadrates (2m x 2m dimension) established in the habitat type and monitored for four seasons, namely, pre-monsoon (March, April and May), monsoon (June. July, August and September), retreating monsoon (October and November), and winter (December, January and February) (Borthakur, 1986). An approximate representation is given in Figure 3.

The Shannon-Wiener index (H') for diversity, Simpson index (D) for dominance, and Margalef index for species richness in the four selected habitat types were also computed. Order-wise relative abundance and species-wise abundance in the different habitats were also computed. The descriptions and mathematical expressions are outlined below. The indices were estimated using PAST (v.3.26) (Hammer et al., 2019) and SPSS (v.23).

Shannon-Weiner index (H') determines the diversity of insect species in a particular habitat type. The higher the H' value, the greater is the diversity. Expression (i) gives the formula.

$$H' = - \sum p_i \ln p_i \;\ldots\ldots\; \text{(i)}$$

Where p_i = proportion of individuals found in i^{th} species

Simpson's index (D) defines the probability of drawing any two individuals at random from a very large community of the same species. If D increases, we can say that diversity has decreased. This index, defined by expression (ii), accounts for both aspects of diversity, i.e., richness and evenness.

$$D = \sum\left(\frac{\sum n_i\,[n_i - 1]}{N\,[N-1]}\right) \;\ldots\ldots\; \text{(ii)}$$

Where, n_i = individuals in i^{th} species, N = total number of individuals

Margalef's index (R) gives a precise idea about a species' richness. It attempts to compensate for the effects of sampling by taking a ratio of species richness by the total number of individuals in a sample, given in expression (iii).

R = (S-1) / lnN

Where, S = total species in a community, N = total number of individuals in that community.

Entomophagy study

Understanding the entomophagy attitudes and distribution among the tribal population near MNP required conducting a survey. Methods included interactions with the villagers through questionnaires, field surveys, and a market survey. The villages were selected randomly and were surveyed once per season for the whole year. Questions were asked to a mixed group of ethnic people which included individuals from all sections of the society. The market survey helped record the economic importance of these insects for the local economy. Questions pertained to the number of insects sold per week/month, their market prices, and how popular were the insects in ethnic cuisine. Overall, the questionnaire survey included 2672 respondents from 30 villages. Written consent was obtained from the respondents during the field interviews.

Biochemical analysis

Studying the importance of edible insects in food security required us to conduct their biochemical analysis. The analysis was for macronutrients and micronutrients in the laboratory of the Institute of Advanced Study in Science & Technology (IASST), Guwahati.

The protein content of the edible insects was estimated following the method of Lowry et al., (1951) using bovine serum albumin as a standard protein. In a series of test tubes, 0.10 - 1.0 ml of the standard BSA (bovine serum albumin) was taken and made up to 1 ml by adding distilled water. Next, 1.5 ml of protein reagent was added to the above solution and allowed to stand for 10 minutes at room temperature. Then, 0.5 ml of 10% diluted Folin-Ciocalteau reagent was added and incubated for 20 min in room temperature at dark to develop colour. The blue colour developed was read at 660 nm using spectrophotometer against a blank solution prepared by replacing BSA with water. A standard curve was prepared by putting the BSA concentrations in x-ordinate against the ODs in the y-ordinate. For tissue (insect) sample, 0.1 ml of insect tissue homogenate was added with distilled water to make 1 ml total volume. After that 1.5 ml protein reagent, 0.5 ml Folio reagent was added and incubated for 20 minutes. The colour developed was observed at 660 nm. The values of absorbance were noted and the content of tissue protein was calculated from the standard graph of BSA.

Estimation of carbohydrate was done by following the anthrone method (Sadasivam and Manickam, 2008). In a series of cleaned test tubes 0.10, 0.50, 1.00, 2.50, 3.00, 4.00, 5.00, 7.50; 10.00 mg /ml of standard glucose solutions were taken. Next, 5 ml anthrone solution was added to the above solution. Similarly, for insects, 1 ml samples supernatant was taken in a clean test tube. Next, 5 ml anthrone solution was added and then incubated for 15 min at 90°C. After the incubation was over, the colour developed was read at 625 nm in a spectrophotometer against a blank solution, containing all the chemicals except the sample. The absorbance values were noted and the concentrations of carbohydrate present in the insects were calculated from the standard graph of glucose.

The total lipid was estimated using chloroform methanol method described by Folch et al. (1957). To a known weight of dried, powdered sample taken in a test tube, 5 ml of chloroform-methanol (2:1) mixture was added and incubated overnight at room temperature after closing the mouth of the test tube with aluminium foil. After incubation, the mixture was filtered using What-man No.1 filter paper. The filtrate was collected in a pre-weighed 10 ml beaker which was kept on a hot plate. The beaker with the residue at the bottom was weighed after the chloroform methanol gets evaporated and the weight of the empty beaker was subtracted from this to know the weight of the lipid present in the sample. The result was been expressed as mg of lipids per 100 mg of dry tissue material similar to protein and carbohydrate.

The mineral elements were determined by atomic absorption spectroscopy (AAS). All the value of the micronutrients of the sample was recorded in ppm (parts per million) and calculated. The resultant values in AAS were converted into mg/100 g sample using expression (iv).

µg/gm of sample = (AAS reading x volume taken)/wt. of sample …. (iv)

(1 ppm = 0.001 mg/g)

Results

Table 1 shows the order-wise number of edible insects found in the study area. In MNP, the order Orthopteran recorded the maximum number with 8 species, followed by Hymenoptera with 4 species. The order Hemiptera was found to have 3 species and Lepidoptera with 2 species. The order Coleoptera, Isoptera, Blattodea, Mantodea, and Odonata accounted for 1 from each species and family. A total of 9,213 edible insects were recorded from AFH, 1455 in FBH, 3435 in OFH and 6497 individuals in SAH, during the field observation. No common abundant species was found in a single habitat. Most of the insects were found in two or three habitats during the study period.

Table 2 showcases the types of edible insects consumed by the ethnic people. In this table, the local and common name, the scientific name with their taxonomy, and their seasonal availability, edible parts, and mode of consumption are tabulated. Seasonal availability was maximum during June to September, gradually reducing towards the winter season. Species of the order Orthoptera were most abundant in May to September, whereas, Coleopterans were usually available from April to September. Insects belonging to the Hemiptera and Hymenoptera were found to be restricted to the period lasting from April to October, whereas, Mantodea were available from June to October. Some edible insects like *Hydrophilus olivaceus, Lethocerus indicus, Periplaneta americana* and *Gryllotalpa africana* were found to be available throughout the year, but in the winter, they were less abundant than during the pre-monsoon and monsoon season.

Simpson index (D) for dominance, Shannon-Wiener index (H') for diversity, and Margalef index for evenness/equitability were calculated in the four selected habitats (Table 3). Further, species abundance was found to be the highest in *Chondracris rosea* with 18.64, followed by *Gryllotalpa africana* with 8.50 in AFH. In FBH, the highest species abundance was found in *Heiroglyphus banian* with 8.91, followed by *Polistis olivaceus* with 5.20. In OFH, *Gryllus bimaculatus* was the highest abundant species with 5.1, followed by *Lethocerus indicus* with 3.17. Table 4 shows the relative abundance of the edible species in selected habitats. *Chondracris rosea* has the highest relative abundance (11.50%) followed by *Choroedocus robustus* (8.92%), the least relative abundant insect species includes *Laccotrephes ruber* (0.42%).

As regards the relative abundance of edible insect species, order Orthoptera has the highest relative abundance (56.30%) followed by Coleoptera (8.02%) and order Odonata has the least relative abundance (0.66%) (Table 4). Seasonal variation in abundance of edible insects (Figure 4) shows *Mantis religiosa* (466) to be the most abundant species (344) found in monsoon season followed by *Periplaneta americana* (798), and the least abundant species is *Mecopoda elongate* (13). In pre-monsoon, *Anthera assama* (443) has the highest presence and *Acheta domestica* (3) has the lowest. *Choroedocus robustus* has availability of 420 individuals during retreating monsoon compared to 10 individuals of *Gryllus bimuculatus*. Finally. In winter, *Vespa affinis* has the highest availability (112) compared to 12 individuals of *Heiroglyphus banian*. Highest insect species was observed during monsoon season (4808) followed by pre-monsoon (2785), retreating monsoon (2106), and winter (774).

Further, the proportion of ethnic communities practicing entomophagy in MNP has been graphically represented in Figure 5. We categorised the age-groups of consumers, who considered the insect-eating habit favourable, into four groups, namely, less than 60 years, between 40-60 years, between 20-40 years and greater than 20 years (Figure 6). Consumers in the 20-40 group responded highly favourably while those in less than 20 years group responded less favourably owing to different variations of entomophobia. There are various reasons for eating insects which were found among the different ethnic groups during the questionnaire survey (Figure 7). The different modes of insect consumption have been presented in Figure 8. Finally, Table 5 showcases the nutritional composition of all insect species recorded in the study. The highest total nutritional composition can be seen in termites (*Microtermes obesi*). Water beetle (*Diplonychus rusticus*) contains the maximum protein. Lower quantities of protein can be seen in rock bee (*Apis dorsata*), field crickets (*Gryllus bimaculatus*), and termites. Almost all the insect species are high in Omega-3 and Omega-6 content, with a good amount of essential amino acid and lipid content. Magnesium and carbohydrate contents are minimal while calcium is moderately present. The species-wise nutrient composition in colour-codes is represented in Figure 9 (content-specific) and Figure 10 (species-specific).

Discussion

Edible insect diversity and abundance

As part of this study, we find that species of the order Orthoptera are popular among the ethnic people for consumption purposes. The edible species majorly include both short and long-horned grasshoppers (*Eupreponotus inflatus, Choroedocus robustus, Chondracris rosea, Mecopoda elongate and Heiroglyphus banian*), field crickets (*Gryllus bimculatus*), house crickets (*Acheta domestica*) and mole crickets (*Gryllotalpa Africana*). Other species include potter wasp (*Vespa affinis)* and paper wasp (*Polistis olivaceus*), Indian honey bee (*Apis indica*) and rock bee (*Apis dorsata*), giant water bug (*Lethocerus indicus*) and so on. The ethnic (tribal) communities consuming these insects included mainly of the Adivashis, followed by the Bodo, Rabha, and Sarania communities. A section of the non-tribal population also consumed insects as part of their diets.

