

1 ***Monograph***

2 **THE GREAT IMITATION GAME OF ARTHROPODS: DIVERSITY OF**
3 **TERRESTRIAL ARTHROPODS EXHIBITING MIMICRY FROM HAZARIBAG**
4 **PLATEAU REGION**

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11

12 **ABSTRACT**

13 Arthropods have co-evolved adaptive traits like mimicry due to their co-existence in shared
14 habitats with different species over millions of years. These imitations, which can be
15 morphological, chemical signatures, or behavioural patterns, have fascinated biologists for
16 centuries. Mimicry, where one animal resembles another, can involve imitation of morphology,
17 sound or scent particles of unpleasant animals or predators. Masquerading, on the other hand,
18 involves imitating an inanimate and unpalatable model like bird droppings. The Chotanagpur
19 (or Chhotanagpur) Plateau, characterized by its ancient origins and extensive forest cover, has
20 a rich biodiversity, but a significant portion of this biodiversity remains unrecorded or
21 inadequately documented. Hazaribag (or Hazaribagh) Plateau region being one of the densely
22 forested regions of Chotanapur Plateau presents unlimited opportunities to study biodiversity
23 and natural history of arthropods. A review of literature found that most published works from
24 Chotanagpur Plateau focus on recording and cataloguing insect species, with some studies
25 focusing on diversity of specific taxa. Behavioural studies including systematic study of
26 mimicry in arthropods is altogether missing. The scope of present study is extensive and broad,
27 with a focus on biodiversity and mimicry, particularly Batesian mimicry and among Batesian
28 mimics, particularly ant mimics. The present work provides an overview of mimicry among
29 terrestrial arthropods in the Hazaribag Plateau region, highlighting the arthropod diversity,
30 geography and uniqueness of the region. The Hazaribag Plateau region has high biodiversity,

31 leading to ecological interactions and an evolutionary arms race. Present study records a large
32 number of arthropod mimic species, with Batesian mimics being the most abundant. Ant
33 mimics are the most abundant among Batesian mimics. Among all ant mimics, spiders form a
34 significant part. Some arthropods use multiple modes of imitation across their life cycle.
35 Present study shows that mimics are widespread in nature.

36 **KEYWORDS**

37 Aggressive mimicry, Batesian mimicry, Chemical mimicry, Chotanagpur plateau, Müllerian
38 mimicry, Wasmannian mimicry

39

40 **INTRODUCTION**

41 Mimicry is one of the most fascinating examples of natural selection. In 1860, in his letter to
42 Darwin, Wallace wrote in the footnote, “Natural Selection explains almost everything in nature,
43 but there is one class of phenomena I cannot bring under it, – the repetition of the forms and
44 colours of animals in distinct groups, but the two always occurring in the same country and
45 generally on the very same spot.” Mallet (2001) considered theory of mimicry as the oldest
46 Darwinian theory not attributed to Darwin. Mimicry is the product of co-evolution (Zimmer *et*
47 *al.*, 2016). The phenomenon of mimicry was discovered in arthropods (Bates, 1862).
48 Subsequently, the phenomenon of mimicry has been extensively studied in numerous models
49 of insects and non-insect arthropods. Arthropods are ancient animals. Million years of co-
50 existence of different arthropods in a common habitat has made them acquire adaptive traits
51 which are shared by different species in that area, or one harmless species has acquired
52 similarities in form and function with respect to another species which is relatively obnoxious.
53 Such an “imitation” in arthropods evolved early in evolutionary timescale. *Eophyllum*
54 *messelensis*, a leaf mimicking stick insect fossil has been reported to be as old as 47 million
55 years (Eocene) and it closely resembles extant insect mimics (Wedmann *et al.*, 2007). These
56 imitations are not only morphological, but many arthropods also copy chemical signatures and
57 behavioural patterns of others. Some arthropods like the large blue butterfly *Phengaris arion*
58 Linnaeus, 1758 larvae are master tricksters. They evolved to exhibit multiple imitations
59 associated with *Myrmica* sp. Latreille, 1804 ants simultaneously to parasitize their nest
60 (Sielezniew *et al.*, 2010; DeVries *et al.*, 1993; Cobb, 2009; Settele *et al.*, 2011). Such imitations
61 among arthropods have fascinated biologists for centuries. When one animal resembles

62 another, it is termed mimicry (Evans, 1965). Mimicry may also involve imitation of sound,
63 scent particles and even specific body parts of unpleasant animals or predators instead of
64 mimicking the entire animal. Presence of eyespots on lepidopteran wings is one such example.
65 These eyespots often mimic eyes of cats and owls. Such eyespots form components of deimatic
66 (or dymatic) behaviour or startle display where sudden displays of these eyespots help a
67 defenseless animal to scare off or temporarily distract a predator allowing the animal to escape
68 (Stevens, 2005; Edmunds, 2004). Imitating an inanimate and unpalatable model like bird
69 droppings falls under the category of masquerading (Skelhorn, 2015). Masquerading is
70 different from camouflage. In camouflage, the animal can hide itself by blending with the
71 surrounding background due to its shape and/or colouration. In other words, it is simulation of
72 an uninteresting background (Vane-Wright, 1976). Mimicry of background colour, disruptive
73 colouration and mimicking even shape of objects like leaves, twigs, bark, thorns, etc. comes
74 under camouflage. Some authors use the term crypsis which includes both camouflage and
75 masquerading (Richardson and Anholt, 2010). One of the most cited examples of studies
76 pertaining to the role of camouflage in increasing species survival is the study of Industrial
77 Melanism in peppered moth *Biston betularia* by Henry Bernard Davis Kettlewell during 1890s
78 (Kettlewell, 1955). Obnoxious animals are often brightly coloured. Display of such a warning
79 colouration is called aposematism (Poulton, 1890; Cott, 1940). Many aposematic animals are
80 preferred models for harmless mimics or different species of look-alike aposematic forms may
81 constitute a mimicry ring among themselves or different kinds of mimics residing in a common
82 habitat may form mimicry complexes together.

83 The primary plateaus found within the Indian peninsula include the Deccan and Karnataka
84 Plateau situated in the southern region of India, the Chotanagpur (also spelt as Chhotanagpur)
85 Plateau located in the eastern part of the country, and the Shillong Plateau situated in the north-
86 eastern region of India. The sampling sites chosen for present study belong to the Chotanagpur
87 Plateau. The Chotanagpur Plateau is comprised of the most ancient landmass on the planet,
88 exhibiting geological evidence of prehistoric river systems, tidal plains, and beaches that date
89 back over 3.2 billion years. These geological features provide insight into this landmass being
90 the earliest crust that was exposed to the Earth's atmosphere (Chowdhury *et al.*, 2021). The
91 Chotanagpur Plateau is primarily located inside the state of Jharkhand, however a small portion
92 of it also extends into the adjacent states of West Bengal, Odisha, and Chhattisgarh. The
93 Chotanagpur Plateau spans around 75,000 square kilometres and exhibits an average elevation
94 ranging from 600 to 800 metres above the mean sea level. The eastern Indian plateau

95 experienced uplift throughout the Cenozoic era, which persisted into the Quaternary period and
96 continues to the present day (Kailasam, 1979). This geological process has led to the formation
97 of many geomorphic features such as gorges, rapids, rivers, and waterfalls. The Chotanagpur
98 Plateau is predominantly comprised of Archean granites and gneisses, interspersed with
99 regions containing Gondwana and Dharwar deposits from a geological perspective. The forests
100 of the Chotanagpur Plateau represent a significant and valuable natural resource. The forests
101 exhibit a range of characteristics, namely in terms of height and rainfall, encompassing tropical
102 moist deciduous forests as well as dry deciduous forests. The region exhibits a monsoonal
103 climate characterised by an average annual precipitation ranging from 100 to 150 cm and a
104 mean annual temperature fluctuating between 20 °C and 29 °C (Hazra *et al.*, 2020). The
105 Chotanagpur Plateau has been divided into three different regions (called steps) based on the
106 elevation of the land above sea level.

- 107 a. Regions falling between 910 to 1,070 metres (3,000 to 3,500 ft) above sea level: It
108 comprises the western plateau and are flat topped. Therefore, these are also known as
109 pats.
- 110 b. Regions with average elevation of 610 metres (2,000 ft): It comprises of Ranchi Plateau
111 and Hazaribag (also spelled as Hazaribagh) Plateau. Koderma Plateau is part of lower
112 Hazaribag Plateau. Damodar Trough falls between Ranchi and Hazaribag Plateau.
113 Palamu region is part of the eastern Ranchi Plateau. Hazaribag Plateau forms a major
114 portion of Northern Chotanagpur Plateau. It is the study area of the present work.
- 115 c. Regions with average elevation of 300 metres (1,000 ft): It comprises of Manbhum-
116 Singhbhum regions. This region harbours the famous Saranda forest, which is
117 considered the best Sal forest in entire Asia.

118 The Chotanagpur Plateau, characterised by its ancient origins and extensive forest cover, has a
119 rich biodiversity. A significant portion of the biodiversity within the invertebrate faunal realm
120 from this region remains unrecorded or inadequately documented. The Chotanagpur Plateau is
121 primarily located inside the state of Jharkhand. Zoological Survey of India (ZSI) keeps
122 publishing catalogues of different arthropod taxa of India from time to time. These catalogues
123 contain records from Jharkhand also but these publications lack comprehensive data regarding
124 arthropod diversity from Jharkhand. There are very limited number of studies from Jharkhand
125 concerning taxonomy and diversity of arthropods. Most of these studies revolve around
126 agricultural insects including insects associated with lac culture and sericulture. Behavioural,

127 evolutionary and molecular aspects have not been explored so far. There is a notable absence
128 of comprehensive scientific investigations focused on the Biology of spiders from Jharkhand.
129 While conducting a review of literature, it was found that most of the published works out of
130 the limited list of studies conducted on arthropod taxonomy and diversity from the state of
131 Jharkhand concern with recording and cataloguing insect species. Nayeem and Usmani (2012)
132 studied grasshopper and locust fauna of Jharkhand. Sureshan and Sambath (2009) catalogued
133 mantis fauna of Jharkhand and Bihar. Bhowmick (1993) catalogues grasshopper fauna. Kumari
134 and Kumer (2003), Lakra *et al.* (2021), Lata *et al.* (2021) studied aquatic insects of Jharkhand.
135 Sonali (2022) studied water beetles of Hazaribag Wildlife Sanctuary. Sambath (2011), Patra *et*
136 *al.* (2022), Singh (2019), Singh *et al.* (2017), Singh *et al.* (2017), Singh and Ahmad (2017),
137 Singh and Ranjan (2016), Singh *et al.* (2018) studied lepidopteran diversity from different parts
138 of Jharkhand. There are some studies concerning Dipteran diversity (Nandi and Mazumdar,
139 2014; Mahato *et al.*, 2022; Mahato and Gupta, 2018). Chaudhary *et al.* (2014) worked on
140 biodiversity and seasonality of ladybird beetles in mango farms. Saha and Hembrom (2020)
141 worked on insect diversity of Dumka. Mandal (2016) documented Blattodea of Jharkhand.
142 Chandrasekhar and Chatterjee (2004) worked on fresh water crustaceans. Mandal (2014),
143 Mandal (2018), Mandal *et al.* (2017), Mandal *et al.* (2016), Mandal and Suman (2014), Yadav
144 (2017) worked mainly on non-insect hexapods. There are instances of discovery of new species
145 and new distributional records of arthropod species from Jharkhand (Sambath, 2013; Singh *et*
146 *al.*, 2017; Dwari and Mondal, 2017; Chattopadhyay, 2020; Chattopadhyay, 2020; Mandal,
147 2014; Sureshan and Sambath, 2012; Nandi and Mazumdar, 2014). Recently, a new arthropod
148 species (*Coriophagus chaudhuri* Hui, Mukherjee and Hazra, 2023) has been discovered from
149 Jamtara (Hui *et al.*, 2023). Studies on evolution of arthropods from Jharkhand is restricted to a
150 limited number palaeontological records (Hazra *et al.*, 2022; Hazra *et al.*, 2022; Hazra *et al.*,
151 2022). These studies deal with insect-plant interactions in geological past.

152 With respect to arthropod behavioural biology, no study has been conducted from Jharkhand
153 to explore mimicry among arthropods but there are some interesting publications from India
154 pertaining to work on mimicry among arthropods outside Jharkhand. Kumari and Rastogi
155 (2018) worked on ecological interactions between ant and its mimics. Some Indian workers
156 have also explored Ecology and behaviour of ant mimicking spiders (Moinudheen, 2021;
157 Vijayan *et al.*, 2021; Subramaniam *et al.*, 2023; Nathan *et al.*, 2023; Uma *et al.*, 2013; Ramesh
158 *et al.*, 2016). There are many interesting works on the evolution of eye spots in butterflies,
159 pupal camouflage and camouflage among other arthropods from India (Kodandaramaiah *et al.*,

160 2009; Kodandaramaiah, 2009; Kodandaramaiah, 2011; Merilaita *et al.*, 2011; Kodandaramaiah
161 *et al.*, 2013; Mayekar and Kodandaramaiah, 2017; Murali *et al.*, 2021). In contemporary times,
162 a significant number of noteworthy scientific studies focusing on arthropod mimicry in India
163 have been attributed to Dr. Krushnamegh Kunte, National Centre for Biological Sciences, Tata
164 Institute of Fundamental Research, Bengaluru, India. He works on Evolutionary Biology,
165 Behavioural Biology and Molecular Biology of mimicry using butterflies as models (Kikuchi
166 *et al.*, 2023; Basu *et al.*, 2023; Kizhakke and Kunte, 2022; Kunte *et al.*, 2021; Deshmukh *et al.*,
167 2020; Baral *et al.*, 2019; Kunte *et al.*, 2014).

168 Present work is the first such study from Jharkhand which takes into account the diversity and
169 behavioural biology of mimics in an integrated manner. Conventionally, mimicry has broadly
170 been classified as Batesian mimicry, Müllerian mimicry, and aggressive mimicry. Wasmannian
171 mimicry may be considered a subtype of both Batesian and aggressive mimicry. Chemical
172 mimicry may include either of the mimics from the above-mentioned types. These are true
173 mimics. Camouflage, masquerading, deimatic behaviour, mimicry of specific body part of
174 other animal or own body part are not considered true mimicry, and these will be dealt
175 separately under “other” type of imitation (or so called “mimicry”) in the present work. Each
176 of these mimics are further grouped under distinct subgroups based on the model it mimics.
177 Arthropods exhibiting simple colour-camouflage have been omitted due to their huge numbers.
178 Almost all arthropods with a good vision are aware of the background where they can perfectly
179 camouflage. Therefore, only such arthropods are listed which mimic a particular animate or
180 inanimate model or its body part (or parts) and the chemical mimics. Present work deals with
181 the diversity of terrestrial arthropods exhibiting mimicry from Hazaribag Plateau region. In this
182 regard, extensive sampling has been conducted over different parts of Hazaribag Plateau region
183 to record different arthropod mimics from this region. All recorded taxa have been carefully
184 identified, studied, and categorized under different categories of mimics followed by detailed
185 analysis of mimic diversity *vis-à-vis* model animals. More emphasis has been given on Batesian
186 mimicry, particularly on ant mimicry. Efforts have been made to document all the terrestrial
187 arthropods exhibiting mimicry from this region observed during the year 2020 to 2023. Present
188 work would provide an overview of all the terrestrial arthropods and mimic diversity of the
189 Hazaribag Plateau region in a comprehensive manner. Present work would also throw light on
190 the geography of Hazaribag Plateau region and its uniqueness. Importance of Hazaribag
191 Plateau region with respect to its highly diverse arthropod fauna has also been highlighted.