Species diversity, richness, and evenness gives an idea about the variety and diversity of species in the study sites. The most commonly used dominance and diversity indices in ecology are the Simpson index and the Shannon-Wiener index. Simpson index is used to assess the dominance but fails to provide an idea about species richness. Shannon-Wiener index is expected to determine both diversity characteristics (evenness and richness) but does not provide any information on rare species which, however, are very important in studies of biodiversity. Results show that the species dominance is highest in FBH (0.3871), followed by SAH (0.2423), OFH (0.1467), and AFH (0.1148). On the other hand, species diversity, as per H', was highest in AFH (2.822), OFH (2.392), FBH (2.153) and SAH (1.329). This establishes the fact that as insect diversity decreases, their dominance should increase. In MNP, this can be noticed for the forest habitat. Further, this result is corroborated by the Margalef index which is found to be highest for AFH (2.936), OFH (2.294), FBH (1.836), and SAH (0.653).

Notably, forest habitats are the prime source of edible insects for local people. This adverse finding in the case of FBH may be attributed to various reasons. Decreasing forest cover, changes in vegetation type, adverse climatic conditions, or indiscriminate collection and consumption of edible insect. These directly affect the insect diversity and rejuvenation of insect species. In the case of MNP, high temperatures, inadequate rainfall, and vegetation cover may also have influenced the population density of these edible insects. Notably, the overall climate of Assam has warmed by over 0.5^0 C for the past decade which is expected to rise up to 2.2^0C by 2050.

It should be noted that Shannon-Weiner and Simpson diversities increase as richness increases for a given pattern of evenness, and increase as evenness increases for a given richness, but they do not always follow the same trend. Simpson diversity is less susceptible to richness and sensitive to evenness than Shannon index which, in turn, is more receptive to evenness. At the other extreme, the Berger-Parker index, depends entirely on evenness- it is simply the inverse of the proportion of individuals in the community that belongs to the single most common species, while the other indices (Margalef) are dependent on the number of species. Apart from the diversity and distribution patterns for insect taxa, interactions between insect groupings and plant groups are another important topic requiring urgent research attention. This is because plants provide key habitat parameters for many insect species ranging from shelter to breeding sites. This has not been covered under this study and could be pointed out as its limitation.

Our analysis of seasonal diversity of edible insect species shows that the diversity of the edible insects was greater during monsoon and pre-monsoon season, moderate in the retreating monsoon season, and lowest in the winter season. As per the survey report, it was found that the abundance of insects found today is much lower than what it was earlier. A decreasing pattern is corroborated by Doley & Kalita (2011), Narzary & Sarmah (2015), Das et al. (2012), with slight changes. This establishes that seasonal availability of edible insects is declining with time while remaining constant at some points. This calls for urgent ecosystem restoration to sustain the distribution pattern and abundance of edible insects. Anthropogenic disturbances and deforestation are seen rampant in the fringes of MNP. Ground-level evidence glaringly shows that villagers are converting forest lands into agricultural fields. This is an outcome of the burgeoning population of Assam where the human population density is 398 persons per km^2 which is way above the global density of 14.7 persons per km^2. Such anthropogenic pressure (Morris, 2010) is bound to destroy species composition, community structure, and insect diversity (Bolvin et al., 2016).

In the regional context, a study of the diversity of insects consumed by the people in Dhemaji District of Assam revealed that a total of 14 species of insects were used as food (Doley & Kalita, 2011). 40 species of edible insects were recorded in Karbi Anglong District of Assam (Ronghang & Ahmed, 2010), further corroborated by Hanse & Teron (2012). Another study involving the ethnic community of the Bodos, recorded 25 species of local insects, belonging to eight orders and fourteen families which are consumed as food (Narzary & Sarmah, 2015). In this study, out of 22 edible species, the consumption of Orthopteran species was the highest constituting about 33.33%, followed by Hymenoptera with 20%, Coleoptera with 16.66%, Hemiptera with 10%, Lepidoptera with 6.66%, Isoptera with 3.33%, Odonata with 3.33%, Blattodea with 3.33% and Mantodea also with 3.33%. The maximum types of species consumed in the study area is from order Orthoptera which comprise 8 species of which 7 are short-horned and long-horned grasshoppers. This is corroborated by Ronghang & Ahmed (2010) and Das & Hazarika (2019).

Entomophagy, food security, and its economic implications

The field investigation revealed that most of the respondents found insects to be tasty and delicious (59%), while a section found them to be an inexpensive source of food (17.1%). Traditional medicinal food is also one of the reasons why edible insects are collected (Meyer-Rochow, 2017). This indicates the substantial preference of insects in the food habits of people and underscores their importance in the allocation of household costs and sustaining food security. This can be corroborated with the findings of Mozhui et al. (2017) for Nagaland, where the ethnic people considered insects as a regular food source, rather than an emergency food item. The local people favoured eating insects mostly by frying, roasting, or smoked. This emphasises the wide variety of ways through which insects may be consumed. However, a low percentage of respondents claimed them to be easily available food as collecting them is rather difficult compared to conventional livestock. This calls for the development of an insect farming industry as well. Further, a large number of respondents in the 20-40 years and 40-60 years age bracket favoured eating insects due to the various reasons as in Figure 6. Entomophagy, as such, is highly popular among the youth population. This corroborates the observation of Vaccaro et al. (2019) but does not agree with the study by Ghosh et al. (2020), carried out in Ethiopia.

Besides, the nutritional significance of edible insects has been well established by current scientific literature. This is further corroborated by the results of this study. Also, it is observed that nutrients vary widely across insect species wherein some are rich in protein and lipids while others are rich in mineral content. Chen et al. (2009) note that edible insects are rich in protein and fat, but sometimes may lack carbohydrate content. However, insects like bees, honeypot ants, etc., are very rich in carbohydrates. Our study verifies this fact as we can see from Figure 7 that the insects are rich in protein but have minimal carbohydrates. Notably, they have high omega-3, omega-6, and essential amino-acid content. Besides, Collavo et al. (2005) note that the presence of high essential amino acids is a major reason for insects having high-quality protein. This is validated by our study where most of the recorded insects show high protein and amino acid characteristics. These insects also have good calcium content and a moderate presence of magnesium.

The biochemical analysis suggests that the edible insects should potentially be able to supplement the diet obtained from livestock. This is necessitated by the fact that the majority of the population near MNP belong to low- or lower-middle-income category people. Their demography is skewed towards ethnic backgrounds and hence, the economy is highly underdeveloped. Rearing livestock and maintaining animal husbandry practices, require a substantial amount of money. The piggery sector is robust in this area. Practicing this requires large amounts of land and also involves substantial capital. However, the nutritional benefits gained from it are not enough to compensate for the effort. Also, insects generally meet the WHO recommendation for amino acid content with nymphs being their most abundant source (Tang et al., 2019). Coleoptera has a higher amount of protein than most livestock. More importantly, edible insects bear many non-health related benefits related to environmental and financial costs than livestock.

On the other hand, it is important to note that many edible insects have higher energy, sodium, and saturated fat content than typical livestock (Payne et al., 2016; Tang et al., 2019). This diminishes their worth as alternative nutrient sources to fight nutrition-related diseases. This is because the saturated fat content of edible insects is not recommended for people with heart disease risk, obesity, or metabolism issues. Further, some beetle or butterfly species produce dangerous toxins that are harmful to human health. Such species must be identified before being consumed as food (Blum, 1994). However, insects have very high micronutrient content which can be extracted or consumed at a third of the cost than other food products.

MNP is also a highly flood-ravaged area with untimely floods occurring during the sowing period. Floods in 2019 affected over a million people of Assam with a majority from the Baksa District (where MNP is located) and the adjacent district of Barpeta. This frequently uproots livelihood of the local people rendering them vulnerable to high food insecurity. It should be noted that these ethnic people otherwise have decent livestock and animal husbandry resources. With floods, they tend to lose livestock in a large-scale manner. At this juncture, edible insects can play a significant role in maintaining the nutritional content of their diet intact.

Among the edible insects in the study area, aquatic insects (water beetles) are quite favourable groups among the consumers due to their taste. Besides food and feed of humans and other animals, the predatory species of Coleoptera such as ladybird beetles are considered important biological control agents of aphids and scale insects (Arya & Verma, 2020). In our study, it was observed that water beetles are rich in protein content and have a considerable amount of lipid and carbohydrate. There is also a positive correlation between protein and lipid content. This establishes the fact that when the protein content in any insect increases then the lipid content in it also increases. Also, it can be inferred that the insects are rich in protein and carbohydrate contents together. *Hydrophilus olivaceus* (water scavenger) have a high quantity of protein, a good quantity of lipid and a considerable amount of carbohydrate compared to *Phyllophaga spp.* (June beetle), another commonly consumed Coleoptera. The protein content of adult *H. parallela* was approximately 24%, which is higher than the 16% protein content of silkworm (Longvah et al., 2011). On a dry weight (DW) basis, *H. parallela* contained 70.57 g of protein/100 g, which is comparable to the protein content of beef and pork (40–75 g of protein/100 g DW; Bukkens, 1997).

Animal protein is superior to plant; therefore, the best protein supplements should include some animal protein. Thus, insects may provide for good quality protein ingredients to produce a high standard protein supplement for the food industry (Ssepuuya et al., 2017). It was also found that the lipid content of larvae (37.87%) was higher than the soybean (14.60%). From the energy point of view, lipids are important because one gram of lipid provides more than 9 kcal of energy when oxidized in the body. Lipids are structural components of all tissues and indispensable in cell membranes structure and cell organelles (Drin, 2014). The fat content of pupae and larvae of edible Coleoptera is higher than that of the adult insect. These results coupled with the significant role played by edible insects in the local food habits make it undeniable that the desirability of food security in their context is valid as they can be considered as viable sources of macro- and micro-nutrients for human beings.

Edible insects such as beetles have been a rich source of proteins and also other nutrients for a long time and have been preferred over traditional livestock by several communities all over the world (Losey et al., 2006). For instance, indigenous communities of Mexico are involved in buying and selling edible insects, which are also processed and sold in urban markets. Insects have low-fat content and as such, there has been a high worldwide demand for edible insects. Additionally, aquatic insects are commonly exported from South Asian nations to the United States which are prepared and served in high-end eateries. The estimated size of this market was approximately USD 40 million in 2015. Moreover, in the Lao PDR, insects can be found in markets as ready-to-eat snacks or fried with lime leaves (van Huis, 2003). Concerning agriculture, beetles have been found to contribute more than a billion dollars in environmental and economic benefits globally. This comes from the fact that they recycle cattle manure, thereby, improving pasture growth, yielding high agricultural benefits, and thus, augmenting the livelihood of agriculturalists. In the context of MNP, a gap in the literature has been observed wherein comprehensive studies on beetles' economic benefits haven't been witnessed.

Rearing insects have high environmental benefits with respect to food and feed. They also have tremendous scope in terms of organic farming while helping to reduce environmental contamination, as they emit lesser greenhouse gases and ammonia, compared to other livestock (Dangles & Casas, 2019). Given the inclination of Bodos and other tribes in eating insects and rearing them to an extent, economic policies must target rearing practices of insects, rather than solely focussing on animal husbandry. Therefore, several strategies could be employed that can help in efficiently and sustainably making use of such natural biodiversity in augmenting the societal income and its food security, following learnings of other countries like South Korea (Meyer-Rochow et al., 2019).

Our study shows that edible insects are of considerable nutritional value and expanding their acceptability as human food can be expected to improve the nutritional status of people and possible reduction of their costs. With wide insect diversity, the nutritional status of people also gets widened while costs get reduced (Dickie et al., 2019). For instance, mealworms consist of six fatty acids and unsaturated omega-3 components that are equivalent to those found in fish, and also higher than those found in pigs and cattle (Raheem et al., 2019). Since nutrition has been one of the core components in the evolution of economic policies as well as family welfare, it is necessary that the insect eating habits of ethnic people in the study area must be widely augmented while focussing on the preservation of its insect diversity.

Certain insects like silkworms, honey bees, and as of late bumble bees and wasps have been traditionally domesticated ones since they have high economic value. As such, insect farming is much needed in the study area. This concept is widely prevalent in Korea, Thailand, Vietnam, and Laos PDR. Vertical farming is another technique that can immensely strengthen local economics and help in the exploitation of new protein sources (Specht et al., 2019). Family-run enterprises are mostly involved in this business along with other firms that have commercialised insects as not only food but also sources of protein and other health supplements.

Insect diversity can be critical for livelihood development since, in some developing countries, the poorest members of a society are engaged in gathering and rearing of mini-livestock (Mason et al., 2018). Industrial-scale interventions can also augment their livelihoods that have now been observed in the case of silkworms of Assam. Given the relatively process of rearing, accessibility, and transportation of insects, the people of Study area can immensely benefit if steps to set up an Insect Marketing Hub, assisted by an Insect Development Authority is set up. The hub should be created following a hub-and-spoke model that would not only pertain to processing and distribution matters but also training and R&D issues.

Conclusions

In this study, we made an effort to record the edible insect diversity and abundance, characteristics, and attitudes of the ethnic communities involved in entomophagy that are residing in the fringes of the Manas National Park, a Natural World Heritage Site. A total of 22 species of edible insects belonging to fifteen families and nine orders were recorded from different habitat types. Out of these 22 species, we recorded a maximum number of 8 Orthopteran species followed by Hymenoptera (4), Hemiptera (3), Lepidoptera (2), Blattodea (2) and 1 species each from Coleoptera, Odonata, and Mantodea. Diversity indices such as Shannon-Wiener, Simpson dominance, and Margalef indices were computed. Results of the study show that edible insect diversity has significantly decreased in the forest habitat. For a region highly dominated by entomophagy, such decreasing diversity raises a red flag. The field investigation showed that edible insects are highly sought after by local people. We identified the entomophagy practicing population mainly belonging to the Adivashi, Bodo, Rabha, and Sarania communities. They consume insects via different modes of preparation, such as fried, smoked, raw, etc. Moreover, people preferring entomophagy mainly belong to the youth (20-40 year) population. Therefore, our results conclude that MNP is a place vibrant with a high diversity, and abundance of edible insects. Further, it was found that these insects are good sources of protein, lipid, essential amino acids, omega-3, and omega-6 content, besides calcium, magnesium, and carbohydrate content. This validates edible insects as a future alternative source for an adequately nutrient-rich diet, proving to be majorly desirable in the context of food security. Preservation of such diversity necessitates the adoption of efficient and unique conservation techniques along with appropriate policymaking which can go a long way in augmenting greater insect diversity and also the food security of people in South Asia.

Acknowledgements

We would like to thank Mr. A.M. Singh, PCCF, Government of Assam, and the Director of Manas National Park for their incredible assistance and support throughout the study. We also thank the Director, IAAST, Guwahati for his encouragement and guidance throughout the study. Special thanks to Prof. Scott V. Edwards, Curator of Ornithology in the Museum of Comparative Zoology, Harvard University, and Prof. V.B. Meyer-Rochow, Department of Ecology & Genetics, University of Oulu, Finland, for guiding us in preparing the final draft of this paper. We also thank the respondents and forest rangers/personnel associated with Manas National Park, for helping us in specimen collection and providing relevant valuable inputs. Lastly, heartfelt thanks go out to the Centre for Environment, Education and Economic Development (CEEED) for giving us excellent logistic support.

References

1. Arya, M. K., & Verma, A. (2020). An insight into the butterflies (Lepidoptera, Papilionoidea) associated with protected area network of Uttarakhand, Western Himalaya. In Current state and future impacts of climate change on biodiversity (pp. 154-178). IGI Global.
2. Bernard, T., & Womeni, H. M. (2017). Entomophagy: Insects as food. *Insect Physiology and Ecology*, 233-249.
3. Barthakur, M. (1986). Weather and climate of north east India. *Northeastern Geographer,* 18 (1&2), 20-27.
4. Blum, M. S. (1994). The limits of entomophagy: a discretionary gourmand in a world of toxic insects. *The Food Insects Newsletter*, *7*(1), 1-6.
5. Boivin, N. L., Zeder, M. A., Fuller, D. Q., Crowther, A., Larson, G., Erlandson, J. M., ... & Petraglia, M. D. (2016). Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. *Proceedings of the National Academy of Sciences*, *113*(23), 6388-6396.
6. Bukkens, S.G. (1997). The nutritional value of edible insects. *Ecology of Food and Nutrition*, 36(2-4), 287-319.

7. Chakravorty, J. (2009). Entomophagy, an ethnic cultural attribute can be exploited to control increased insect population due to global climate change: a case study. In International Human Dimensions Programme, Seventh International Science Conference on Human Dimensions of Global Environmental Change, held at Bonn, Germany (pp. 26-30).
8. Chakravorty, J., Ghosh, S., & Meyer-Rochow, V. B. (2013). Comparative survey of entomophagy and entomotherapeutic practices in six tribes of Eastern Arunachal Pradesh (India). *Journal of Ethnobiology and Ethnomedicine*, *9*(1), 50.
9. Chakravorty, J., Meyer-Rochow, V. B., & Ghosh, S. (2011). Vertebrates used for medicinal purposes by members of the Nyishi and Galo tribes in Arunachal Pradesh (North-East India). *Journal of Ethnobiology and Ethnomedicine, 7*(1), 13.
10. Chen, X., Feng, Y., & Chen, Z. (2009). Common edible insects and their utilization in China. *Entomological research, 39*(5), 299-303.
11. Collavo, A., Glew, R. H., Huang, Y. S., Chuang, L. T., Bosse, R. & Paoletti, M. G. (2005). House cricket small-scale farming. Ecological implications of mini-livestock. *Potential of insects, rodents, frogs and snails, 27*, 515-540.
12. Dangles, O. & Casas, J. (2019). Ecosystem services provided by insects for achieving sustainable development goals. *Ecosystem Services,* 35, 109-115.
13. Das, J. K., Hazarika, A. K., & Khan, I. I. (2012). Nutritional value of some edible insects in Baksa District, BTAD, Assam. *The Clarion-International Multidisciplinary Journal*, *1*(1), 112-115.
14. Das, J. K., & Hazarika, A. K. (2019). Study on the diversity of aquatic edible insects in Baksa district of Assam with reference to Hemipteran species (Bellostomatidae and Nepidae). *The Clarion-International Multidisciplinary Journal*, *8*(1), 15-21.
15. Dickie, F., Miyamoto, M. & Collins, C. (2019). *The Potential of Insect Farming to Increase Food Security*. Intech Open Publications, United States.
16. Doley, A.K. & Kalita, J. (2011). An investigation on edible insects and their role in Socioeconomic development of rural communities, A case study on Edible insects of Dhemaji District of Assam (India). *Social Science Researcher,* 1, 1-11.
17. Drin, G. (2014). Topological regulation of lipid balance in cells. *Annual Review of Biochemistry*, 83, 51-77.
18. Dumont, H. J. (1987). A population study of Scapholeberis rammneri Dumont and Pensaert (Cladocera: Daphniidae). *Hydrobiologia*, 145(1), 275-284.
19. Elemo, B.O., Elemo, G.N., Makinde, M.A. & Erukainure, O.L. (2011). Chemical evaluation of African palm weevil, Rhychophorus phoenicis, larvae as a food source. *Journal of Insect Science*, 11(1), 146-152.
20. Folch, J., Lees, M., & Stanley, G. S. (1957). A simple method for the isolation and purification of total lipides from animal tissues. *Journal of biological chemistry*, *226*(1), 497-509.

21. Ghosh, A. K., & Sengupta, T. (1982). *Handbook on insect collection, preservation and study*. Zoological Survey of India, Kolkata.
22. Ghosh, S., Jung, C., Meyer-Rochow, V. B., & Dekebo, A. (2020). Perception of entomophagy by residents of Korea and Ethiopia revealed through structured questionnaire. *Journal of Insects as Food and Feed*, *6*(1), 59-64.
23. Hammer, Ø., Harper, D.A.T. and Ryan, P.D. (2019). *Paleontological Statistics (PAST),* ver. 3.26.
24. Hanse, R., & Teron, R. (2012). Ethnozoological practices among the Karbi tribes in Karbi Anglong district of Assam (India). *The Ecoscan*, *1*, 117-20.
25. Jongema, Y. (2015). List of edible insects of the world. Wageningen UR, Wageningen, the Netherlands.
26. Johnson, D. V. (2010). The contribution of edible forest insects to human nutrition and to forest management. *Forest insects as food: Humans bite back*, *5*.
27. Khoury, C. K., Bjorkman, A. D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., ... & Struik, P. C. (2014). Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences, 111*(11), 4001-4006.
28. Kulshrestha, R., & Jain, N. (2016). A note on the biodiversity of insects collected from a college campus of Jhalawar District, Rajasthan. *Bioscience Biotechnology Research Communication*s, 9(2), 331-334.
29. Longvah, T., Mangthya, K. and Ramulu, P. (2011). Nutrient composition and protein quality evaluation of Eri silkworm (Samia ricinii) prepupae and pupae. *Food Chemistry*, 128(2), 400-403.
30. Losey, J.E. & Vaughan, M. (2006). The Economic Value of Ecological Services Provided by Insects. *BioScience,* 56(4), 311-323.
31. Lowry, O., Rosebrough, N., Farr, A., & Randall, R. (1951). Protein determination by a modified Folin phenol method. *J. biol. Chem*, 193, 265-275.
32. Macadam, C. R., & Stockan, J. A. (2017). The diversity of aquatic insects used as human food. *Journal of Insects as Food and Feed*, *3*(3), 203-209.
33. Mason, J., Black, R., Booth, S., Brentano, A., Broadbent, B., Conolly, P., Finley, J., Goldin, J., Griffin, T., Hagen, K., Lesnik, J., Lewis, G., Pan, Z., Ramos, J.M., Ranalli, M., Rojas, G., Shockley, M., Stull, V.J., & Swietlik, D. (2018). Fostering Strategies to Expand the Consumption of Edible Insects, The Value of a Tripartite Coalition between Academia, Industry, and Government. *Current Developments in Nutrition,* 2(8).
34. Meyer-Rochow, V. B. (1975). Can insects help to ease the problem of world food shortage. *Search*, *6*(7), 261-262.
35. Meyer-Rochow, V. B. (2017). Therapeutic arthropods and other, largely terrestrial, folk-medicinally important invertebrates: a comparative survey and review. *Journal of Ethnobiology and Ethnomedicine*, *13*(1), 9.