192

193 **MATERIALS AND METHODS**

194 **Study area**

195 The present work involves extensive sampling over different parts of Hazaribag Plateau region.
196 The Hazaribag Plateau, located in the state of Jharkhand in India, exhibits a variety of
197 geographical features that contribute to its distinct landscape and environmental importance.
198 The Hazaribag Plateau is a constituent of the extensive Chotanagpur Plateau, located in the
199 northeastern region of the state of Jharkhand. The geographical coordinates of its approximate
200 location fall within the latitude range of 23°30'N to 24°30'N and the longitude range of 85°30'E
201 to 86°15'E. The plateau encompasses a considerable expanse of around 6,154 square
202 kilometers, rendering it a significant geographic unit within the region. The Hazaribag Plateau
203 exhibits an average elevation of around 610 meters relative to sea level. The terrain exhibits
204 undulations, featuring elevations in the form of hills, depressions in the form of valleys, and
205 elevated flat areas known as plateaus. The topography consists of a combination of
206 flatlands and steep slopes, resulting in a diversified and aesthetically captivating geographical
207 setting. The region is characterised by the presence of several rivers, such as the Damodar and
208 Barakar, which have had a significant role in sculpting its terrain. The Hazaribag Plateau
209 exhibits efficient drainage systems facilitated by multiple rivers and their respective tributaries.
210 The Damodar River, which is a significant river in the region, plays a vital part in the
211 hydrological system of the plateau. The existence of these aquatic formations not only impacts
212 the geographical features but also sustains agricultural practices in the adjacent low-lying areas.
213 The plateau is embellished with lush forests, predominantly comprising sal, mahua, bamboo,
214 and many medicinal plants. The presence of these forests not only serves to enhance the
215 biodiversity of the region, but also fulfils a crucial function in preserving ecological
216 equilibrium. The vegetation cover exhibits variability across the plateau, displaying several
217 forest types that sustain a wide range of plant and animal species. The Hazaribag Plateau is
218 characterized by a sub-tropical climate that exhibits marked seasonal variations. Summers are
219 typically characterised by high temperatures, whilst winters tend to be somewhat cooler. The
220 southwest monsoon winds bring monsoon rains, which take place between the months of June
221 and September. These rains play a crucial role in enhancing soil fertility and facilitating
222 agricultural practices. The area of Hazaribag Plateau consists of present districts of Hazaribag,
223 Chatra, Koderma and Giridih with some parts of Bokaro and Ramgarh (Figure 1).

224 **Site mapping and geo-tagging**

225 The geographical extent of the Hazaribag Plateau was plotted on a map by geo-referencing
226 available geographical information retrieved via extensive data mining (Figure 1). Note that
227 the precise maps of Hazaribag Plateau are not publically available. ArcGIS Desktop 10.8.1
228 software was used for geo-referencing and mapping purposes. Geo-tagged photographs of the
229 sampling site were taken using the GPS Map Camera 1.4.4 software installed in a Samsung
230 Galaxy M42 mobile device. The same mobile device was used for photography and video
231 recording whenever required during the study. Total ten sampling sites were selected from
232 Hazaribag Plateau region. These sites are forested areas, natural hills, and areas around water
233 bodies. Longitude and latitude of each sampling site were recorded using Google Maps
234 software (Table 1). All these sampling sites have been marked precisely on the map of
235 Hazaribag Plateau in Figure 1.

236

237 **Table 1. Sampling sites from Hazaribag Plateau region with latitude and longitude of**
238 **each site.**

S.NO.	SAMPLING SITES	LATITUDE	LONGITUDE
1.	Churchu Forest	23°94'N	85°47'E
2.	Babhanbai (or Babhanbay) Hill	23°95'N	85°38'E
3.	Sitagarh (or Sitagrah) Hills	23°96'N	85°43'E
4.	Silwar Hills	23°99'N	85°44'E
5.	Hazaribag Lake	24°01'N	85°36'E
6.	Cannhary (or Canary) Hill	24°01'N	85°39'E
7.	Parasnath Hills	23°94'N	86°18'E
8.	Hazaribag Wildlife Sanctuary (entry)	24°14'N	85°38'E
9.	Mahudi Hills	24°58'N	85°28'E
10.	Chatra Forest	24°22'N	84°89'E

239

240 **Acquisition of meteorological data of the study area**

241 Meteorological data of average daily temperature and precipitation at Hazaribag Plateau region
242 over last nineteen years (1st January, 2001 to 31st December, 2019) was retrieved using SWAT
243 (Soil and Water Assessment Tool) model which is an open access tool managed by Texas A&M
244 University, Texas, USA and University of Guelph, Guelph, Canada. This data was plotted on
245 a graph as a dot plot and a line chart using Microsoft Excel to indicate yearly trends in values
246 of precipitation and temperature respectively at Hazaribag Plateau region. Using this data,
247 average value of daily precipitation and minimum and maximum temperature was also
248 calculated for this area.

249 **Sampling**

250 For the current investigation, the designated region was consistently surveyed over a period of
251 about twenty-four months, spanning from January 2021 to December 2022. The minimum
252 requirement was to conduct at least two visits per month. A total of 48 visits were conducted
253 throughout this time-period. Most of the visits were made during daylight hours, specifically
254 between 11:00 am and 04:00 pm (42 visits). Some of the visits were conducted for extended
255 periods up to 10:00 pm for sampling of nocturnal arthropods (6 visits). All observations
256 conducted in situ were captured within the same time interval. Systematic observations were
257 carried out regularly to investigate the behavioural patterns of the arthropods in its natural
258 habitat. Highest number on visits was conducted to Hazaribag Wildlife Sanctuary which
259 constitutes the most extensive expanse of forested land inside the Hazaribag Plateau (36 visits).
260 Most of the sampling was conducted randomly for the first time followed by repetitive
261 sampling over same areas after these are identified as potential sites more useful for the present
262 study. Sampling involved exploring the designated area, digital recording of the sampling sites
263 and the observed mimic (as well as its model if spotted) in the form of photographs and video
264 recordings followed by collection. *In situ* observations were thoroughly recorded in the
265 laboratory notebook for further analysis.

266 **Collection and preservation**

267 Collection of selected specimens of special interest was carried out using standard techniques
268 used in Entomology and Arachnology. Most of the mimic arthropods to be collected were listed

269 from published works. Many mimics were collected based on their apparent resemblances with
270 other animate or inanimate models. Some specimens were collected by chance which were later
271 found to be a mimic. Likewise, some models were also collected and preserved. Various
272 techniques were employed for collecting terrestrial arthropod specimens from different
273 sampling sites of the Hazaribag Plateau region. The diurnal collection methods employed in
274 this investigation encompassed the utilisation of a pan trap, sweep net, aspirator, and manual
275 collection techniques. The methods employed for nocturnal collection included the utilisation
276 of a light trap as well as manual collection techniques involving the placement of a light source
277 over a vertically suspended tightened white sheet (Figure 2.).

278 **a. Sweep net.** The collection of specimens was conducted during daylight hours in both
279 the morning and evening. This was done by utilising small polythene bags and
280 employing several sweepings on various types of vegetation, including grasses, herbs,
281 and shrubs, within forested regions. The specimens were killed using a tiny amount of
282 ethyl acetate-soaked cotton swabs, while specimens intended for molecular studies
283 were immediately placed in 70% alcohol.

284 **b. Light trap (mercury vapour lamp).** In order to capture nocturnal insects, light traps
285 were strategically placed in both field and adjacent woodland regions during the
286 evening hours and illuminated throughout the night. The insects that were gathered
287 within the container of the light trap were effectively exterminated in unison through
288 the utilisation of a little cotton swab saturated with either 100% ethyl acetate or
289 benzene.

290 **c. Aspirator (or pooter).** During the diurnal period, aspirators were employed to gather
291 specimens from plants, whereas during the nocturnal period, they were collected in
292 close proximity to light sources. The collected specimens were transported to a killing
293 bottle that was charged with ethyl acetate.

294 **d. Pan trap.** Pan trap was designed using a shallow bowl filled with a solution consisting
295 of water and soap. Pan traps are designed to mimic the appearance of flowers and are
296 commonly used to capture insects that visit flowers, such as pollinators. Insects possess
297 the capacity to be drawn towards specific colours, a phenomenon contingent upon their
298 ability to discern and differentiate particular wavelengths of light. Yellow colour is
299 known to be the most visually prominent colour for insects when compared to blue and
300 white. Therefore, yellow pan traps were used. Insects get drawn into the soapy water

301 and become trapped, rendering them impossible to leave. Consequently, they remain
302 inside water, facilitating their utilisation for research purposes.

303 **e. Manual collection.** Collection of many soft bodied insects and spiders require
304 manually picking them carefully using hands or forceps. Manual picking was conducted
305 both for diurnal and nocturnal arthropods. Nocturnal manual collection was performed
306 in presence of light trap and by hanging a white sheet nearby a bright light source.

307 Following the killing of collected specimens, they were morphologically segregated and
308 subsequently stored in butter paper envelopes. These envelopes were appropriately labelled
309 with relevant information, such as the locality name, collecting date, location coordinates,
310 elevation, collector's name, and host plant (in case of herbivorous arthropod). The butter paper
311 envelopes were brought to the laboratory in specialised containers designed for specimen
312 storage for further studies. Spiders, caterpillars and nymphs were transferred to containers with
313 70% alcohol after collection. Winged insects were pinned and dried properly. All these
314 specimens were labelled and placed within insect cabinet boxes in order to facilitate additional
315 examination and analysis.

316 **Identification**

317 In order to conduct a thorough examination and capture accurate photographs for identification
318 purposes, specimens that met specific criteria were chosen. These criteria included cleanliness,
319 intactness, and suitability for the study of important morphological characteristics. Both *in situ*
320 photographs and collected specimens were used to record the taxonomic identity of the mimic.
321 Identification of the taxa was carried using available literature, keys, arthropod data bases and
322 with the help of various experts. Most mimics were identified precisely up to species level
323 while few of them could only be identified up to genus due to lack of collected specimens and
324 insufficient information in the photographs captured *in situ*.

325 **Categorization of taxa under different types and sub-types of mimics**

326 All arthropods were classified and grouped into their respective taxa based on their
327 morphological characteristics. After taxonomic identity was ascertained, these arthropods were
328 categorized and tabulated under various types and sub-types of mimicry with their species
329 name and order. These categories are following.

330 A. “Other” type of imitations

- 331 1) Body part mimicry
- 332 I. Vertebrate eye mimicry (deimatic behaviour)
- 333 II. Auto-mimicry
- 334 2) Imperfect imitation of snakes to various extents
- 335 3) Camouflage
- 336 I. Leaf mimicry
- 337 II. Twig mimicry
- 338 III. Thorn mimicry
- 339 IV. Wood/Bark mimicry
- 340 V. Foliage/different plant parts mimicry
- 341 VI. Flower mimicry
- 342 4) Masquerading
- 343 I. Bird drop mimicry
- 344 II. Dung mimicry
- 345 B. Batesian mimicry
- 346 1) Ant mimicry (myrmecomorphy)
- 347 2) Wasp mimicry
- 348 3) Honeybee mimicry
- 349 4) Bumblebee mimicry
- 350 5) Velvet ant mimicry
- 351 6) Blister beetle mimicry
- 352 7) Ladybird beetle mimicry
- 353 8) Spider mimicry
- 354 9) Mimicry among butterflies (sex-limited mimicry)
- 355 C. Müllerian mimicry (mimicry rings)
- 356 D. Aggressive mimicry
- 357 1) Mealybug mimicry
- 358 2) Ant mimicry
- 359 3) Hoverfly mimicry
- 360 E. Chemical mimicry
- 361 1) Ant mimicry
- 362 2) Honeybee mimicry

363 Batesian mimics may further be accurate or inaccurate, transformational and polymorphic.
364 Additionally, some of the Batesian, aggressive or chemical mimics may exhibit Wasmannian
365 mimicry. Different sub-categories under each major mimicry type were created based on the
366 model group being mimicked in general. This simple sub-classification was crucial for studying
367 mimics in large number and their diversity.

368 **Data submission**

369 Occurrence data of all the taxa reported in the present work was tabulated and deposited to the
370 public repository of Global Biodiversity Information Facility (GBIF) in the standard Darwin
371 Core metadata format developed by Biodiversity Information Standards or Taxonomic
372 Databases Working Group (TDWG) (GBIF, 2025).

373 **Data analysis**

374 Number of mimic species were counted and plotted onto a pie-chart according to the type of
375 mimicry they exhibit. Similarly, a bar graph was plotted to represent share of different
376 arthropod orders in Batesian mimicry. Based on the general model animal being mimicked by
377 Batesian mimics, a bar graph was plotted to indicate at what frequency a particular model is
378 being mimicked. Order-wise share of arthropods in mimicking specific model group was also
379 presented in a bar graph. Heatmap was created to display abundance of mimics in different
380 sub-categories of Batesian mimicry. Share of different orders of mimics in imitating ants
381 (myrmecomorphy) was plotted separately in a bar graph. A pie-chart representing cumulative
382 share of different arthropod orders in mimicry was also plotted along with a Pareto chart to
383 indicate relative share of different orders in mimic diversity. Microsoft Excel and Sigma Plot
384 software were used for generating different graphs and pie-charts. Heatmapper tool was used
385 to create heatmap using the acquired data. This data was further used for quantitating mimic
386 diversity in this area.

387 **Quantitation of mimic diversity**

388 The measurement of species diversity is a commonly assessed parameter in the field of
389 ecology; nevertheless, the methodologies employed for its quantification are intricate and
390 occasionally subject to controversy. The diversity index is a quantitative metric used to assess
391 the level of species diversity within a particular ecological community. What has actually been
392 done in the present work is not the quantitation of species diversity *per se*, but a quantitation

393 of the mimic diversity based on available data. Two popular diversity indices, Shannon-Wiener
394 diversity Index and Gini-Simpson diversity Index, have been used for this purpose with
395 modification. The Shannon Wiener diversity index is an information statistic index, wherein it
396 is assumed that all species are adequately represented in a given sample and that the sampling
397 process is conducted randomly. It measures species richness. The Gini Simpson index is
398 classified as a dominance index due to its tendency to assign greater significance to species
399 that are more common or dominating. In this scenario, the presence of a limited number of
400 individuals from a small number of uncommon species will not have a significant impact on
401 overall biodiversity. It measures the relative abundance of species (Simpson, 1949; Hurlbert,
402 1971). Both of these indexes rely on the number of individuals per species as the primary
403 parameter for their calculation. In present work, number of mimic species per order has been
404 used to substitute number of individuals per species. In present work, these indices have been
405 used to calculate mimic richness over different orders of mimics and mimic dominance over
406 different orders based on the number of mimic species per order.

407 The value of Gini Simpson index (1-D) is derived from Simpson index (D) which is calculated
408 as follows:

$$409 \quad D = \sum_{i=1}^S (ni/N)^2$$

410 Where, where n_i is the number of individuals in species i , and N is the total number of species
411 in the sample. In present work, n_i represents the number of mimic species in an order, and N is
412 the total number or orders containing mimics in the study area.

413 The Shannon Wiener diversity index is calculated as follows:

$$414 \quad H = - \sum_{i=1}^S p_i * \ln(p_i)$$

415 where p_i is the proportion of individuals that belong to species i . In present study, p_i represents
416 the proportion of mimic species that belong to order i .