36. Meyer-Rochow, V. B., Ghosh, S., & Jung, C. (2019). Farming of insects for food and feed in South Korea: tradition and innovation. *Berliner und Munchener Tierarztliche Wochenschrift*, *132*(5-6), 236-244.
37. Morris, R. J. (2010). Anthropogenic impacts on tropical forest biodiversity: a network structure and ecosystem functioning perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1558), 3709-3718.
38. Mozhui, L., Kakati, L. N., & Changkija, S. (2017). A study on the use of insects as food in seven tribal communities in Nagaland, Northeast India. *Journal of Human Ecology*, *60*(1), 42-53.
39. Musundire, R., Zvidzai, J. C., & Chidewe, C. (2014). Bio-active compounds composition in edible stinkbugs consumed in South-Eastern districts of Zimbabwe. International Journal of Biology, 6(3), 36.
40. Narzari, S., & Sarmah, J. (2015). A study on the prevalence of entomophagy among the Bodos of Assam. *Journal of entomology and zoological studies*, *3*(2), 315-320.
41. Okrikata, E., & Yusuf, O. A. (2016). Diversity and Abundance of Insects in Wukari, Taraba. *International Biological and Biomedical Journal,* 2(4), 156-166.
42. Payne, C. L. R., Scarborough, P., Rayner, M., & Nonaka, K. (2016). Are edible insects more or less 'healthy'than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over-and undernutrition. *European journal of clinical nutrition*, *70*(3), 285-291.
43. Prinz, W.A. (2014). The Lipid Trade. *Nature Reviews Molecular Cell Biology*, 15(2).
44. Rabha, B. (2016). Edible insects as tribal food among the Rabhas of Assam. *International Journal of Management and Social Sciences*, *3*(2), 349-357.
45. Raheem, D., Raposo, A., Oluwole, O. B., Nieuwland, M., Saraiva, A., & Carrascosa, C. (2019). Entomophagy: Nutritional, ecological, safety and legislation aspects. *Food Research International*, *126*, 108672.
46. Ramos-Elorduy, J., Carbajal Valdés, L. A., & Pino Moreno, J. M. (2012). Socio-economic and cultural aspects associated with handling grasshopper germplasm in traditional markets of Cuautla, Morelos, Mexico. *Journal of Human Ecology, 40*(1), 85-94.
47. Rattanapan, R. (2000). Edible insect diversity and cytogenetic studies on short-tail crickets (Genus Rachytrupes) in northeastern Thailand. Unpublished M.Sc. Thesis. Khon Kaen University, Thailand.
48. Ronghang, R. & Ahmed, R. (2010). Edible insects and their conservation strategy in Karbi Anglong district of Assam, North East India. *The Bioscan,* 2, 515-521.
49. Rumpold, B. A., & Schluter, O. K. (2013). Nutritional composition and safety aspects of edible insects. *Molecular Nutrition & Food Research,* 57(5), 802-823.
50. Sadasivam, S., & Manickam, A. (2008). Biochemical Methods. New Age International (P) Limited, New Delhi, 4-10.

51. Shantibala, T., Lokeshwari, R. K., & Debaraj, H. (2014). Nutritional and antinutritional composition of the five species of aquatic edible insects consumed in Manipur, India. *Journal of Insect Science*, *14*(1).
52. Singh, K. M., Singh, M. P., Kumawat, M. M., & Riba, T. (2013). Entomophagy by the tribal communities of North East India. *Indian Journal of Entomology*, *75*(2), 132-136.
53. Specht, K., Zoll, F., Schümann, H., Bela, J., Kachel, J., & Robischon, M. (2019). How Will We Eat and Produce in the Cities of the Future? From Edible Insects to Vertical Farming—A Study on the Perception and Acceptability of New Approaches. *Sustainability*, *11*(16), 4315.
54. Srivastava, S.K., Babu, N. and Pandey, H. Traditional insect bioprospecting – As human food and medicine. *Indian Journal of Traditional Knowledge,* 8(4), 485-494.
55. Ssepuuya, G., Namulawa, V., Mbabazi, D., Mugerwa, S., Fuuna, P., Nampijja, Z. and Nakimbugwe, D. (2017). Use of insects for fish and poultry compound feed in sub-Saharan Africa, A systematic review. *Journal of Insects as Food and Feed*, 3(4), 289-302.
56. Vaccaro, D., Anderson, K., Clark, L., Gluhosky, E., Lutch, S., & Lachman, S. (2019). Inquiries of Entomophagy: Developing and Determining the Efficacy of Youth-Based Curriculum. *Undergraduate Theses, Professional Papers, and Capstone Artifacts*. 226.
57. van Huis, A. (2003). Insects as food in sub-Saharan Africa. *International Journal of Tropical Insect Science,* 23(03), 163-185.
58. van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, 58, 563-583.
59. Yi, Z., Jinchao, F., Dayuan, X., Weiguo, S., & Axmacher, J. C. (2012). A comparison of terrestrial arthropod sampling methods. *Journal of Resources and Ecology,* 3(2), 174-182.
60. Zhang, C.X., Tang, X.D. & Cheng, J.A. (2008). The utilization and industrialization of insect resources in Chna. *Entomological Research, 38*(S1), S38-S47.

Figure 1

Study Area.

A; Map of India (Map data © 2020 Bing)

B; Map of Assam (Map data © 2020 Bing)

C; Map of Manas National Park (Map data © 2020 Google)

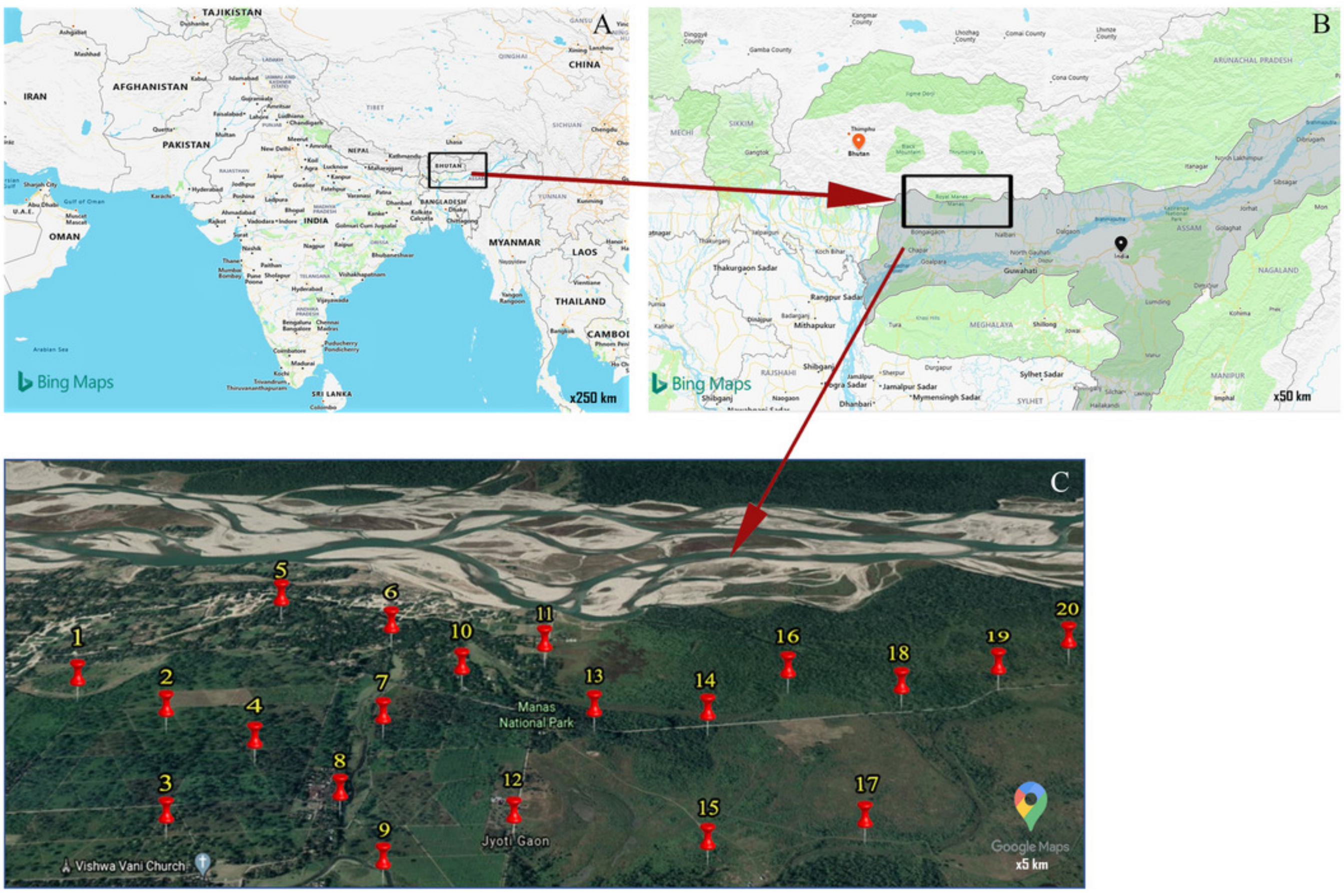

Figure 2

Methodology.

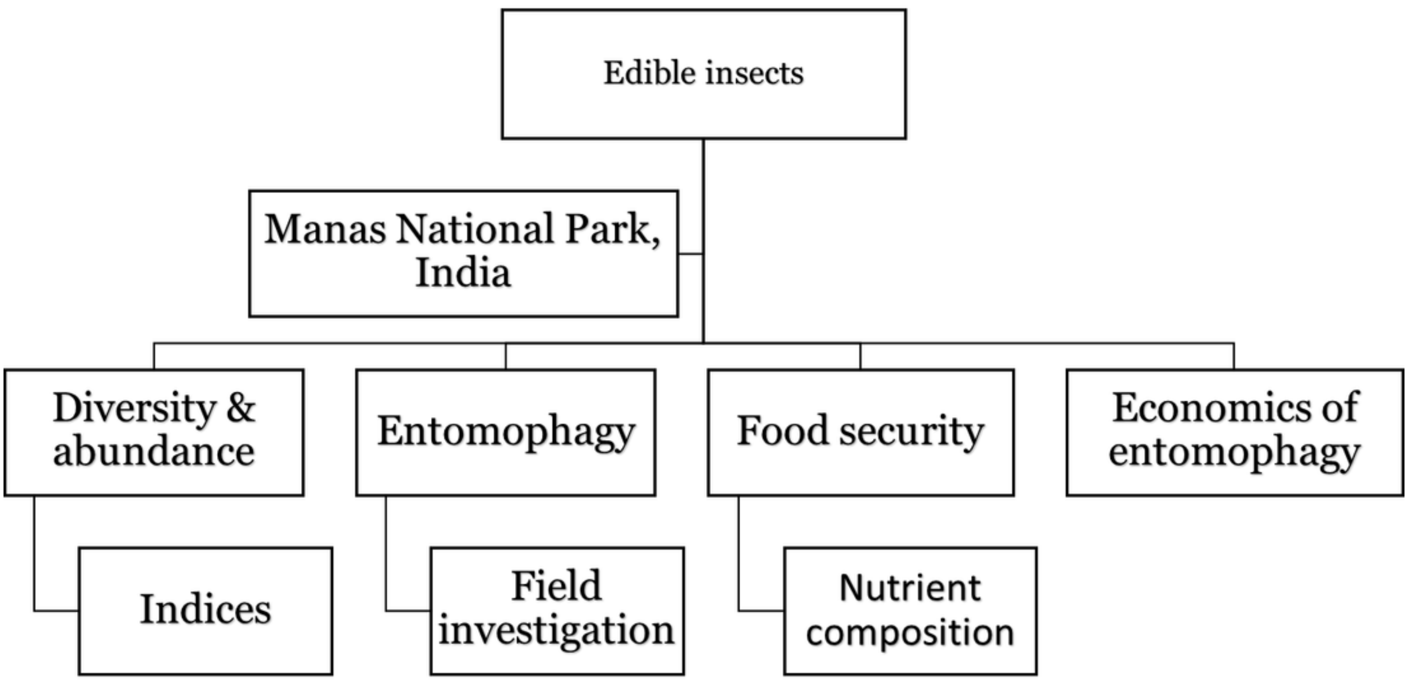

Figure 3

Representation of different edible insect habitats.

A; Swampy Area Habitat (SAH)

B; Forest/Backyard Forest Habitat (FBH)

C; Open Field Habitat (OFH)

D; Agircultural Field Habitat (AFH)

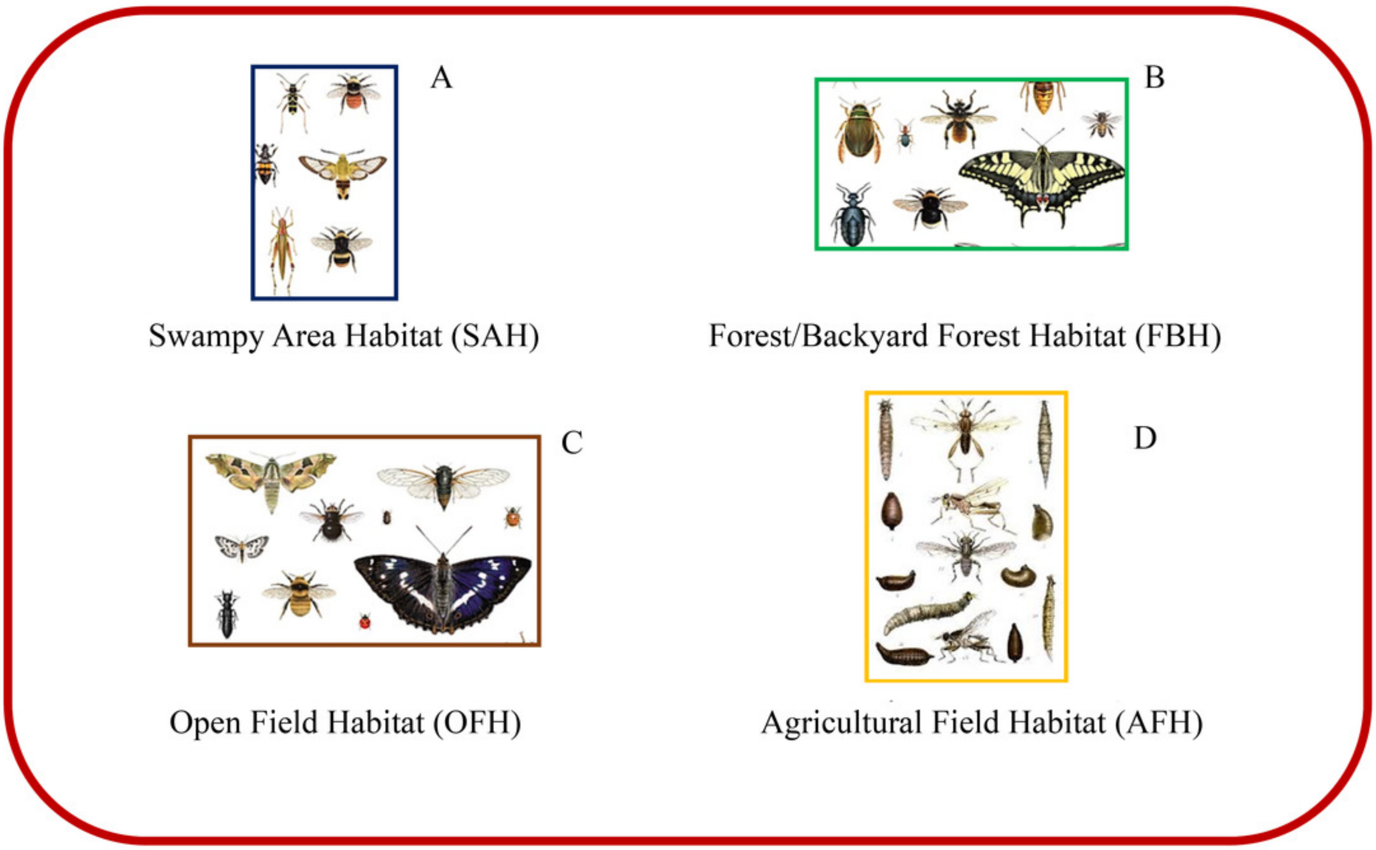

Figure 4

Seasonal availability of insects.

Blue section indicates pre-monsoon availability of insect; red section indcates monsoon; yellow indicates retreating monsoon and green section indicates availability in winter.

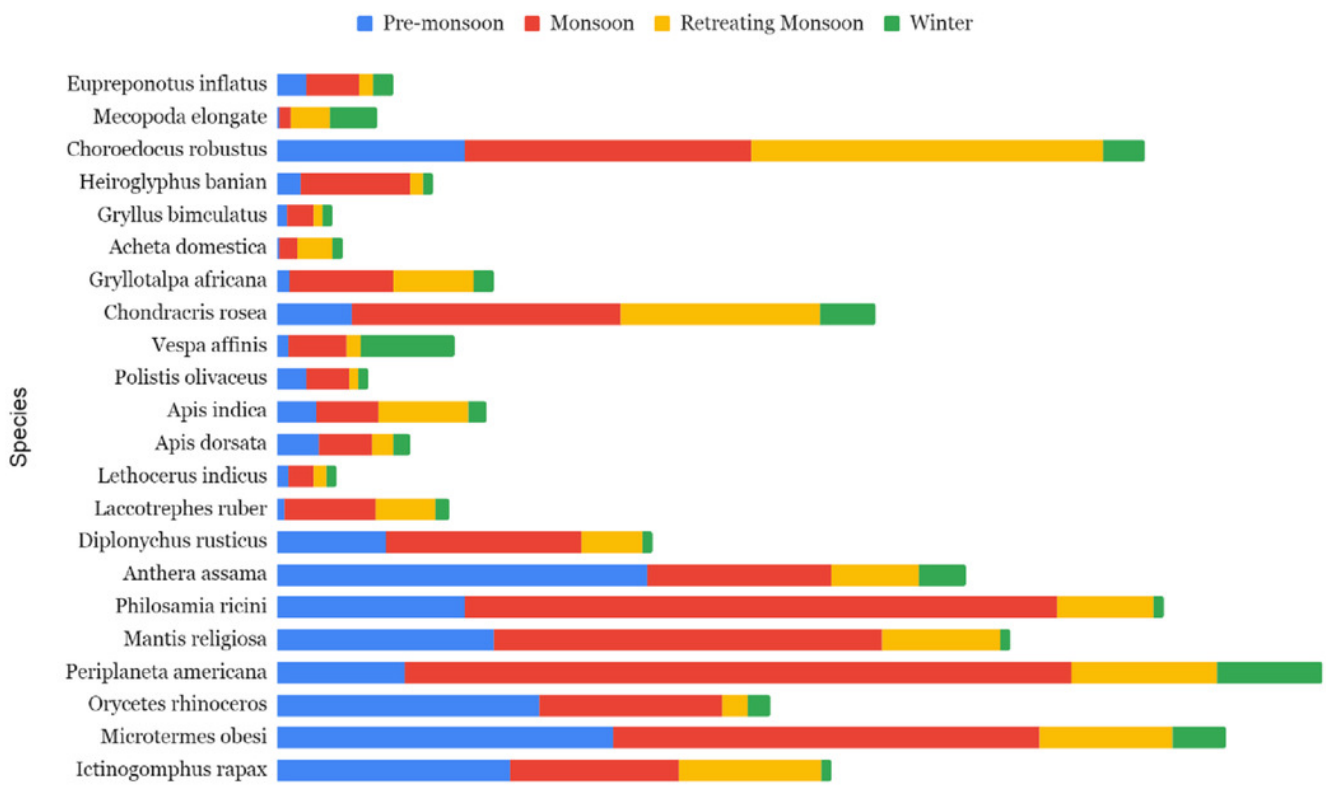

Figure 5

Entomophagy of different ethnic groups.

The brown bar indicates the respondent groups. The yellow line indicates the quantum of positive response.