417

418 **RESULTS**

419 **Weather conditions of Hazaribag Plateau region**

420 Based on daily temperature and precipitation data of nineteen years, the average daily
421 precipitation was calculated as 3.101 mm. Average daily maximum and minimum temperature
422 was calculated as 30.4 °C and 18.7 °C respectively. The yearly pattern of change in
423 precipitation and temperature is shown graphically in Figure 3. The changes are almost similar
424 across years over Hazaribag Plateau region. Such weather conditions favour stability and
425 growth of different communities, high biodiversity and rich bioresources.

426 **GBIF Dataset Specifications**

427 The occurrence data titled “Diversity of terrestrial arthropods exhibiting mimicry from
428 Hazaribagh Plateau region” can be accessed using the following links:

429 Preferred identifier: <https://doi.org/10.15468/kuk8p7>

430 Alternative identifiers: https://cloud.gbif.org/asia/resource?r=arthropodmimics_rahul

431 The dataset includes forty standard Darwin Core terms viz. recordNumber, occurrenceID,
432 datasetName, institutionCode, eventDate, samplingProtocol, basisOfRecord, organismName,
433 scientificName, scientificNameAuthorship, namePublishedInYear, behavior, sex, lifeStage,
434 individualCount, associatedSequences, year, month, day, eventDate, decimalLongitude,
435 decimalLatitude, kingdom, phylum, class, order, genus, specificEpithet, infraspecificEpithet,
436 continent, country, countryCode, stateProvince, locality, habitat, locationRemarks,
437 previousIdentifications, taxonRemarks, recordedBy and recordedByID. Here is a concise yet
438 comprehensive description of each of these 40 standard Darwin Core terms (GBIF, 2025).
439 These are widely used in biodiversity data sharing across the world.

440 **A. Occurrence Terms (information about individual records)**

- 441 1. **recordNumber**: A unique identifier assigned to the specimen or observation by the
442 data recorder (often a field number).
- 443 2. **occurrenceID**: A globally unique identifier for the occurrence record.
- 444 3. **datasetName**: The name of the dataset from which the record originates.
- 445 4. **institutionCode**: An abbreviation identifying the institution housing the data or
446 specimen (e.g., "ZSI" for Zoological Survey of India).
- 447 5. **eventID**: A unique identifier for the sampling event related to this record.

- 448 6. **samplingProtocol**: The method or protocol used during sampling (e.g., "pitfall trap",
449 "transect walk").
- 450 7. **basisOfRecord**: The type of record, such as "PreservedSpecimen",
451 "HumanObservation", "MachineObservation", etc.
- 452 8. **organismName**: The name applied to the organism at the time of recording (may be
453 informal or vernacular).
- 454 9. **scientificName**: The full scientific name (including authorship if known) of the
455 organism.
- 456 10. **scientificNameAuthorship**: The authorship of the scientific name (e.g., "Linnaeus,
457 1758").
- 458 11. **namePublishedInYear**: The year in which the scientific name was published.
- 459 12. **behavior**: Observed behavior of the organism at the time of the event (e.g., "feeding",
460 "mating").
- 461 13. **sex**: The sex of the organism (e.g., "male", "female", "unknown").
- 462 14. **lifeStage**: The developmental stage of the organism (e.g., "adult", "juvenile", "larva").
- 463 15. **individualCount**: The number of individuals recorded in the occurrence.
- 464 16. **associatedSequences**: Links or identifiers to associated genetic or molecular sequence
465 data (e.g., GenBank IDs).

466 **B. Event Terms (time-related information)**

- 467 17. **year**: The year of the occurrence event (e.g., "2025").
- 468 18. **month**: The month of the occurrence event (1–12).
- 469 19. **day**: The day of the occurrence event (1–31).
- 470 20. **eventDate**: The full date (or date range) when the occurrence took place (in ISO 8601
471 format, e.g., "2025-04-17").

472 **C. Location Terms (geographic and environmental information)**

- 473 21. **decimalLongitude**: The longitude of the location in decimal degrees.
- 474 22. **decimalLatitude**: The latitude of the location in decimal degrees.
- 475 23. **kingdom**: The taxonomic kingdom of the organism (e.g., "Animalia").
- 476 24. **phylum**: The taxonomic phylum (e.g., "Chordata").
- 477 25. **class**: The class (e.g., "Insecta").
- 478 26. **order**: The order (e.g., "Lepidoptera").

- 479 27. **genus**: The genus of the organism (e.g., "*Papilio*").
- 480 28. **specificEpithet**: The species name (excluding genus), e.g., "*demoleus*".
- 481 29. **infraspecificEpithet**: The subspecies, variety, or other infraspecific name, if any.
- 482 30. **continent**: The continent where the organism was recorded (e.g., "Asia").
- 483 31. **country**: The name of the country (e.g., "India").
- 484 32. **countryCode**: The ISO 3166-1-alpha-2 country code (e.g., "IN").
- 485 33. **stateProvince**: The state, province, or equivalent administrative division (e.g., "West
486 Bengal").
- 487 34. **locality**: The specific place name or locality description (e.g., "Sundarbans National
488 Park").
- 489 35. **habitat**: Description of the habitat in which the organism was found (e.g., "tropical
490 mangrove", "dry deciduous forest").
- 491 36. **locationRemarks**: Additional notes or comments about the location.

492 **D. Identification Terms (taxonomic interpretation)**

- 493 37. **previousIdentifications**: Any earlier identifications or alternative names that were
494 applied to the specimen or observation.
- 495 38. **taxonRemarks**: Comments or notes about the taxonomic identification or
496 classification.

497 **E. Record-level Metadata**

- 498 39. **recordedBy**: The name(s) of the person(s) who recorded or collected the occurrence.
- 499 40. **recordedByID**: A globally unique identifier for the person(s) who recorded the
500 occurrence (e.g., ORCID, Wikidata ID).

501

502 **Terrestrial arthropods exhibiting “other” type of imitations from Hazaribag Plateau** 503 **region**

504 As many as 59 species from seven arthropod orders were observed to exhibit deimatic
505 behaviour, camouflage, automimicry, imperfect imitation of snakes and masquerading (Table
506 2). This list doesn't include colour camouflages. Ten species of Lepidoptera were found to
507 exhibit deimatic behaviour in the form of display of false eyes or eye spots to threaten the

508 predators. These false eyes are mostly present over the wings in adults or in pair on lateral side
509 of the caterpillar (Figure 4). Round shaped eyes of owls, snakes, frogs and cats are favoured
510 and most effective models for false eye display in many moths like *Spirama retorta* Clerck,
511 1764 and *Erebus macrops* Linnaeus, 1768. Caterpillars of *Theretra* sp. Hübner, 1819 and
512 *Eudocima fullonia* Clerck, 1764 exhibit false eyes on the lateral side of the anterior half of the
513 body. When threatened, these fold their bodies and acquire defensive positions to
514 conspicuously display their eyespots as if these are directly looking at the observer. Some
515 eyespots are not so conspicuous and less perfect in comparison to others. For example, eyespots
516 of *Papilio demoleus* Linnaeus, 1758 butterflies are not as prominent as *Spirama retorta* Clerck,
517 1764 or *Erebus macrops* Linnaeus, 1768. Four species were observed to exhibit automimicry
518 or self-mimicry where a false head is present away from the real head of the mimic to distract
519 the predators momentarily to get time to escape (Figure 5). Injury to head is often lethal. Three
520 Lepidopterans *Tajuria cippus* Moore, 1881, *Spindasis vulcanus* Fabricius, 1775 and *Lampides*
521 *boeticus* Linnaeus, 1767 bear a false head at the posterior tip of each hind wing. The centipede
522 *Scutigera coleoptrata* Linnaeus, 1758 has a posterior end exactly like its real head. Twelve
523 species, all Lepidopteran caterpillars, were found to exhibit imperfect imitation of snakes to
524 various extents like aposematic colouration, presence of false eyes and viper like head (Figure
525 6). The larva of *Papilio demoleus* Linnaeus, 1758 exhibits a distinctive defensive organ called
526 the Osmeterium, which bears a striking resemblance to the forked tongue of a snake. The
527 osmeterial organ is situated in the thoracic region of the body, oriented in an inverted fashion.
528 When the larva encounters any type of threat, it undergoes eversion, leading to the release of a
529 pungent odour. The pungent smell of this chemical serves the function of deterring ants,
530 diminutive spiders, and mantids. Thirty four species were found to mimic different parts of
531 plants or look like plant itself (Figure 7-10). Thirteen species of Lepidoptera were found to
532 mimic leaves to various degrees. *Callidrepana patrana* Moore, 1866, *Callidrepana argenteola*
533 Moore, 1860, *Kallima inachus* Doyère, 1840 and *Gastropacha* sp. Ochsenheimer, 1810 mimic
534 dry leaves so perfectly that it is indistinguishable for an predator to spot these from the bunch
535 of dry leaves (Figure 7). Eight arthropod species from four different orders (Phasmatodea,
536 Mantodea, Lepidoptera and Aranae) mimic twigs and appear as part of the tree branch itself
537 (Figure 8). *Oxyrachis tarandus* Fabricius (cow bug) bears spine like structure on the dorsal side
538 of its thorax due to which the cow bugs look like thorns present over the stem or branches of a
539 plant while they are feeding on the plant sap (Figure 9). Six arthropod species (one Coleoptera
540 and five Lepidoptera) have evolved strategies to blend with woods or bark (Figure 9). The
541 elytra of *Xylorhiza adusta* Wiedemann, 1819 is specialized in both its colour and texture to

542 mimic the coarse bark or surface of the tree trunk. Two bag worm larvae of unidentified
 543 Psychid moths construct a case of wooden twigs around it as protective covering to appear like
 544 the part of a plant itself. Three species of Lepidoptera were found to exactly blend with plants
 545 during their caterpillar stages due to their foliage or plant like look (Figure 10). Three species
 546 of Mantodea were found to exhibit floral patterns to imitate flowers (Figure 10). Seven species
 547 of arthropods were found to exhibit masquerading. Six of the masquerade species from three
 548 orders (four Lepidoptera, one Hemiptera and one Aranae) mimic bird droppings whereas one
 549 spider species mimics mammalian dung (Figure 11).

550

551 **Table 2. Species exhibiting deimatic behaviour, camouflage, automimicry, imperfect**
 552 **imitation of snakes and masquerading (“other” type of imitation)**

S.No.	Mimic species	Mimic life stage	Mimic order	Mimicry subtype	Type of mimicry
1.	<i>Spirama retorta</i> Clerck, 1764	Adult	Lepidoptera	Vertebrate eye mimicry	Body part mimicry
2.	<i>Erebus macrops</i> Linnaeus, 1768	Adult	Lepidoptera		
3.	<i>Theretra</i> sp. Hübner, 1819	Caterpillar	Lepidoptera		
4.	<i>Junonia almana</i> Linnaeus, 1758	Adult	Lepidoptera		
5.	<i>Bicyclus anynana</i> Butler, 1879	Adult	Lepidoptera		
6.	<i>Erebus</i> sp. Latreille, 1810	Adult	Lepidoptera		
7.	<i>Papilio demoleus</i> Linnaeus, 1758	Adult	Lepidoptera		
8.	<i>Junonia orithya</i> Linnaeus, 1758	Adult	Lepidoptera		

9.	<i>Junonia atlites</i> Linnaeus, 1763	Adult	Lepidoptera		
10.	<i>Eudocima fullonia</i> Clerck, 1764	Caterpillar	Lepidoptera		
11.	<i>Tajuria cippus</i> Moore, 1881	Adult	Lepidoptera	Auto-mimicry	
12.	<i>Spindasis vulcanus</i> Fabricius, 1775	Adult	Lepidoptera		
13.	<i>Lampides boeticus</i> Linnaeus, 1767	Adult	Lepidoptera		
14.	<i>Scutigera coleoptrata</i> Linnaeus, 1758	Adult	Scutigero-morpha		
15.	<i>Eupanacra mydon</i> Walker, 1856	Caterpillar	Lepidoptera	Aposematic display of colours,	Imperfect imitation of snakes to various extents
16.	<i>Daphnis nerii</i> Linnaeus, 1758	Caterpillar	Lepidoptera	display of false eyes,	
17.	<i>Pergesa acteus</i> Cramer, 1779	Caterpillar	Lepidoptera	viper like shape of the head, snake tongue like structural display	
18.	Eight unidentified Sphingid moth larvae	Caterpillar	Lepidoptera		
19.	<i>Papilio demoleus</i> Linnaeus, 1758	Caterpillar	Lepidoptera		
20.	<i>Callidrepana patrana</i> Moore, 1866	Adult	Lepidoptera	Leaf mimicry	Camouflage

21.	<i>Callidrepana argenteola</i> Moore, 1860	Adult	Lepidoptera		
22.	<i>Cricula trifenestrata</i> Helfer, 1837	Adult	Lepidoptera		
23.	<i>Telchines vialis</i> Moore, 1883	Adult	Lepidoptera		
24.	<i>Elymnias</i> Hübner, 1818	Adult	Lepidoptera		
25.	<i>Kallima inachus</i> Doyère, 1840	Adult	Lepidoptera		
26.	<i>Sacada approximans</i> Leech, 1889	Adult	Lepidoptera		
27.	<i>Hamodes propitia</i> Guérin-Méneville, 1831	Adult	Lepidoptera		
28.	An unidentified moth species	Adult	Lepidoptera		
29.	<i>Omphacodes directa</i> Walker, 1861	Adult	Lepidoptera		
30.	<i>Comibaena cassidara</i> Guenée, 1858	Adult	Lepidoptera		
31.	<i>Daphnis nerii</i> Linnaeus, 1758	Adult	Lepidoptera		
32.	<i>Gastropacha</i> sp. Ochsenheimer, 1810	Adult	Lepidoptera		

33.	<i>Peucetia viridana</i> Stoliczka, 1869	Adult	Aranae	Twig mimicry	
34.	<i>Medauroidea</i> sp. Zompro, 2000	Adult	Phasmatodea		
35.	<i>Schizocephala bicornis</i> Linnaeus, 1758	Adult	Mantodea		
36.	<i>Carausius morosus</i> Sinéty, 1901	Adult	Phasmatodea		
37.	<i>Aethalochroa insignis</i> Wood- Mason, 1878	Adult	Mantodea		
38.	<i>Phyllocrania</i> sp. Burmeister, 1838	Adult	Mantodea		
39.	Two caterpillars of unidentified Geomatrid moths	Caterpillar	Lepidoptera		
40.	<i>Athyma selenophora</i> , <u>Kollar</u> , 1844	Caterpillar	Lepidoptera		
41.	<i>Oxyrachis tarandus</i> Fabricius	Adult	Hemiptera	Thorn mimicry	
42.	<i>Euthalia lubentina</i> Cramer, 1777	Caterpillar	Lepidoptera	Foliage / different plant parts mimicry	
43.	<i>Miresa</i> sp. Walker, 1855	Caterpillar	Lepidoptera		

44.	<i>Rapala</i> sp. Moore, 1881	Caterpillar	Lepidoptera		
45.	<i>Xylorhiza</i> <i>adusta</i> Wiedemann, 1819	Adult	Coleoptera	Wood / bark mimicry	
46.	<i>Phalera grotei</i> Moore, 1859	Adult	Lepidoptera		
47.	<i>Phalera</i> sp. Hübner, 1819 (unidentified species)	Adult	Lepidoptera		
48.	A bag worm larva of an unidentified Psychid moth	Caterpillar	Lepidoptera		
49.	A bag worm larva of an unidentified Psychid moth	Caterpillar	Lepidoptera		
50.	<i>Creobroter</i> <i>pictipennis</i> Wood-Mason, 1878	Adult	Mantodea	Flower mimicry	
51.	<i>Creobroter</i> <i>gemmatus</i> Saussure 1869	Adult	Mantodea		
52.	<i>Theopropus</i> <i>elegans</i> Westwood, 1832	Adult	Mantodea		
53.	<i>Acontia nitidula</i> Fabricius, 1787	Adult	Lepidoptera	Bird drops mimicry	Masquera- ding

54.	<i>Papilio</i> sp. Linnaeus, 1758	Caterpillar	Lepidoptera		
55.	<i>Leucinodes</i> <i>orbonalis</i> Guenée, 1854	Adult	Lepidoptera		
56.	<i>Tonica</i> <i>niviferana</i> Walker, 1864	Adult	Lepidoptera		
57.	<i>Gasterocantha</i> <i>kuhli</i> C.L.Koch, 1837	Adult	Aranae		
58.	<i>Pulvinaria</i> <i>urbicola</i> Cockerell, 1893	Ovipositing female	Hemiptera		
59.	<i>Pasilobus</i> <i>kotigeharus</i> Tikadar, 1963	Adult	Aranae	Dung mimicry	

553

554 **Terrestrial arthropods exhibiting Batesian mimicry from Hazaribag Plateau region**

555 Batesian mimics are not very rare in Hazaribag Plateau region. Sixty one arthropod species
556 have been documented to exhibit Batesian mimicry (Table 3). Out of these, 25 species are ant
557 mimics or myrmecomorphs (Figure 12-13). These species include both accurate ant mimics
558 and inaccurate ant mimics. For example, *Myrmarachne melanocephala* MacLeay, 1839 and
559 *Myrmaplata plataleoides* O. Pickard-Cambridge, 1869 strongly resemble their specific model
560 ant species. These are specialists and are accurate ant mimics. Whereas *Portia albimana*
561 Simon, 1900 and *Harmochirus brachiatus* Thorell, 1877 mimic black ants in general due to
562 their partial resemblance with black ants. These are generalists and are inaccurate ant mimics.
563 Some Hemipteran species like *Metochus uniguttatus*, Thunberg, 1822 and *Dieuches leucocera*,
564 Walker 1872 even bear contrasting colour patterns of black and white to imitate ants in place
565 of an ant like body structure. One of the interesting findings of the present study is about a
566 mantis *Euantissa pulchra* Olivier, 1792 which exhibits cannibalistic nymphal siblicide apart
567 from mimicry during starving conditions. *Myrmaplata plataleoides* O. Pickard-Cambridge,

1869 also exhibit transformational and polymorphic mimicry (Figure 14). Out of all myrmecomorphic species reported from Hazaribag Plateau region, 12 (including a species which is also a transformational and a polymorphic mimic) are spiders (Aranae) and other 13 include mimics from the orders Hemiptera, Mantodea, Lepidoptera, Orthoptera and Coleoptera (Figure 30). There are three velvet ant (Mutillidae) mimicking species reported from the study area out of which two are spiders (Aranae) and one is a Diptera (Figure 15). There are fifteen wasp mimics (Figure 16-17) out of which nine are moths (Lepidoptera), four are Diptera and two are Neuroptera. There are four honeybee mimics and all belong to Diptera (Figure 18). One mimic from Lepidoptera and three from Diptera (total four) mimic bumblebees (Figure 19). There are two blister beetle mimicking Cerambycids (Order Coleoptera) (Figure 20). There are three inaccurate ladybird beetle mimics (two Aranae and one Mantodea) (Figure 21). Out of these three *Theridula gonygaster* Simon, 1873 and *Mangora baii* Mi and Li, 2021 exhibit conspicuous ladybird beetle like spots over their plump round abdomen. The inner face of the flattened oval femur of the forelimb of the mantis *Hestiasula brunneriana* Saussure, 1871 mimics pattern and shape of red-black ladybird beetle (Figure 21A). The forelegs are alternatively protracted and retracted to display these chromatic markings during defensive behaviour, courtship, and intra-specific communication (Edmunds, 1972; Loxton, 1979; Larsen, 2002; Zhu *et al.*, 2012; Schwarz and Konopik, 2014). *Brenthia* sp. Clemens, 1860 (Lepidoptera) mimics sitting posture of Salticids (jumping spiders) and display its colour patterns to look like a jumping spider in general to evade attacks of far by predators (Figure 22). Rota and Wagner (2006) had previously reported this behaviour. Two butterfly (Lepidoptera) species exhibiting sex-limited Batesian mimicry have been reported from the study area. Female butterflies of *Papilio polytes* Linnaeus, 1758 form *Stichius* mimic *Pachliopta aristolochiae* Fabricius, 1775 and female of *Hyplolimnas misippus* Linnaeus, 1764 is known to mimic *Danaus chrysippus* Linnaeus, 1758 (Figure 23). Sex-limited mimicry is associated with survival of the species and race continuation as female bears the future offspring in the form of eggs in its body for a longer duration.

Table 3. Batesian mimics and their models from Hazaribag Plateau region

S.No.	Mimic species	Mimic order	Mimic life stage	Model / Remarks	Mimicry sub-type
-------	---------------	-------------	------------------	-----------------	------------------

1.	<i>Myrmarachne melanocephala</i> MacLeay, 1839	Aranae	Adult	<i>Tetraponera rufonigra</i> Jerdon, 1851	Ant mimicry
2.	<i>Myrmarachne</i> sp. McLeay, 1839	Aranae	Adult	<i>Camponotus compressus</i> Fabricius, 1787	
3.	<i>Myrmarachne</i> sp. McLeay, 1839	Aranae	Adult	Red-black bicoloured ant	
4.	<i>Myrmaplata plataleoides</i> O. Pickard- Cambridge, 1869 typical red form	Aranae	Adult (collected from Pondicherry for comparison)	<i>Oecophylla smaragdina</i> Fabricius, 1775	
5.	<i>Myrmaplata plataleoides</i> O. Pickard- Cambridge, 1869 melanic morpho-variant	Aranae	Adult	<i>Camponotus compressus</i> Fabricius, 1787	
6.	<i>Myrmecotypus</i> sp. O. Pickard- Cambridge, 1894	Aranae	Adult	<i>Camponotus compressus</i> Fabricius, 1787	
7.	<i>Corinnomma severum</i> Thorell, 1877	Aranae	Adult	<i>Camponotus compressus</i>	

				Fabricius, 1787
8.	<i>Castianeira</i> sp. Keyserling, 1879	Aranae	Adult	<i>Camponotus</i> <i>compressus</i> Fabricius, 1787
9.	<i>Castianeira</i> <i>flavipes</i> Gravely, 1931	Aranae	Adult	<i>Camponotus</i> <i>compressus</i> Fabricius, 1787
10.	<i>Portia albimana</i> Simon, 1900	Aranae	Adult	Black ant (generalist)
11.	<i>Idiops</i> sp. Perty, 1833	Aranae	Adult	<i>Camponotus</i> <i>compressus</i> Fabricius, 1787
12.	<i>Harmochirus</i> <i>brachiatus</i> Thorell, 1877	Aranae	Adult	<i>Camponotus</i> <i>compressus</i> Fabricius, 1787
13.	<i>Macroxiphus</i> sp. Pictat, 1888	Orthoptera	Nymph	Ant (generalist)
14.	<i>Letana</i> <i>megastridula</i> Ingrisch, 1990	Orthoptera	Nymph	<i>Camponotus</i> <i>compressus</i> Fabricius, 1787

15.	<i>Metochus uniguttatus</i> , Thunberg, 1822	Hemiptera	Adult	<i>Camponotus compressus</i> Fabricius, 1787
16.	<i>Dieuches leucocera</i> , Walker 1872	Hemiptera	Adult	<i>Camponotus compressus</i> Fabricius, 1787
17.	Ant mimicking nymph of a Coreid bug	Hemiptera	Nymph	<i>Camponotus compressus</i> Fabricius, 1787
18.	<i>Riptortus serripes</i> Fabricius, 1775	Hemiptera	Nymph	<i>Camponotus compressus</i> Fabricius, 1787
19.	<i>Gralliclava horrens</i> Dohrn, 1860	Hemiptera	Nymph	<i>Camponotus compressus</i> Fabricius, 1787
20.	<i>Dulichius inflatus</i> Kirby, 1891	Hemiptera	Adult	<i>Polyrrhachis exercita</i> Walker, 1859
21.	<i>Stauropus alternus</i> Walker, 1855	Lepidoptera	Caterpillar (First instar)	Black ant (generalist)

22.	<i>Euantissa pulchra</i> Olivier, 1792	Mantodea	Nymph	<i>Camponotus compressus</i> Fabricius, 1787	
23.	<i>Hestiasula brunneriana</i> Saussure, 1871	Mantodea	Nymph	<i>Camponotus compressus</i> Fabricius, 1787	
24.	<i>Neocollyris bonellii</i> , Guérin-Méneville, 1833	Coleoptera	Adult	<i>Camponotus compressus</i> Fabricius, 1787	
25.	<i>Clypeuspinus</i> sp. Balkenohl, 2021	Coleoptera	Adult	<i>Camponotus compressus</i> Fabricius, 1787	
26.	<i>Myrmaplata plataleoides</i> O. Pickard-Cambridge, 1869 typical red form	Aranae	Different moulting stages (collected from Pondicherry for comparison)	Different moults mimic different ants	Ant mimicry (Transformational mimicry)
27.	<i>Myrmaplata plataleoides</i> O. Pickard-Cambridge, 1869	Aranae	Adult	Different morpho-variant mimics	Ant mimicry (Polymorphic mimicry)

				different ants	
28.	<i>Coenoptychus pulcher</i> Simon 1885	Aranae	Adult	Red-black velvet ant (generalist)	Velvet ant mimicry
29.	<i>Graptartia granulosa</i> Simon, 1896	Aranae	Adult	Red-black velvet ant (generalist)	
30.	<i>Hemipenthes</i> sp. Loew, 1869	Diptera	Adult	Velvet ant (generalist)	
31.	<i>Amata passalis</i> Fabricius, 1781	Lepidoptera	Adult	Yellow- black banded wasp (generalist)	Wasp mimicry
32.	<i>Amata cyssea</i> Stoll, 1782	Lepidoptera	Adult	Yellow- black banded wasp (generalist)	
33.	<i>Amata</i> sp. Fabricius, 1807	Lepidoptera	Adult	Yellow- black banded wasp (generalist)	
34.	<i>Amata</i> sp. Fabricius, 1807	Lepidoptera	Adult	Yellow- black banded wasp (generalist)	
35.	<i>Amata sperbius</i> Fabricius, 1787	Lepidoptera	Adult	Yellow- black banded	

				wasp (generalist)
36.	<i>Syntomoides imaon</i> Cramer, 1779	Lepidoptera	Adult	Yellow- black banded wasp (generalist)
37.	<i>Eressa confinis</i> Walker, 1854	Lepidoptera	Adult	Yellow- black banded wasp (generalist)
38.	<i>Eressa</i> sp. Walker, 1854	Lepidoptera	Adult	Yellow- black banded wasp (generalist)
39.	<i>Caeneressa diaphana</i> Kollar, 1844	Lepidoptera	Adult	Yellow- black banded wasp (generalist)
40.	<i>Episyrphus balteatus</i> De Geer, 1776	Diptera	Adult	Yellow- black banded wasp (generalist)
41.	<i>Bactrocera cucurbitae</i> Coquillett, 1849	Diptera	Adult	Yellow- black banded wasp (generalist)

42.	<i>Asarkina salvia</i> , Fabricius 1794	Diptera	Adult	Yellow- black banded wasp (generalist)	
43.	<i>Chrysanthrax</i> sp. Osten- Sacken, 1886	Diptera	Adult	<i>Polistes</i> <i>olivaceus</i> DeGeer, 1773	
44.	<i>Euclimacia</i> sp. Enderlein, 1910	Neuroptera	Adult	<i>Polistes</i> <i>olivaceus</i> DeGeer, 1773	
45.	<i>Mantispa</i> sp. Illiger, 1798	Neuroptera	Adult	<i>Phimenes</i> <i>flavopictus</i> Blanchard, 1845	
46.	<i>Eristalis tenax</i> Linnaeus, 1758	Diptera	Adult	Honeybee (generalist)	Honeybee mimicry
47.	<i>Eristalinus</i> sp. Linnaeus, 1758	Diptera	Adult	Honeybee (generalist)	
48.	<i>Mesembrius</i> <i>bengalensis</i> Wiedemann, 1819	Diptera	Adult	Honeybee (generalist)	
49.	<i>Stomorhina</i> sp. Rondani, 1861	Diptera	Adult	Honeybee (generalist)	
50.	<i>Bombylisoma</i> sp. Rondani, 1856	Diptera	Adult	Bumblebee (generalist)	Bumblebee mimicry
51.	<i>Bombomyia</i> sp. Greathead, 1995	Diptera	Adult	<i>Bombus</i> <i>rufofasciatus</i>	

				s Smith, 1852	
52.	<i>Bombylella</i> sp. Greathead, 1995	Diptera	Adult	Bumblebee (generalist)	
53.	<i>Cephonodes hylas</i> Linnaeus, 1771	Lepidoptera	Adult	Bumblebee (generalist)	
54.	<i>Purpuricenus sanguinolentus</i> Olivier, 1795	Coleoptera	Adult	<i>Hycleus phaleratus</i> (= <i>Mylabris phalerata</i>) Thunberg, 1791 red morph	Blister beetle mimicry
55.	<i>Zonopterus flavitarsis</i> Hope, 1843	Coleoptera	Adult	<i>Hycleus pustulatus</i> (= <i>Mylabris pustulata</i>) Pallas, 1781 yellow morph	
56.	<i>Theridula gonygaster</i> Simon, 1873	Aranae	Adult	Ladybird beetle (generalist)	Ladybird beetle mimicry
57.	<i>Hestiasula brunneriana</i> Saussure, 1871	Mantodea	Adult	Ladybird beetle (generalist)	
58.	<i>Mangora bairi</i> Mi and Li, 2021	Aranae	Adult	Ladybird beetle (generalist)	
59.	<i>Brenthia</i> sp. Clemens, 1860	Lepidoptera	Adult	Salticid	Spider mimicry

60.	<i>Papilio polytes</i> Linnaeus, 1758 form <i>Stichius</i>	Lepidoptera	Adult female	<i>Pachliopta aristolochiae</i> Fabricius, 1775	Lepidoptera (Sex-limited mimicry)
61.	<i>Hyplolimnas misippus</i> Linnaeus, 1764	Lepidoptera	Adult female	<i>Danaus chrysippus</i> Linnaeus, 1758	

596

597 **Terrestrial arthropods exhibiting Müllerian mimicry from Hazaribag Plateau region**

598 Twelve Müllerian mimicry rings comprising of 46 species were discovered from Hazaribag
599 Plateau region in the present study (Table 4). In general, these mimicry rings comprise of eight
600 species of velvet ants, six species of wasps, four species of black ants, four species of
601 bicoloured ants, three species of red ants, two species of adult butterflies, two more species of
602 adult butterflies, caterpillars of two butterfly species, five species of black ladybird beetles,
603 four species of spotted ladybird beetles, five species of Pyrrhocorid bugs and two blister beetle
604 species respectively (Figure 24-25). All of these species are obnoxious and distasteful in nature
605 to general predators. This distastefulness along with the display of aposematic colour patterns
606 incur relative survival benefits to all the members of each mimicry ring.