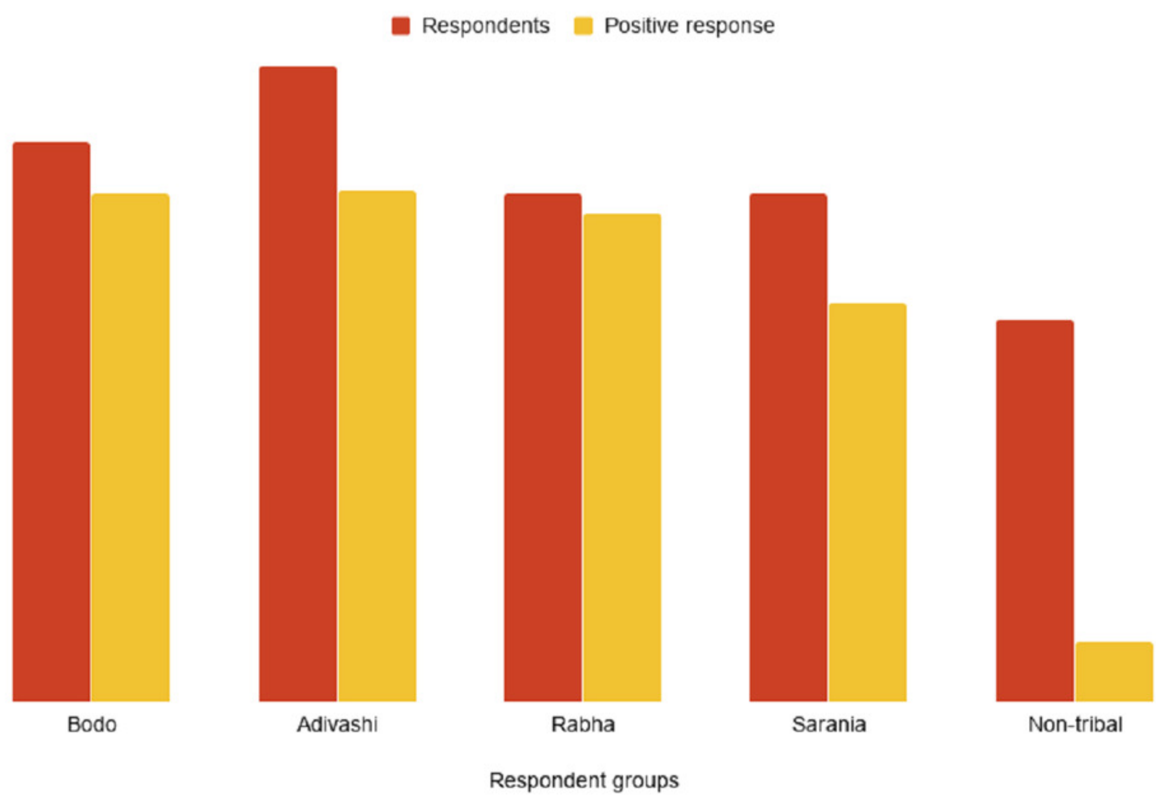

Figure 6

Age group of consumers favouring entomophagy.

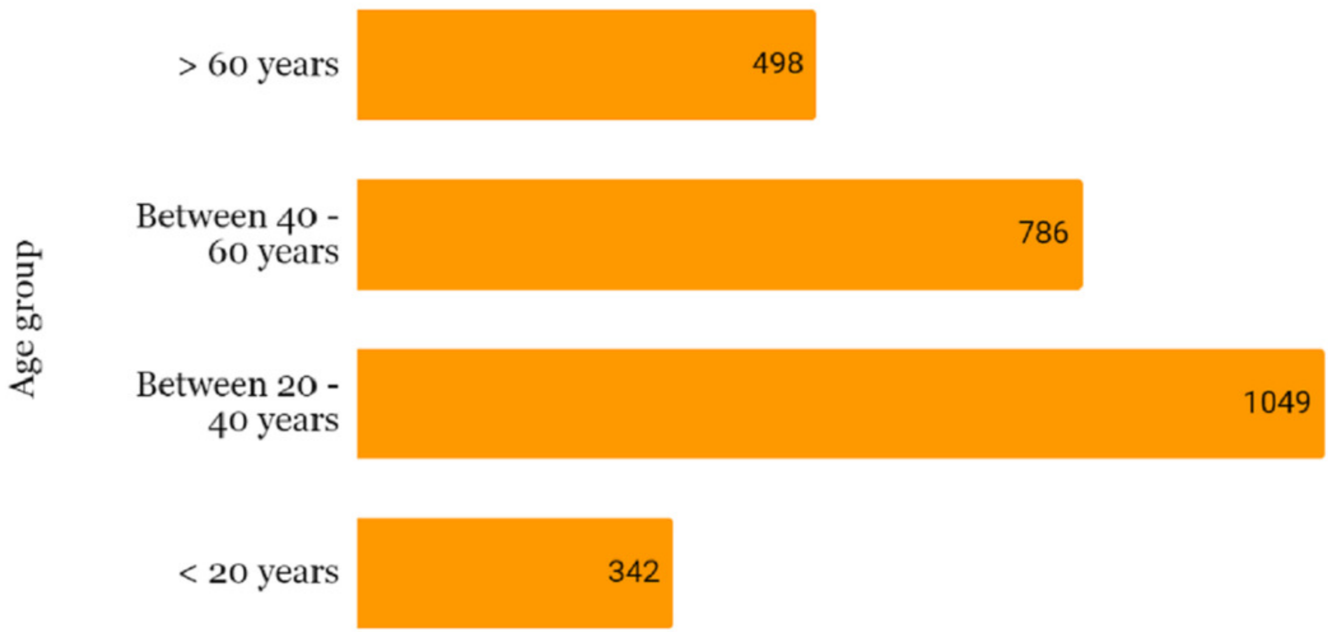

Figure 7

Different reasons for practicing entomophagy.

The coloured sections of the pie display the different reasons why insect-eating (entomophagy) is practiced by the local people.

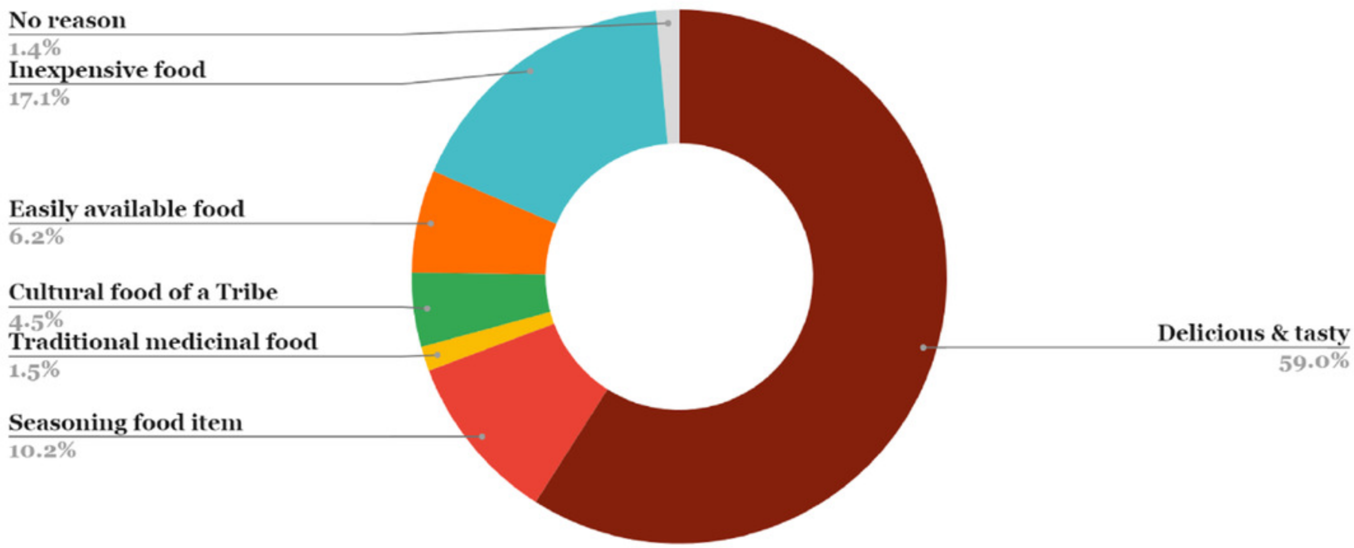

Figure 8

Different modes of eating insects.

The different coloured sections show the different modes/ways of eating insects by the local people.

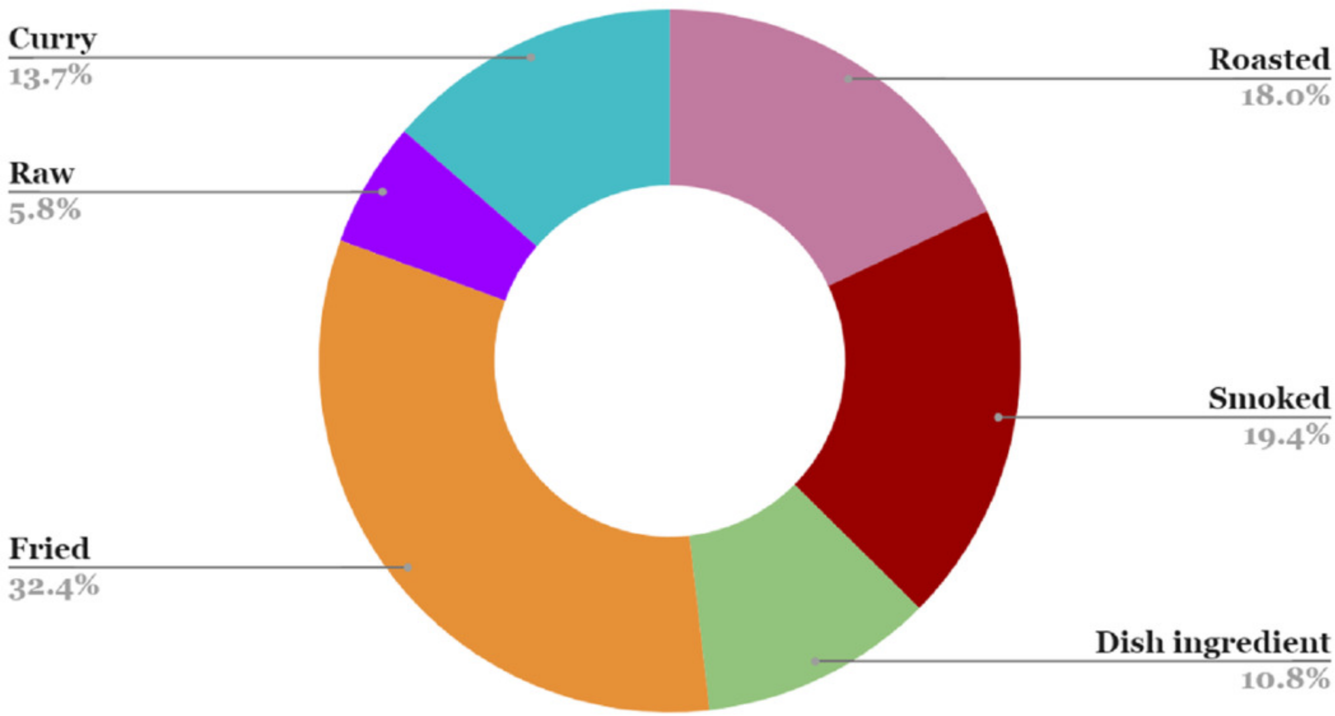

Figure 9

Combined nutrient composition (content specific).

A; Carbohydrate content

B; Magnesium content

C; Essential amino acid content

D; Lipid content

E; Omega-3 content

F; Omega-6 content

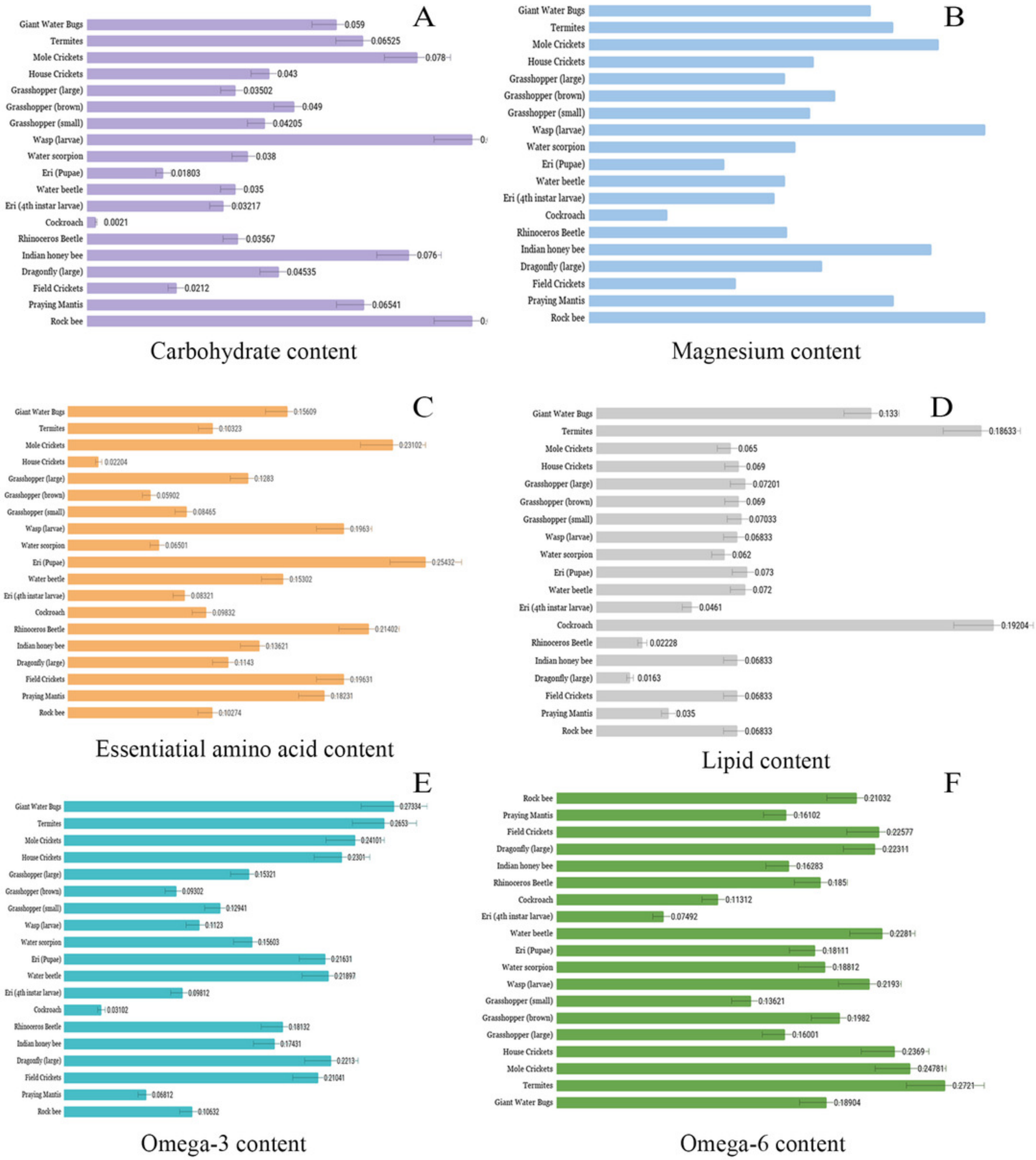
A
Giant Water Bugs
0.059
Termites
0.06525
Mole Crickets
0.078
House Crickets
0.043
Grasshopper (large)
0.03502
Grasshopper (brown)
0.049
Grasshopper (small)
0.04205
Wasp (larvae)
Water scorpion
0.038
Eri (Pupae)
0.01803
Water beetle
0.035
Eri (4th instar larvae)
0.03217
Cockroach
0.0021
Rhinoceros Beetle
0.03567
Indian honey bee
0.076
Dragonfly (large)
0.04535
Field Crickets
0.0212
Praying Mantis
0.06541
Rock bee
Carbohydrate content
B
Giant Water Bugs
Termites
Mole Crickets
House Crickets
Grasshopper (large)
Grasshopper (brown)
Grasshopper (small)
Wasp (larvae)
Water scorpion
Eri (Pupae)
Water beetle
Eri (4th instar larvae)
Cockroach
Rhinoceros Beetle
Indian honey bee
Dragonfly (large)
Field Crickets
Praying Mantis
Rock bee
Magnesium content
C
Giant Water Bugs
0.15609
Termites
0.10323
Mole Crickets
0.23102
House Crickets
0.02204
Grasshopper (large)
0.1283
Grasshopper (brown)
0.05902
Grasshopper (small)
0.08465
Wasp (larvae)
0.1963
Water scorpion
0.06501
Eri (Pupae)
0.25432
Water beetle
0.15302
Eri (4th instar larvae)
0.08321
Cockroach
0.09832
Rhinoceros Beetle
0.21402
Indian honey bee
0.13621
Dragonfly (large)
0.1143
Field Crickets
0.19631
Praying Mantis
0.18231
Rock bee
0.10274
Essentiatial amino acid content
D
Giant Water Bugs
0.133
Termites
0.18633
Mole Crickets
0.065
House Crickets
0.069
Grasshopper (large)
0.07201
Grasshopper (brown)
0.069
Grasshopper (small)
0.07033
Wasp (larvae)
0.06833
Water scorpion
0.062
Eri (Pupae)
0.073
Water beetle
0.072
Eri (4th instar larvae)
0.0461
Cockroach
0.19204
Rhinoceros Beetle
0.02228
Indian honey bee
0.06833
Dragonfly (large)
0.0163
Field Crickets
0.06833
Praying Mantis
0.035
Rock bee
0.06833
Lipid content
E
Giant Water Bugs
0.27334
Termites
0.2653
Mole Crickets
0.24101
House Crickets
0.2301
Grasshopper (large)
0.15321
Grasshopper (brown)
0.09302
Grasshopper (small)
0.12941
Wasp (larvae)
0.1123
Water scorpion
0.15603
Eri (Pupae)
0.21631
Water beetle
0.21897
Eri (4th instar larvae)
0.09812
Cockroach
0.03102
Rhinoceros Beetle
0.18132
Indian honey bee
0.17431
Dragonfly (large)
0.2213
Field Crickets
0.21041
Praying Mantis
0.06812
Rock bee
0.10632
Omega-3 content
F
Rock bee
0.21032
Praying Mantis
0.16102
Field Crickets
0.22577
Dragonfly (large)
0.22311
Indian honey bee
0.16283
Rhinoceros Beetle
0.185
Cockroach
0.11312
Eri (4th instar larvae)
0.07492
Water beetle
0.2281
Eri (Pupae)
0.18111
Water scorpion
0.18812
Wasp (larvae)
0.2193
Grasshopper (small)
0.13621
Grasshopper (brown)
0.1982
Grasshopper (large)
0.16001
House Crickets
0.2369
Mole Crickets
0.24781
Termites
0.2721
Giant Water Bugs
0.18904
Omega-6 content

Figure 10

Nutrient composition of insects.

The different coloured sections show the nutrient composition of insects with regard to nutrient types.

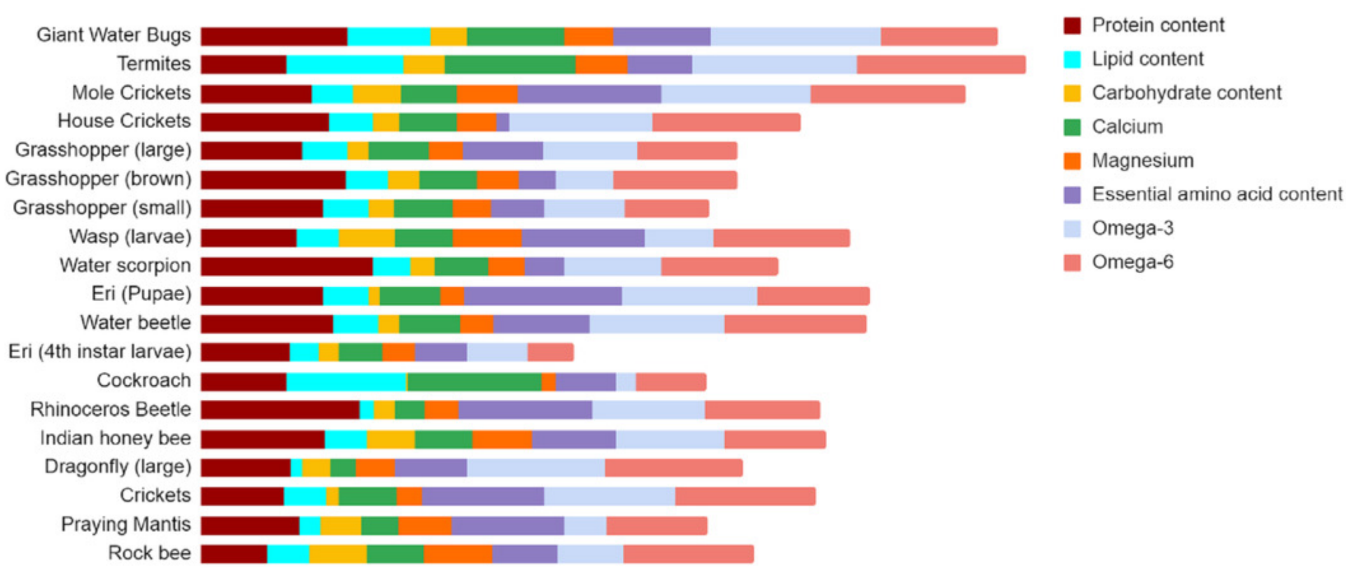

Table 1(on next page)

Order-wise number of edible insects.