607

608 **Table 4. Different Müllerian mimicry rings from Hazaribag Plateau region**

S.No.	Member species of the mimicry ring	Order of mimics
1.	Velvet ants: <i>Orientilla</i> sp. Lelej, 1979; <i>Smicromyrme</i> sp. Thomson, 1870; <i>Trogaspidia villosa</i> Fabricius, 1775; <i>Physetopoda</i> sp. Schuster, 1949; <i>Dasylabris argentipes</i> Smith, 1855; <i>Ephucilla</i> sp. Lelej, 1995; <i>Kurzenkotilla</i> sp. Lelej, 2005	Hymenoptera
2.	Wasps: <i>Delta pyriforme pyriforme</i> Fabricius, 1775; <i>Rhopalidia fasciata</i> Fabricius, 1804; <i>Vespa orientalis</i> Linnaeus, 1761; <i>Oreumenoides edwardsii</i> de Saussure,	Hymenoptera

	1852; <i>Polistes (Polistella) stigma tumulus</i> Fabricius, 1798; <i>Vespa tropica</i> Linnaeus, 1758	
3.	Black ants: <i>Paratrechina longicornis</i> Latreille, 1802; <i>Camponotus angusticollis</i> Jerdon 1851; <i>Camponotus compressus</i> Fabricius, 1787; <i>Camponotus sericius</i> Fabricius, 1798	Hymenoptera
4.	Bicoloured ants: <i>Camponotus irritans</i> F. Smith, 1857; <i>Tetraponera rufonigra</i> Jerdon, 1851; <i>Myrmicoria brunnea</i> Saunders, 1842; <i>Tetramorium smithi</i> Mayr, 1879	Hymenoptera
5.	Red ants: <i>Anoplolepis gracilipes</i> F. Smith, 1857; <i>Oecophylla smaragdina</i> Fabricius, 1775; <i>Monomorium pharaonis</i> Linnaeus, 1758	Hymenoptera
6.	Butterflies: <i>Danaus chrysippus</i> Linnaeus, 1758; <i>Acraea violae</i> Fabricius, 1775	Lepidoptera
7.	Butterflies: <i>Hypolimnas bolina</i> Linnaeus, 1758; <i>Hypolimnus misippus</i> Linnaeus, 1764	Lepidoptera
8.	Black ladybird beetles: <i>Scymnus</i> sp. Kugelann, 1794; <i>Cryptolaemus montrouzieri</i> Mulsant, 1850; <i>Hyperaspis</i> sp. Chevrolat in Dejean, 1837; <i>Cryptognatha</i> Mulsant, 1850; <i>Chilocorus nigritus</i> Fabricius, 1798	Coleoptera
9.	Spotted ladybird beetles: <i>Cheilomenes sexmaculata</i> Fabricius, 1781; <i>Propylea japonica</i> Thunberg, 1781; <i>Harmonia octomaculata</i> Fabricius, 1781; <i>Coccinella transversalis</i> Fabricius, 1781	Coleoptera
10.	Pyrrhocorid bugs: <i>Dysdercus cingulatus</i> Fabricius, 1775; <i>Pyrrhocoris apterus</i> Linnaeus, 1758; <i>Spilostethus hospes</i> Fabricius, 1794; <i>Dysdercus koenigii</i> Fabricius, 1775; <i>Probergrothius nigricornis</i> Stal, 1861	Hemiptera

11.	Butterfly caterpillars: <i>Euploa core</i> Cramer, 1780; <i>Danaus chrysippus</i> Linnaeus, 1758	Lepidoptera
12.	Blister beetles: <i>Hycleus pustulatus</i> (= <i>Mylabris pustulata</i>) Thunberg, 1821; <i>Mylabris phalerata</i> (= <i>Hycleus phaleratus</i>) Pallas, 1781	Coleoptera

609

610 Terrestrial arthropods exhibiting aggressive mimicry from Hazaribag Plateau region

611 Five species of arthropods exhibiting aggressive mimicry have been reported from Hazaribag
612 Plateau region (Table 5, Figure 26). Larvae of three black ladybird beetles *Scymnus* sp.
613 Kugelann, 1794, *Cryptolaemus motrouzeiri* Mulsant, 1850 and *Hyperaspis* Chevrolat in
614 Dejean, 1837 mimic mealybugs to fool ants and feed on mealy bugs as ants rear and protect
615 mealybugs for honeydew. By mimicking mealybugs, these aggressive mimics evade attacks of
616 ants. Similarly, the adult of the crab spider *Amyciaea forticeps* O. Pickard-Cambridge, 1873
617 (Aranae), which attacks workers of the weaver ant *O. smaragdina*, is arguably the most
618 compelling example of aggressive mimicry. *A. forticeps* does not exactly resemble *O.*
619 *smaragdina* under typical conditions but has same colour as these ants and bears false
620 structures like eyes of ants on its abdomen. While hunting, *A. forticeps* adopts a behaviour that
621 makes it appear as though an *O. smaragdina* worker is in trouble or in danger, which attracts
622 the attention of ant workers who come closer to help it. The spider then leaps on its prey and
623 starts consuming it. In one of the observations of the present study, a parasitoid wasp
624 *Echthromorpha agrestoria* Swederus, 1787 (Hymenoptera) was found to recognize and learn
625 the presence of similar colour pattern of the adults of the fly *Episyrphus viridaureus*
626 Wiedemann, 1824 (Diptera) with respect to its own body colour. By learning these
627 resemblances, the wasp effectively parasitized the predatory larvae of these flies.

628

629 **Table 5. Aggressive mimicry among arthropods of Hazaribag Plateau region**

S.No.	Mimic species	Mimic order	Mimic life stage	Model / Remarks	Mimicry sub-type
-------	---------------	-------------	------------------	-----------------	------------------

1.	<i>Scymnus</i> sp. Kugelann, 1794	Coleoptera	Larva	Mealybugs (generalist)	Mealybug mimicry
2.	<i>Cryptolaemus motrouzeiri</i> Mulsant, 1850	Coleoptera	Larva	Mealybugs (generalist)	
3.	<i>Hyperaspis</i> Chevrolat in Dejean, 1837	Coleoptera	Larva	Mealybugs (generalist)	
4.	<i>Amyciaea forticeps</i> O. Pickard- Cambridge, 1873	Aranae	Adult	<i>Oecophylla smaragdina</i> Fabricius, 1775	Ant mimicry
5.	<i>Echthromorpha agrestoria</i> Swederus, 1787	Hymenoptera	Adult	Opportunistic mimic of <i>Episyrphus viridaureus</i> Wiedemann, 1824	Hoverfly mimicry

630

631 **Terrestrial arthropods exhibiting chemical mimicry from Hazaribag Plateau region**

632 Chemical mimicry is hard to explore as it requires chemical analysis of the mimic with respect
633 to the chemical profile of its model species. Based on available literature on arthropods
634 exhibiting chemical mimicry, three species have been identified from Hazaribag Plateau region
635 exhibiting chemical mimicry (Table 6, Figure 27). Two species of the death head moths
636 (Lepidoptera) *Acherontia lachesis* Fabricius, 1798 and *Acherontia styx* Westwood, 1847 have
637 been discovered which are known to mimic bee odour to enter beehives uninjured and steal
638 honey. Another discovered species is a Coleoptera *Paussus* sp. Linnaeus, 1775 which exhibits
639 Wasmannian mimicry where its larvae trick ants by mimicking their chemical signatures to be
640 fed by them.

641

642 **Table 6. Arthropod chemical mimics from Hazaribag Plateau region**

S.No.	Mimic species	Mimic order	Mimic life stage	Model / Remarks	Mimicry sub-type
1.	<i>Paussus</i> sp. Linnaeus, 1775	Coleoptera	Larva, adult	Larvae trick ants to be fed by them (Wasmannian mimicry)	Ant mimicry
2.	<i>Acherontia styx</i> Westwood, 1847	Lepidoptera	Adult	Nocturnal, steals honey	Bee mimicry
3.	<i>Acherontia lachesis</i> Fabricius, 1798	Lepidoptera	Adult	Nocturnal, steals honey	

643

644 **Analysis of data on Batesian mimicry and myrmecomorphy from Hazaribag Plateau**
 645 **region**

646 Regarding terrestrial arthropod mimics, as already discussed above, 174 species have been
 647 reported to exhibit different kinds of mimicry (excluding simple colour camouflages).
 648 Thorough data analysis reveals that Batesian mimicry is exhibited by largest number of species
 649 (35%) at Hazaribag Plateau region (Figure 28A). Among Batesian mimics, ant mimicry is
 650 widespread and most common followed by wasp mimicry (Figure 28B). Order wise analysis
 651 of mimics reveal that spiders (Aranae) are at the top in terms of the number of species
 652 exhibiting myrmecomorphy as well as for exhibiting Batesian mimicry. Lepidoptera has
 653 highest number of wasp mimics followed by Diptera having highest number of honeybee
 654 mimics (Figure 29A). Ant mimicry is the most favoured kind of Batesian mimicry among
 655 arthropods (Figure 29B). Order Aranae has the highest number of ant mimicking species
 656 followed by orders Hemiptera, Mantodea, Orthoptera, Coleoptera and Lepidoptera (Figure 30).

657

658 **2.3.8. Mimic diversity of Hazaribag Plateau region**

659 Hazaribag Plateau region is endowed with magnificent flora and fauna. Plotting the total
660 number of terrestrial arthropod species exhibiting all kinds of mimicry from different orders
661 on a pie chart reveals that species from total eleven orders participate in mimetic displays
662 (Figure 31A). Out of these orders, Lepidoptera has the highest number on mimic species
663 followed by Hymenoptera and Aranae. Order Lepidoptera and Aranae have almost all kind of
664 mimics but Hymenoptera are primarily Müllerian mimics. Pareto chart displaying frequency
665 of different mimics and their share in the mimic diversity reflects that Lepidoptera,
666 Hymenoptera, Aranae, Coleoptera, Hemiptera and Diptera together account for more than 90%
667 of the mimics (Figure 31B). The calculations of different diversity indices for quantitating
668 mimic diversity of Hazaribag Plateau region have been shown in tables 7, 8 and 9. As already
669 mentioned, these indices have been modified for the present study for quantitation of the
670 “mimic order diversity”, not the “species diversity” of an area, as the “number of species per
671 order” has replaced “the number of individuals per species” in calculations of these indices.
672

673 **Table 7. Calculation of Simpson Index for quantitating mimic diversity**

S.NO.	ORDER OF MIMICS	NO. OF MIMICS (n)	n/N	(n/N) ²
1	Lepidoptera	66	0.379	0.144
2	Scutigermorpha	1	0.006	0.000
3	Aranae	22	0.126	0.016
4	Phasmatodea	2	0.011	0.000
5	Mantodea	9	0.052	0.003
6	Hemiptera	13	0.075	0.006
7	Coleoptera	20	0.115	0.013
8	Orthoptera	2	0.011	0.000
9	Diptera	12	0.069	0.005
10	Neuroptera	2	0.011	0.000
11	Hymenoptera	25	0.144	0.021
TOTAL		N=174		Total=0.207 $D = \sum_{i=1}^s (ni/N)^2$ Therefore, D=0.207

674

675 The value of Simpson index spans from 0 to 1. As the value increases, diversity decreases.
676 Given the rather counterintuitive nature of this interpretation, it is common practise to compute
677 Gini Simpson index of diversity by subtracting D from 1 expressed as 1-D. An increase in the
678 value of this indicator corresponds to an increase in diversity. The calculation of Simpson's
679 reciprocal index can alternatively be performed by taking the reciprocal of D, expressed as 1/D.
680 The minimum value for this index is 1, while the maximum value corresponds to the total
681 number of species (total number of order in case of the present study).The Simpson index
682 calculated in table 7 provides a value of similarity index, D, i.e., 0.207. The range of values for
683 Simpson index spans from 0 to 1. As the value increases, diversity decreases (Somerfield *et*
684 *al.*, 2008). The Gini Simpson diversity index as calculated in table 9 provides the value of
685 mimic diversity, i.e., 0.8. This value implies high diversity. Likewise the value of Simpson
686 reciprocal index as calculated in table 9, i.e., 4.94 (out of 11) also reflects high diversity among
687 mimic orders.

688

689 **Table 8. Calculation of Shannon-Weiner Index for quantitating mimic diversity**

S.NO.	ORDER OF MIMICS	NO. OF MIMICS (n _i)	p _i	ln(p _i)	p _i *ln(p _i)
1	Lepidoptera	66	0.379	-0.970	-0.368
2	Scutigeromorpha	1	0.006	-5.116	-0.031
3	Aranae	22	0.126	-2.071	-0.261
4	Phasmatodea	2	0.011	-4.510	-0.050
5	Mantodea	9	0.052	-2.957	-0.154
6	Hemiptera	13	0.075	-2.590	-0.194
7	Coleoptera	20	0.115	-2.163	-0.249
8	Orthoptera	2	0.011	-4.510	-0.050
9	Diptera	12	0.069	-2.674	-0.184
10	Neuroptera	2	0.011	-4.510	-0.050
11	Hymenoptera	25	0.144	-1.938	-0.279
TOTAL		N=174			Total=-1.869

				$H = - \sum_{i=1}^S p_i * \ln(p_i)$ <p>Therefore, H=1.869</p>
--	--	--	--	---

690

691 The calculated value of Shannon Weiner diversity index from table 8, which is also given in
 692 table 9, is 1.87. There is no upper limit to the Shannon Weiner index as such but in real-world
 693 ecological data, its values usually range from 1.5-3.5 (Ortiz-Burgos, 2015). Therefore, the
 694 value of 1.87 indicates moderate level of diversity with more evenness in the distribution of
 695 the number of mimic species across different orders. The term "evenness" pertains to the degree
 696 of similarity in the abundances of various species within a given population (in case of present
 697 study it is various orders in the study area). Its value varies from 0 to 1, with a value of 1
 698 indicating a state of total evenness. As apparent from table 9, the value of evenness has been
 699 calculated as 0.781 which implies near-even abundance of different mimic species across
 700 different orders.

701

702 **Table 9. Different indices of mimic diversity at Hazaribag Plateau region**

DIVERSITY INDICES		
S.NO.	GINI SIMPSON DIVERSITY INDEX	VALUES
1.	Simpson Index (D)	0.2
2.	Gini Simpson Diversity Index (1-D)	0.8
3.	Simpson Reciprocal Index (1/D)	4.94
S.NO.	SHANNON WEINER DIVERSITY INDEX	VALUES
4.	Shannon Weiner Diversity Index (H)	1.87
5.	Evenness [E=H/ln(S)]	0.781
6.	Richness (S, Number of Orders)	11
7.	Total Number of Mimics (N)	174
8.	Average Number of Mimics per Order (M=N/S)	15.8

703

704 **DISCUSSION**

705 Considering the ancient origin of landmass and biodiversity over Chotanagpur Plateau as
706 evident from geological and palaeontological studies conducted by various authors, it won't be
707 an exaggeration to consider Chotanagpur Plateau as a cradle of biodiversity. Hazaribag Plateau
708 is an integral part of this ancient landmass with shared characteristics of the entire Chotanagpur
709 Plateau. Instead of having such uniqueness, this area is underexplored in terms of its flora and
710 fauna. Previous studies on arthropod diversity from this area have been narrow and superficial.
711 Considering these issues pertaining to such studies, present work was undertaken to explore
712 arthropod diversity of Hazaribag Plateau region under the broader umbrella of mimicry.
713 Mimicry has fascinated naturalists for centuries. Mimicry among arthropods is being studied
714 since the times of Darwin, Bates, Wallace, etc. Present study is an unconventional work, one
715 of its kind. Most previous works related to biodiversity focus on natural taxonomic groups.
716 Present work deals with biodiversity of terrestrial arthropods of Hazaribag Wildlife Sanctuary
717 under the common umbrella of mimicry. Instead of selecting a natural clade, a behavioural
718 trait has been considered to study a group of animals. *Prima facie* present approach may appear
719 artificial as different mimics may not be taxonomically inter-related but such an approach
720 allowed to identify various arthropod model for studying mimicry in detail for the present as
721 well as future work. Such an approach unites morpho-taxonomy with behavioural biology.
722 Stable weather conditions over years have favoured high biodiversity at Hazaribag Plateau
723 region. High biodiversity implies more ecological interactions. In such an ecosystem, diversity
724 is also there among predators as well as prey species. Such interactions give rise to evolutionary
725 arms race. Report of a large number of arthropod mimic species from Hazaribag Plateau region
726 in the present study is a testimony of this arms race. Almost all types of mimicry have been
727 recorded among terrestrial arthropods from this region. Among these Batesian mimics are the
728 most abundant. Among Batesian mimics, ant mimics are largest in number. Spiders are the
729 most abundant among arthropods that mimic ants. Ants possess powerful mandibles, inject
730 venom through their stingers, and are capable of summoning other members of their colony for
731 support. In contrast, spiders lack chemical defenses and tend to be solitary creatures.
732 Myrmecomorphy helps them acquire extra layer of protection over predatory attacks. Some
733 myrmecomorphic spiders feed upon ants itself as discussed in case of aggressive mimicry by
734 *Amyciaea forticeps* O. Pickard-Cambridge, 1873. Note that some arthropods like *Papilio* sp.
735 Linnaeus, 1758 use more than one mode of imitations (masquerading in case of early instar
736 larvae, camouflage in case of late instar larvae and Batesian mimicry among adult females)
737 across different stages of their life cycle as part of their survival strategies. There is a wide

738 range of variability among various arthropod mimics in terms of the specific form of imitation
739 they display.

740

741 **CONCLUSIONS**

742 Instead of being the ancient most landmass of the world harbouring rich biodiversity,
743 Chotanagpur Plateau region is completely neglected by modern scientists. The existing works
744 are narrow and focussed on collecting and cataloguing species. A holistic behavioural,
745 evolutionary, ecological as well as molecular studies are altogether missing. Apart from being
746 rich in fossil fuels and minerals, Chotanagpur Plateau is a resourceful area with hidden
747 bioresources which could be of great value to mankind. Also, we can't protect or conserve
748 something if we don't know about it. Chotanagpur Plateau is under threat due to existing and
749 upcoming coal mining projects. Deforestation is rampant due to these projects and we can't
750 even estimate the cost of these activities because we don't have data about existing flora and
751 fauna of the area. We rely on the reports provided by the parties involved in such projects.
752 Therefore, it is very important to study and record the biodiversity of this area and how it is
753 regulating local climate and keep balance in the ecosystem. Present study documents a
754 substantial number of arthropod mimic species, with Batesian mimics exhibiting the highest
755 abundance. Spiders constitute a substantial proportion of the many ant mimics. The study
756 demonstrates the prevalence of mimics in natural environments and suggests that mimics are
757 not as rare as previously thought. Mimics are everywhere. Just because they are mimics, it is
758 hard to spot them easily. Mimicry is a beautiful manifestation of natural selection and
759 arthropods have achieved perfection in it.

760

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765

766

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768 The research was conceptualized by RK. Site visits and data collections were done by RK,
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777 **CONFLICT OF INTEREST**

778 The authors declare that they have no competing interests.

779

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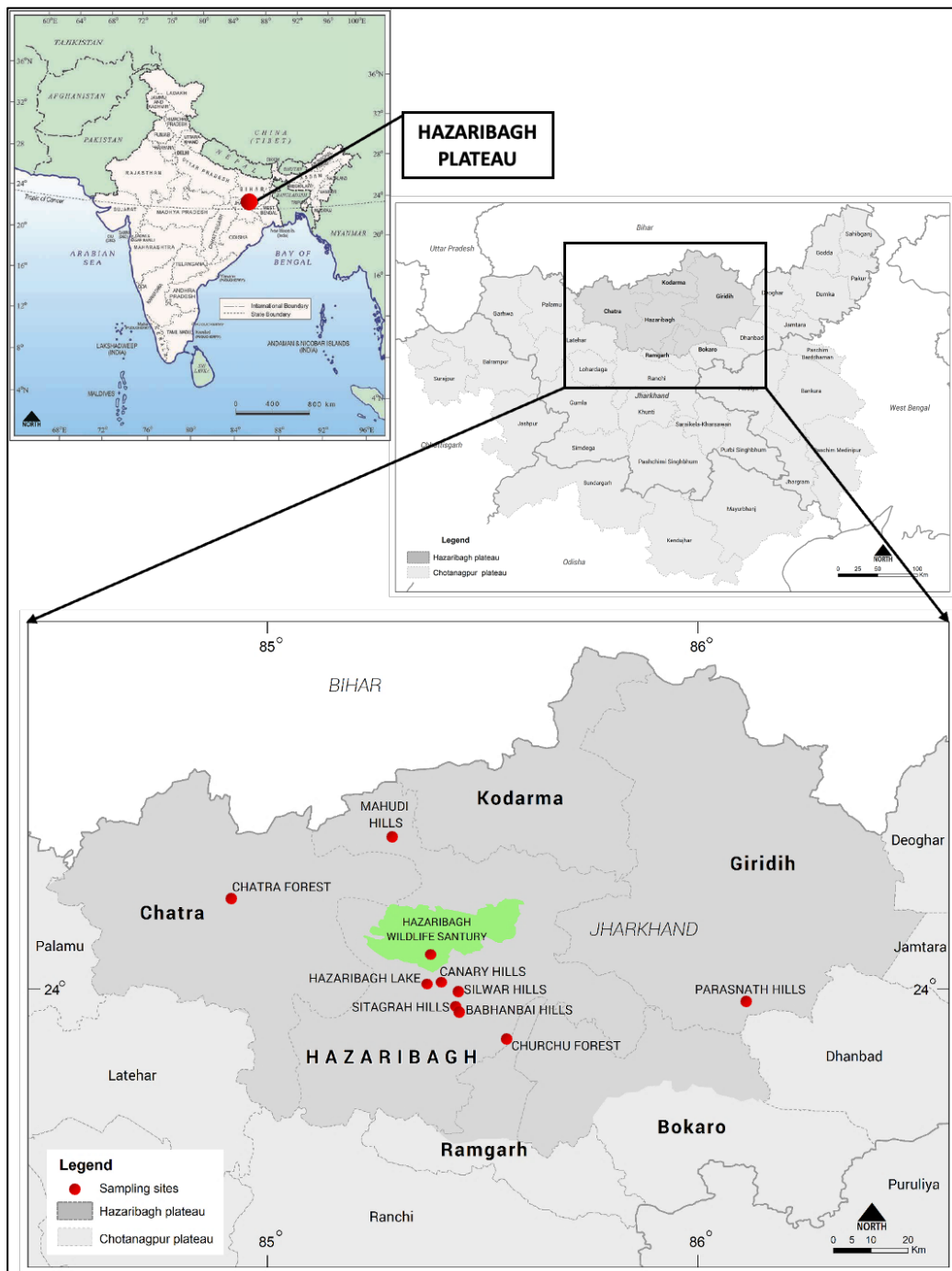
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1003 **FIGURES AND LEGENDS**

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1007 **Figure 1. Maps showing location of Hazaribag (or Hazaribagh) Plateau in India (upper**
 1008 **left map) and Jharkhand (upper right map). The outline map of Hazaribag Plateau is**
 1009 **superimposed over the map of Chotanagpur Plateau to show its location and spread. The**
 1010 **sampling sites associated with the present study is indicated with red dots in the lower map.**



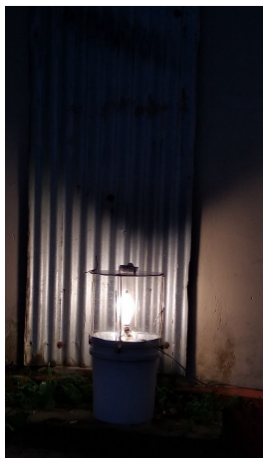
Pan Trap



**Manual Collection
(Diurnal)**



**Manual Collection
(Nocturnal)**



Light Trap



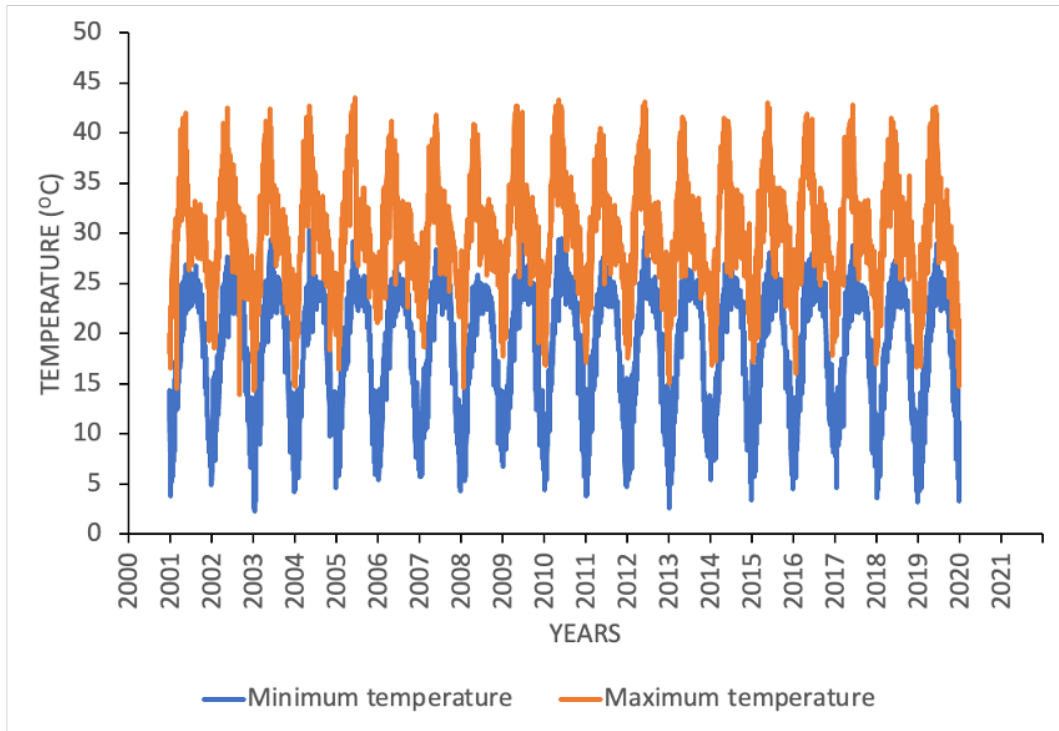
Sweep Net



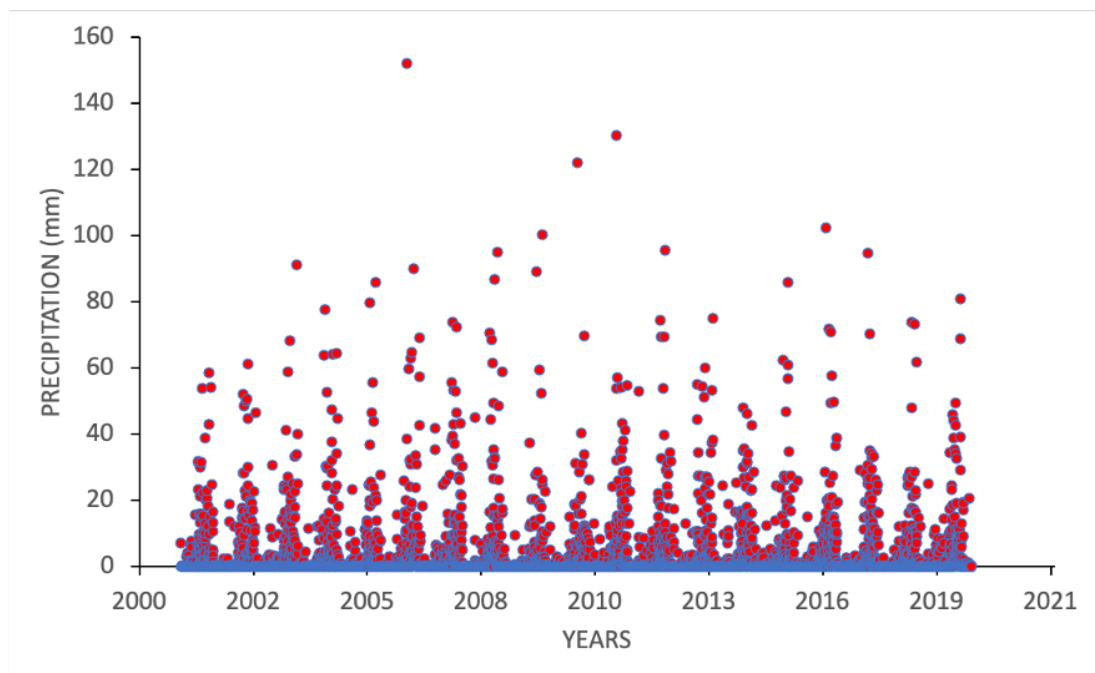
Aspirator

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Figure 2. Different methods used for the collection of terrestrial arthropod specimens from Hazaribag Plateau region. Diurnal collection methods used in this study include use of pan trap, sweep net, aspirator and manual collection. Nocturnal collection methods include use of light trap and manual collection using a light source placed over a white sheet.



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B

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1027 **Figure 3. Average daily temperature and precipitation at Hazaribag Plateau region over**

1028 **last nineteen years (1st January, 2001 to 31st December, 2019). A. Daily average temperature**

1029 **(maximum and minimum). B. Daily average precipitation.**

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Spirama retorta
Clerck, 1764



Erebus macrops
Linnaeus, 1768



***Theretra* sp.**
Hübner, 1819



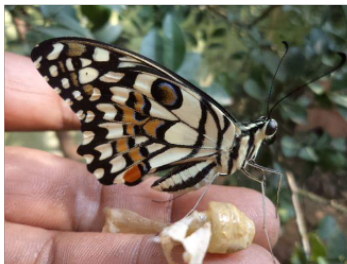
Junonia almana
Linnaeus, 1758



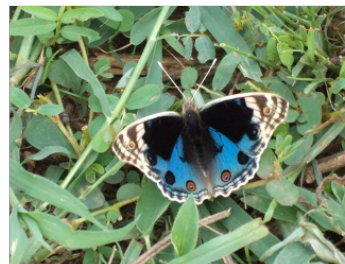
Bicyclus anynana
Butler, 1879



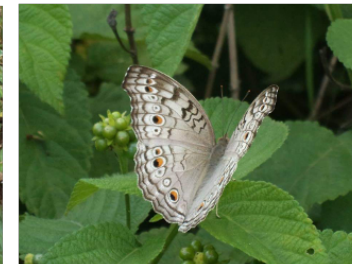
***Erebus* sp.** Latreille,
1810



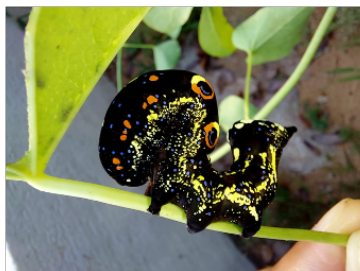
Papilio demoleus
Linnaeus, 1758



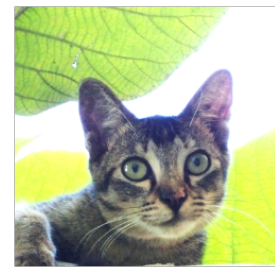
Junonia orithya
Linnaeus, 1758



Junonia atlites
Linnaeus, 1763



Eudocima fullonia
Clerck, 1764 caterpillar



Eyes of predators like owls and cats are models for eyespots

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1033 **Figure 4. Different arthropods from Hazaribag Plateau region exhibiting false eyes or eye**

1034 **spots (deimatic behaviour). These eyespots imitate eyes of predators like owls and cats.**

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Spindasis vulcanus
Fabricius, 1775



Lampides boeticus
Linnaeus, 1767



Tajuria cippus
Moore, 1881



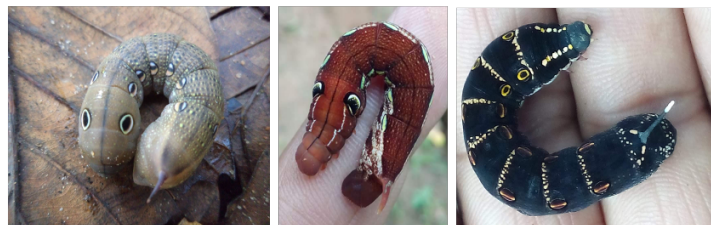
***Scutigera sp.* Linnaeus,
1758 and its exuviae**

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Figure 5. Different arthropods from Hazaribag Plateau region exhibiting automimicry.
All these mimics display a false head to distract the predators from the real head.