Each data point in the right column indicates the number of insects present in the species-type specified in the left column.

Table 1: Order-wise number of edible insects.

Order	Number of species
Orthoptera	8
Hymenoptera	4
Hemiptera	3
Lepidoptera	2
Blattodea	2
Coleoptera	1
Odonata	1
Mantodea	1
Total	22

Table 2(on next page)

Taxonomy with seasonal availability of edible insects in MNP.

Each data point indicates the scientific name, order, family, English name, local name, seasonal availability, edible part, and mode of eating of a particular edible insect.

Table 2: Taxonomy with seasonal availability of edible insects in MNP.

Scientific Name	Order	Family	English name	Local name (Bodo)	Seasonal availability	Edible part	Mode of Eating
Eupreponotus inflatus	Orthoptera	Acrididae	Short-Horned Grasshopper	Gumanargi	May-Sept	Adult	Fried/smoked
Mecopoda elongate	Orthoptera	Tettigoniidae	Long horned grasshopper	Gumakhufri	May-Sept	Adult	Roasted/fried
Choroedocus robustus	Orthoptera	Acrididae	Short-Horned Grasshopper	Gumakhushep	June-Oct	Adult	Fried
Heiroglyphus banian	Orthoptera	Acrididae	Grasshopper	Gumagudul	June-Oct	Adult	Fried/Smoked
Gryllus bimculatus	Orthoptera	Gryllidae	Field Cricket	Fendadangra	May-Sept	Adult	Fried/Smoked
Acheta domestica	Orthoptera	Gryllidae	House Cricket	Gusengra	May-Sept	Adult	Fried/Smoked
Gryllotalpa africana	Orthoptera	Gryllotalpidae	Mole cricket	Sosroma	Whole Year	Adult	Fried/Smoked
Chondracris rosea	Orthoptera	Acrididae	Short horned Grasshopper	Gumanarenga	June-Aug	Adult	Fried
Vespa affinis	Hymenoptera	Vespidae	Potter wasp	Handilorebere	Apr-Sept	Eggs & Larvae	Raw/Roasted/Fried,
Polistis olivaceus	Hymenoptera	Vespidae	Paper wasp	Jothabere	Apr-Oct	Eggs &Larvae	Raw/Fried/ Smoked
Apis indica	Hymenoptera	Apidae	Indian honey bee	Maoubere	May-Sept	Eggs & larvae	Raw
Apis dorsata	Hymenoptera	Apidae	Rock bee	Berema	May-Sept	Eggs & larvae	Raw
Lethocerus indicus	Hemiptera	Belostomatidae	Giant Water bug	Gangjema	Whole Year	Adult	Fried/Smoked
Laccotrephes ruber	Hemiptera	Nepidae	Water scorpion	Omabunda	Jun-Oct	Adult	Fried/Smoked
Diplonychus rusticus	Hemiptera	Belostomatidae	Water beetle	Amphu Dabla	May-Sept	Adult	Fried/Curry
Anthera assama	Lepidoptera	Saturnidae	Muga silkworm	Amphumuga	Apr-Sept	Larvae, Pupae	Fried

Philosamia ricini	Lepidoptera	Saturnidae	Eri silkworm	Amphoulata	Apr-Sept	Larvae, Pupae	Fried
Mantis religiosa	Mantodea	Mantidae	Praying mantis	Gumagangu	June-Nov	Adult	Fried/Smoked
Periplaneta americana	Blattodea	Blattellidae	Cockroach	Thaoamphow	Whole year	Adult	Fried
Orycetes rhinoceros	Coleoptera	Scarabaeidae	Rhinoceros beetle	Jeljer	Sept-Feb	Larvae (Grubs)	Fried
Microtermes obesi	Isoptera	Termitidae	Termite	Wuri	Mar-July	Larvae, Adult	Fried
Ictinogomphus rapax	Odonota	Gomphidae	Dragon fly	Gandula	Mar-Aug	Nymph	Fried

2

Table 3 (on next page)

Diversity indices (habitat type) of edible insects recovered from four selected habitats.

Each data points indicate the different diversity indices of a particular insect type with respect to different habitat types.

Table 3: Diversity indices (habitat type) of edible insects recovered from four selected habitats.

	AFH	FBH	SAH	OFH
Species Richness	24	22	6	23
Total individuals encountered	9213	1455	3435	6497
Simpson	0.1148	0.3871	0.2423	0.1467
Shannon-Wiener	2.822	2.153	1.329	2.392
Margalef	2.936	1.836	0.653	2.294

AFH: Agricultural field habitat; FBH: Forest/backyard forest habitat; SAH: Swampy area habitat; OFH: Open field habitat

Table 4(on next page)

Abundance of edible insect in different terrestrial habitats.

Each data point shows the abundance of different edible insects in the terrestrial habitat types chosen in our study.

1 Table 4: Abundance of edible insect in three different terrestrial habitats.

Order	Species	AFH	Quadrate Occurrence	Abundance	FBH	Quadrate Occurrence	Abundance	OFH	Quadrate Occurrence	Abundance	Relative abundance
Orthoptera	*Eupreponotus inflatus*	44	27	1.63	0	0	0.00	0	0	0.00	5.82
Orthoptera	*Mecopoda elongate*	212	128	1.66	4	3	1.33	384	152	2.53	7.45
Orthoptera	*Choroedocus robustus*	67	39	1.72	20	9	2.22	41	11	3.73	8.92
Orthoptera	*Heiroglyphus banian*	31	21	1.48	78	13	6.00	72	24	3.00	8.75
Orthoptera	*Gryllus bimculatus*	12	9	1.33	44	11	4.00	5	4	1.25	4.22
Orthoptera	*Acheta domestica*	11	8	1.38	5	3	1.67	0	0	0.00	7.96
Orthoptera	*Gryllotalpa africana*	24	17	1.41	3	2	1.50	4	2	2.00	8.83
Orthoptera	*Chondracris rosea*	58	23	2.52	6	3	2.00	25	6	4.17	4.35
Hymenoptera	*Vespa affinis*	0	0	0.00	110	76	1.45	28	8	3.50	0.94
Hymenoptera	*Polistis olivaceus*	13	2	6.50	87	49	1.78	35	13	2.69	0.92
Hymenoptera	*Apis indica*	43	36	1.19	189	49	3.86	44	42	1.05	3.89
Hymenoptera	*Apis dorsata*	4	1	4.00	178	72	2.47	3	1	3.00	2.27
Hemiptera	*Lethocerus indicus*	2	1	2.00	7	7	1.00	88	46	1.91	0.71

Hemiptera	*Laccotrephes ruber*	112	45	2.49	28	21	1.33	74	60	1.23	1.96
Hemiptera	*Diplonychus rusticus*	212	67	3.16	56	29	1.93	184	89	2.07	5.23
Lepidoptera	*Anthera assama*	251	71	3.54	155	59	2.63	445	148	3.01	0.65
Lepidoptera	*Philosamia ricini*	988	56	17.64	24	11	2.18	76	44	1.73	1.59
Mantodea	*Mantis religiosa*	1256	206	6.10	8	7	1.14	40	27	1.48	2.76
Blattodea	*Periplaneta americana*	1205	212	5.68	0	0	0.00	73	32	2.28	0.98
Coleoptera	*Orycetes rhinoceros*	56	48	1.17	29	16	1.81	532	153	3.48	1.13
Isoptera	*Microtermes obesi*	41	8	5.13	79	45	1.76	1043	208	5.01	3.87
Odonota	*Ictinogomphus rapax*	1224	212	5.77	0	0	0.00	66	21	3.14	0.27

Table 5(on next page)

Nutrient composition of edible insects.

Each data point displays the nutrient composition of different edible insects with respect to the nutrient-types detailed in the table.

Table 5: Nutrient composition of edible insects.

Common Name	Protein	Lipid	Carbohydrate	Calcium	Magnesium	Essential amino acid	Omega-3	Omega-6
Giant Water Bugs	0.23412	0.133	0.059	0.15689	0.0788	0.15609	0.27334	0.18904
Termites	0.13859	0.18633	0.06525	0.21022	0.08505	0.10323	0.2653	0.2721
Mole Crickets	0.17823	0.065	0.078	0.08889	0.0978	0.23102	0.24101	0.24781
House Crickets	0.20587	0.069	0.043	0.09289	0.0628	0.02204	0.2301	0.2369
Grasshopper (large)	0.16254	0.07201	0.03502	0.0959	0.05482	0.1283	0.15321	0.16001
Grasshopper (brown)	0.23143	0.069	0.049	0.09289	0.0688	0.05902	0.09302	0.1982
Grasshopper (small)	0.19721	0.07033	0.04205	0.09422	0.06185	0.08465	0.12941	0.13621
Wasp (larvae)	0.15232	0.06833	0.091	0.09222	0.1108	0.1963	0.1123	0.2193
Water scavenger	0.27503	0.062	0.038	0.08589	0.0578	0.06501	0.15603	0.18812
Eri (Pupae)	0.19651	0.073	0.01803	0.09689	0.03783	0.25432	0.21631	0.18111
Water beetle	0.21231	0.072	0.035	0.09589	0.0548	0.15302	0.21897	0.2281
Eri (4th instar larvae)	0.14243	0.0461	0.03217	0.06999	0.05197	0.08321	0.09812	0.07492
Cockroach	0.1374	0.19204	0.0021	0.21593	0.0219	0.09832	0.03102	0.11312

Rhinoceros Beetle	0.25431	0.02228	0.03567	0.04617	0.05547	0.21402	0.18132	0.185
Indian honey bee	0.19842	0.06833	0.076	0.09222	0.0958	0.13621	0.17431	0.16283
Dragonfly (large)	0.14536	0.0163	0.04535	0.04019	0.06515	0.1143	0.2213	0.22311
Crickets	0.13209	0.06833	0.0212	0.09222	0.041	0.19631	0.21041	0.22577
Praying Mantis	0.15672	0.035	0.06541	0.05889	0.08521	0.18231	0.06812	0.16102
Rock bee	0.10602	0.06833	0.09102	0.09222	0.11082	0.10274	0.10632	0.21032