Different snake like aposematic caterpillars



Caterpillars with snake like head and false eyes



Caterpillar of *Papilio demoleus* Linnaeus, 1758 exhibiting red forked-snake-tongue like defensive structure called osmeterium

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1054 **Figure 6. Different caterpillars from Hazaribag Plateau region exhibiting snake like body**
 1055 **and colouration.** Most of these caterpillars are brightly coloured and some also display snake
 1056 like head with false eyes. The caterpillar of the species *Papilio demoleus* is noteworthy for its
 1057 possession of a defensive mechanism known as the Osmeterium, which bears a resemblance to
 1058 the bifurcated tongue of a snake. The osmeterial organ is located within the thoracic part of the
 1059 body, positioned in an inverted manner. When the larva experiences any form of disturbance,
 1060 it undergoes eversion, resulting in the emission of a malodorous scent. This scent serves the
 1061 purpose of repelling ants, small spiders, and mantids.



***Callidrepana patrana* Moore, 1866**

***Callidrepana argenteola* Moore, 1860**



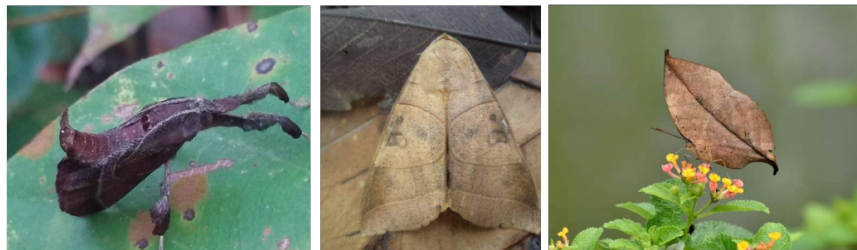
***Cricula trifenestrata* Helfer, 1837**

***Telchines vialis* Moore, 1883**



***Elymnias* sp. Hübner, 1818
emerging from its pupa**

***Hamodes propitia* Guérin-Méneville, 1831**



***Sacada approximans*
Leech, 1889**

**An unidentified
moth species**

***Kallima inachus*
Doyère, 1840**



***Omphacodes directa*
Walker, 1861**

***Daphnis nerii*
Linnaeus,
1758**

***Comibaena
cassidara*
Guenée, 1858**

***Gastropacha* sp.
Ochsenheimer,
1810**

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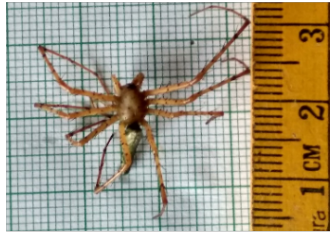
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1065 **Figure 7. Different lepidopterans from Hazaribag Plateau region exhibiting resemblance**

1066 **towards leaves.** Some of these arthropods mimic a dry leaf and some imitate a green leaf. It is

1067 a form of camouflage.



***Peucetia viridans*,
Hentz, 1832**



***Schizocephala bicornis*,
Linnaeus 1758**



***Carausius morosus* Sinéty, 1901**



***Aethalochroa insignis*
Wood-Mason, 1878**



***Medauroidea* sp.
Zompro, 2000**



***Phyllocrania* sp.
Burmeister, 1838**

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caterpillars of unidentified Geomatrid moths



***Athyma selenophora*
Kollar, 1844
caterpillar**

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Figure 8. Different arthropods from Hazaribag Plateau region exhibiting resemblance towards twigs. Some of these arthropods mimic a dry twig and some imitate a green twig. It is also a form of camouflage. Some even bear spine like structures over legs or body surface to imitate thorny twigs.



***Oxyrachis tarandus* Fabricius**



***Xylorhiza adusta* Wiedemann, 1819**



***Phalera grotei*
Moore, 1859**

***Phalera* sp. Hübner,
1819**



**Bag worm caterpillars of
Psychid moths**

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1077 **Figure 9. Different arthropods from Hazaribag Plateau region exhibiting resemblance**

1078 **towards thorns, bark of a tree and wood. It is also a form of camouflage. Some even form a**

1079 **bag like structure around it using wood cuttings during its larval stage to imitate wood.**



Euthalia lubentina
Cramer, 1777
caterpillar



***Miresa* sp.**
Walker, 1855
caterpillars



***Rapala* sp. Moore, 1881**
caterpillar

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Creobroter pictipennis
Wood-Mason,
1878



Creobroter gemmatus
Saussure 1869



Theopropus elegans
Westwood, 1832

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1083 **Figure 10. Different arthropods from Hazaribag Plateau region exhibiting resemblance**

1084 **towards foliage, different plant parts and flowers. It is also a form of camouflage.**

1085 Caterpillars resemble plant parts for protection from being spotted by predators. Many mantids

1086 resemble flowers to prey upon other arthropod pollinators.

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**Caterpillar of *Papilio*
sp. Linnaeus, 1758**



***Tonica niviferana* Walker, 1864**



***Acontia nitidula*
Fabricius, 1787**



***Leucinodes orbonalis* Guenée, 1854**



***Pulvinaria urbicola* Cockerell, 1893**



***Gasterocantha kuhli*
C.L.Koch, 1837**



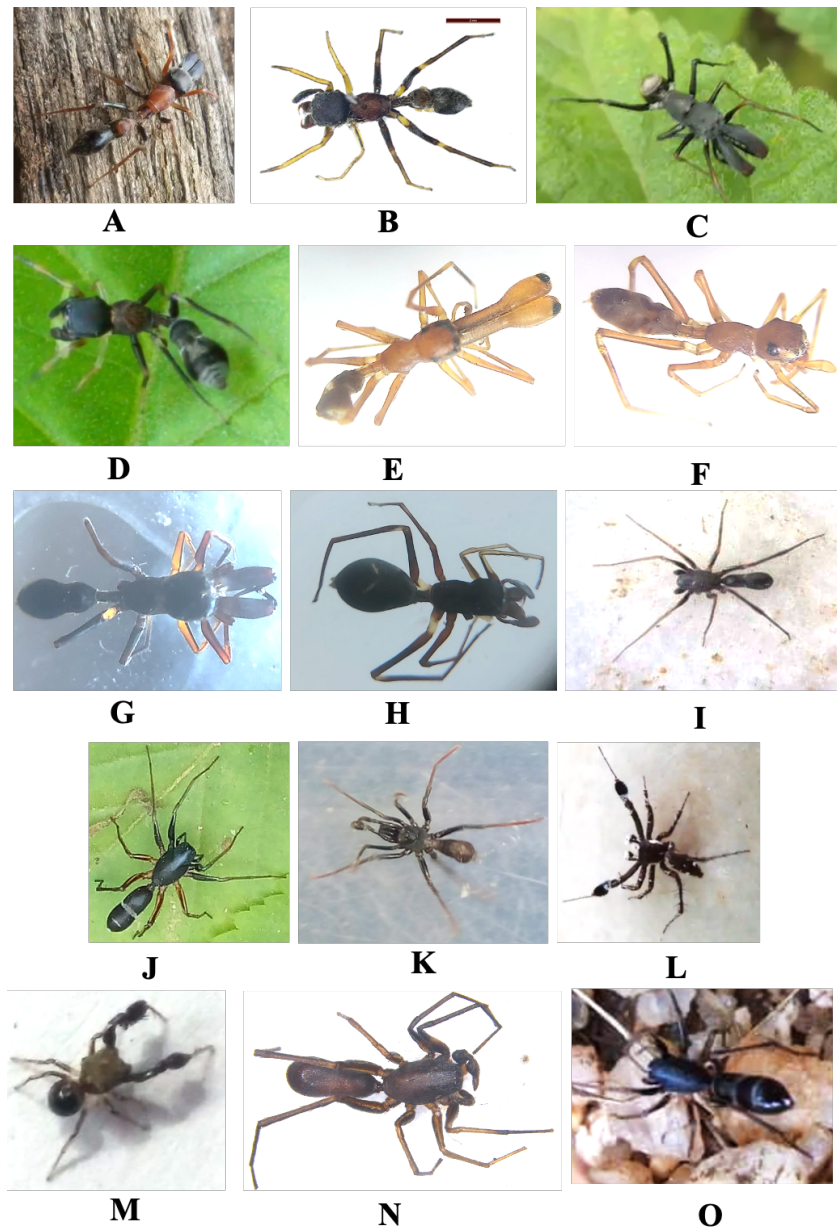
***Pasilobus kotigeharus* Tikadar, 1963**

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1096 **Figure 11. Different arthropods exhibiting masquerading from Hazaribag Plateau**

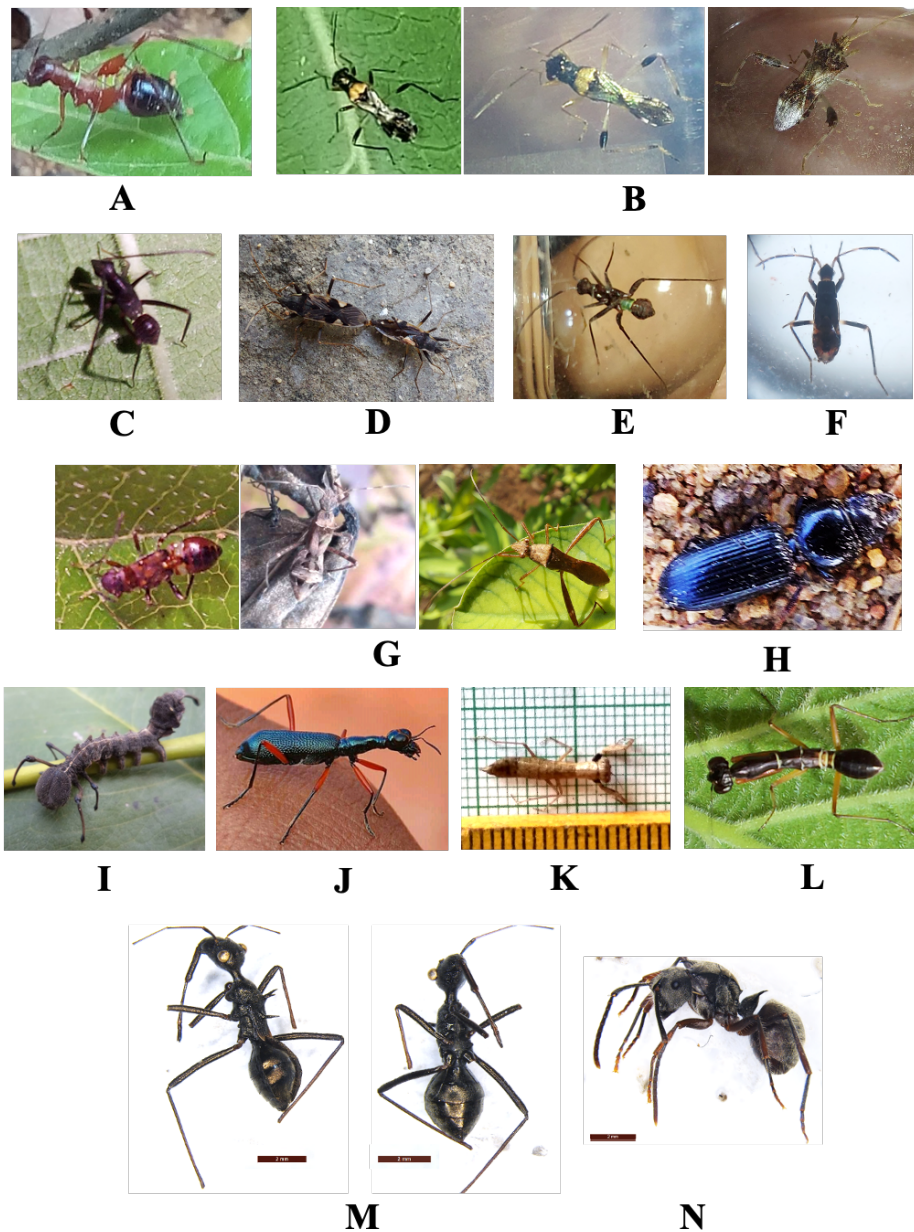
1097 **region. Most of these masquerades either mimic bird droppings or mammalian dung.**



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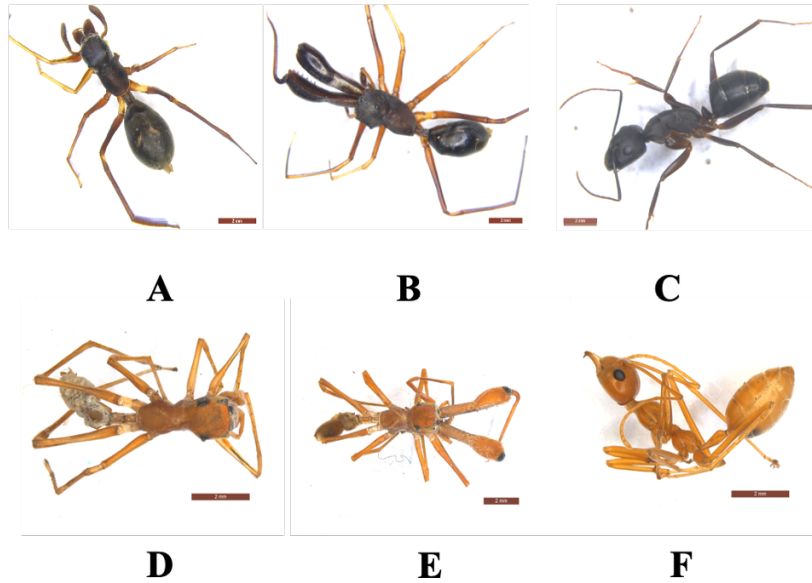
1100 **Figure 12. Ant mimicking spiders from Hazaribag Plateau region.** A. *Myrmarachne*
 1101 *melanocephala* MacLeay, 1839 male. B. *Myrmarachne melanocephala* female. C.
 1102 *Myrmarachne* sp. McLeay, 1839 male. D. *Myrmarachne* sp. female. E. *Myrmaplata*
 1103 *plataleoides* O. Pickard-Cambridge, 1869 typical red male (collected from Pondicherry for
 1104 comparison). F. *Myrmaplata plataleoides* typical red female (collected from Pondicherry for
 1105 comparison). G. *Myrmaplata plataleoides* melanic morpho-variant male. H. *Myrmaplata*
 1106 *plataleoides* melanic morpho-variant female. I. *Myrmecotypus* sp. O. Pickard-Cambridge,
 1107 1894. J. *Corinnomma severum* Thorell, 1877. K. *Idiops* sp. Perty, 1833. L. *Portia albimana*
 1108 Simon, 1900. M. *Harmochirus brachiatus* Thorell, 1877. N. *Castianeira* sp. Keyserling 1879.
 1109 O. *Castianeira flavipes* Gravely, 1931.



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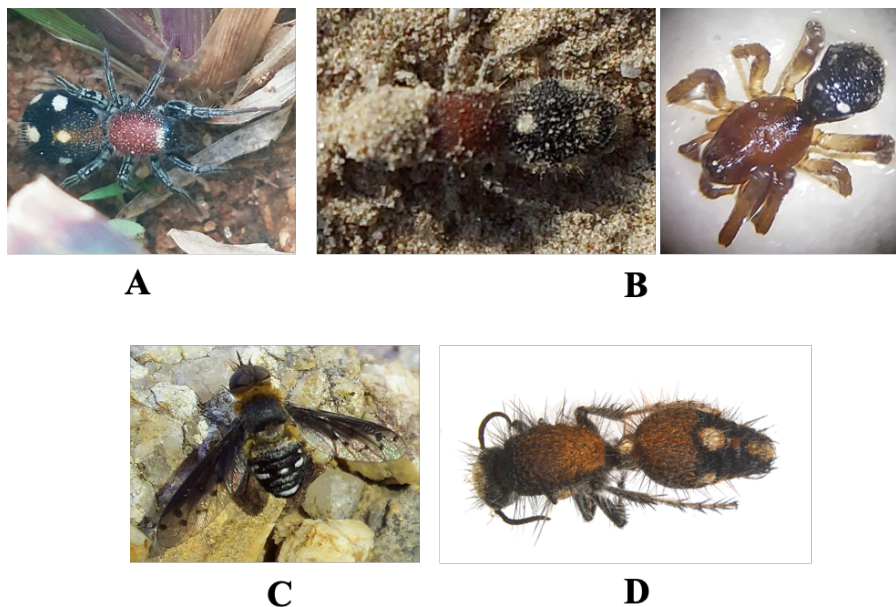
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1112 **Figure 13. Ant mimicking insects from Hazaribag Plateau region.** A. Nymph of
 1113 *Macroxiphus* sp. Pictat, 1888. B. Different instars of *Gralliclava horrens* Dohrn, 1860. C.
 1114 *Letana megastridula* Ingrisich, 1990. D. *Dieuches leucocera*, Walker 1872. E. Ant mimicking
 1115 nymph of a Coreid bug. F. *Metochus uniguttatus*, Thunberg, 1822. G. Different instars of
 1116 *Riptortus serripes* Fabricius, 1775 (from left to right: second instar nymph, fourth instar nymph
 1117 and adult). H. *Clypeuspinus* sp. Balkenohl, 2021. I. First instar larva of *Stauropus alternus*
 1118 Walker, 1855. J. *Neocollyris bonellii*, Guérin-Méneville, 1833. K. *Hestiasula brunneriana*
 1119 Saussure, 1871. L. *Euantissa pulchra* Olivier, 1792. M-N. *Dulichius inflatus* Kirby, 1891 and
 1120 its ant model *Polyrrhachis exercita* Walker, 1859.

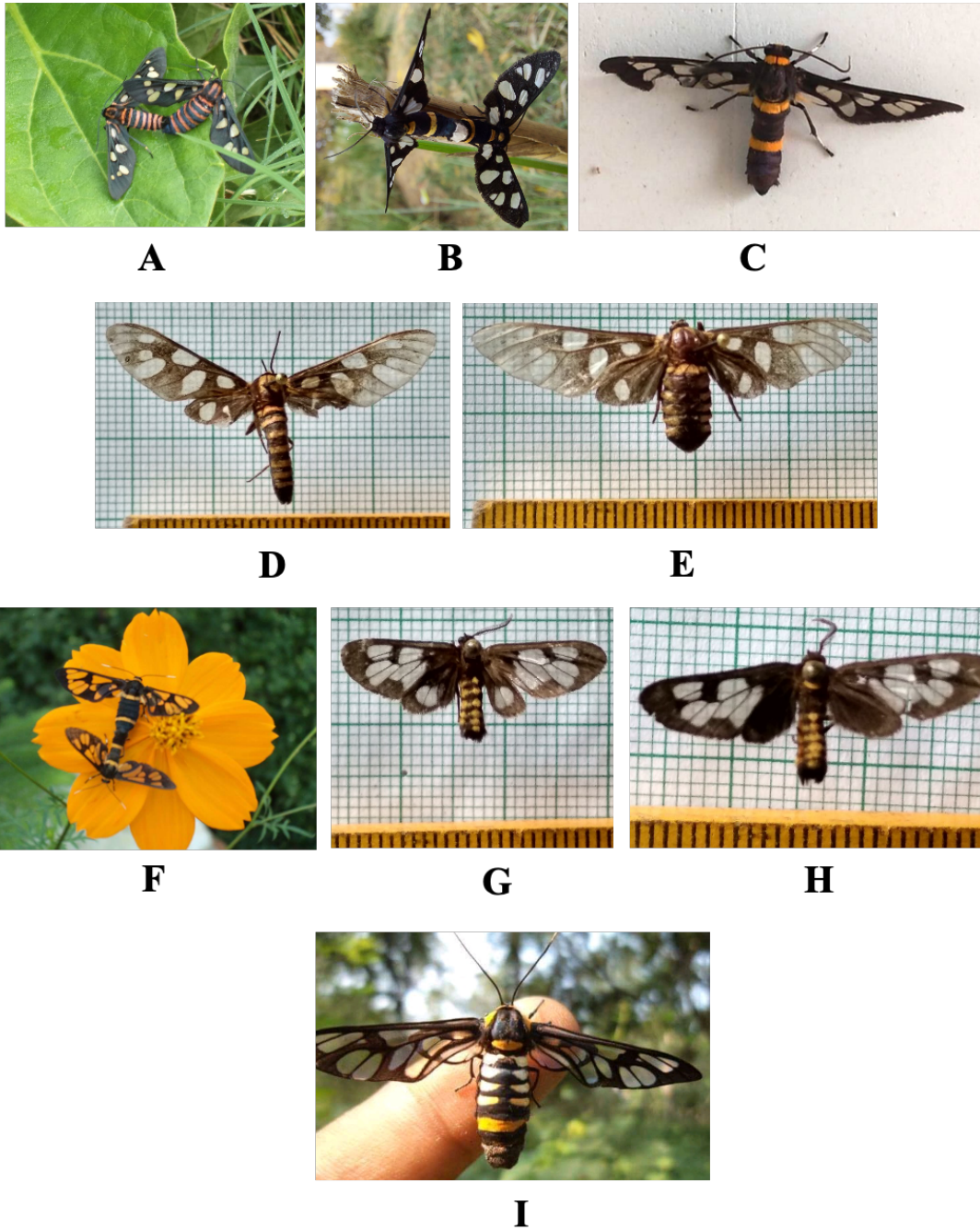


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 1122 **Figure 14. Polymorphic mimicry in ant mimicking jumping spider *Myrmaplata***
 1123 ***plataleoides* O. Pickard-Cambridge, 1869. A. Melanic morpho-variant, female, B. melanic**
 1124 **morpho-variant male, and C. its ant model *Camponotus compressus* Fabricius, 1787, worker.**
 1125 **D. Typical red form, female (collected from Pondicherry for comparison), E. typical red form**
 1126 **(collected from Pondicherry for comparison), male, and F. its ant model *Oecophylla***
 1127 ***smaragdina* Fabricius, 1775, worker.**

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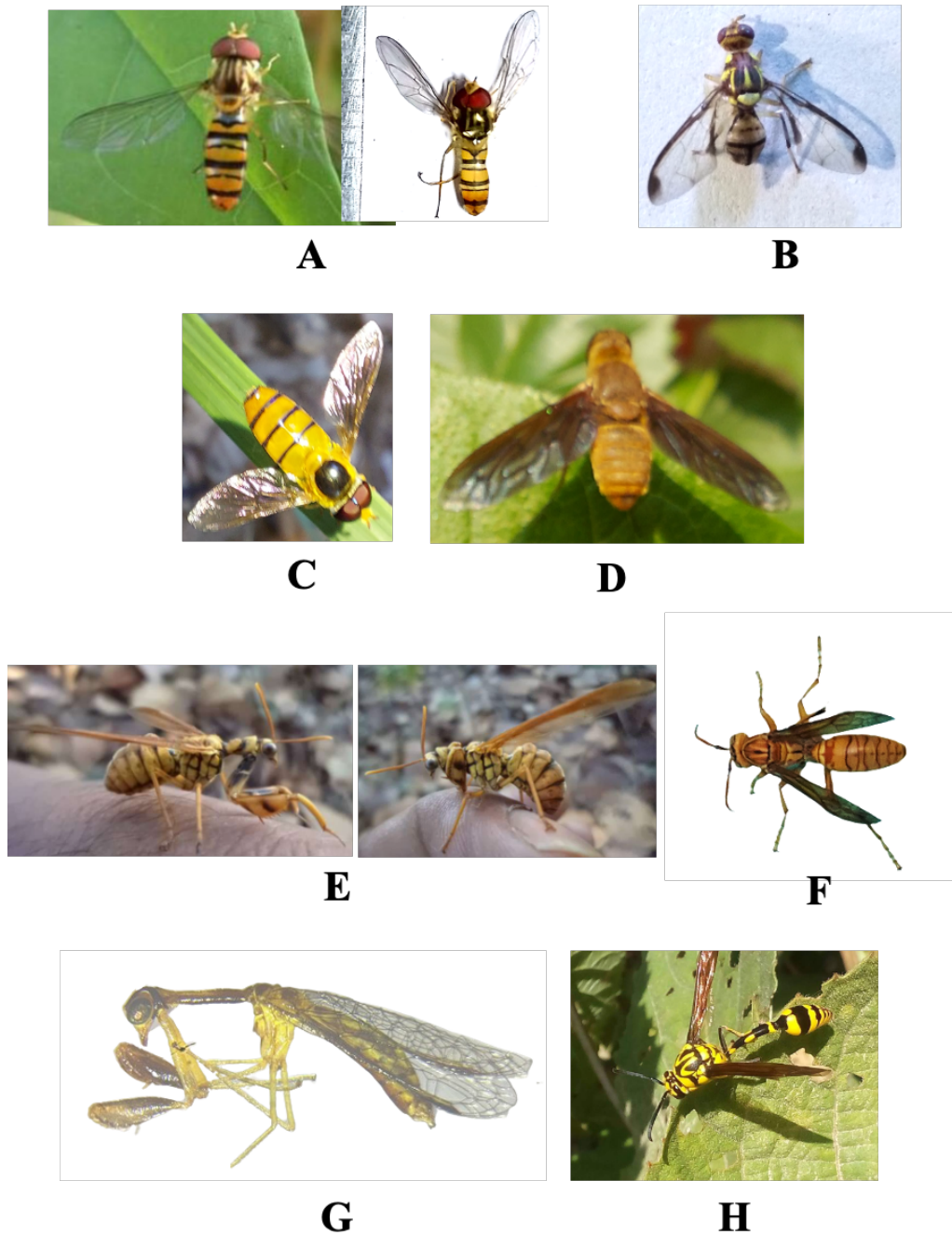


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 1130 **Figure 15. Velvet ant mimics from Hazaribag Plateau region. A. *Coenoptychus pulcher***
 1131 **Simon 1885. B. *Graptartia granulosa* Simon, 1896. C. *Hemipenthes* sp. Loew, 1869. D. A**
 1132 **velvet ant *Dasylabris argentipes* Smith, 1855.**



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Figure 16. Wasp mimicking moths from Hazaribag Plateau region. A. *Amata passalis* Fabricius, 1781. B. *Amata sperbius* Fabricius, 1787. C. *Amata cyssea* Stoll, 1782. D. *Amata* sp. Fabricius, 1807. E. *Amata* sp. Fabricius, 1807. F. *Syntomoides imaon* Cramer, 1779. G. *Eressa confinis* Walker, 1854. H. *Eressa* sp. Walker, 1854. I. *Caeneressa diaphana* Kollar, 1844.



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1145 **Figure 17. Wasp mimicking Dipterans and Neuropterans from Hazaribag Plateau region.**

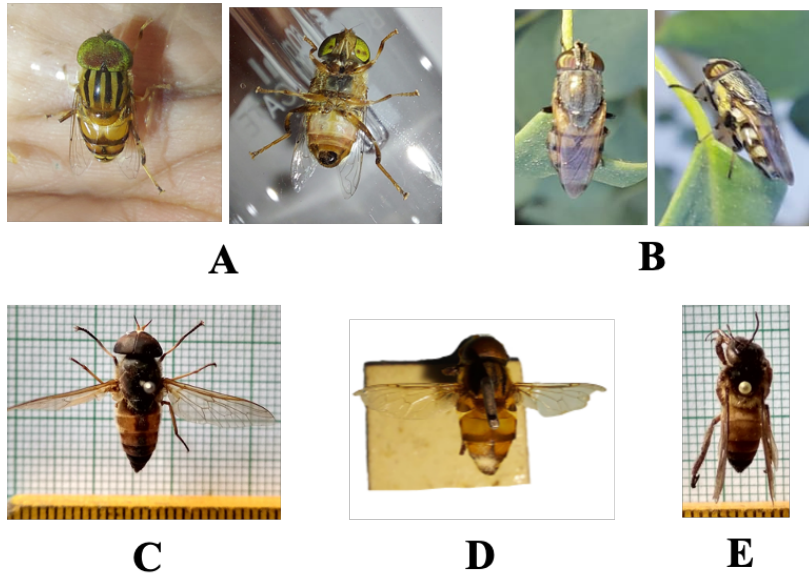
1146 A. *Episyrrhus balteatus* De Geer, 1776. B. *Bactrocera cucurbitae* Coquillett, 1849. C.

1147 *Asarkina salvia*, Fabricius 1794. D. *Chrysanthrax* sp. Osten-Sacken, 1886. E-F. Wasp

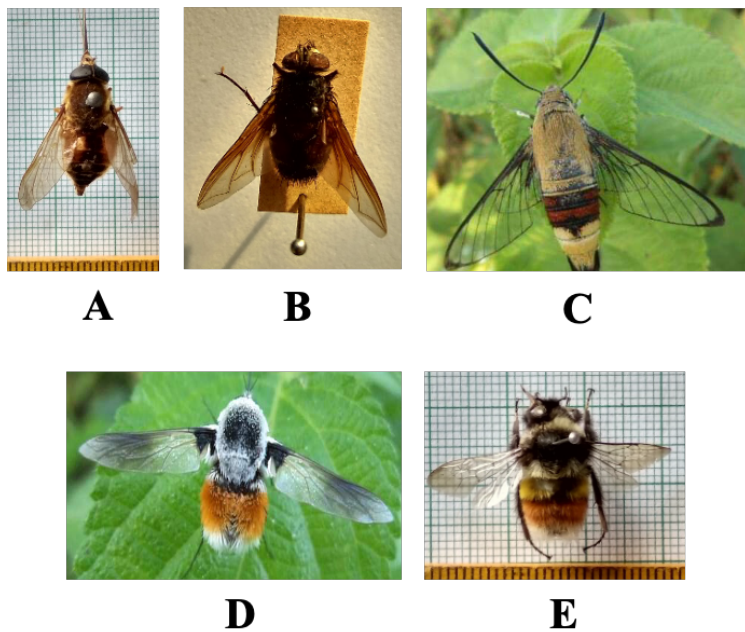
1148 mimicking mantispid *Euclimacia* sp. Enderlein, 1910 (E) and its wasp model *Polistes olivaceus*

1149 DeGeer, 1773. G-H. *Mantispa* sp. Illiger, 1798 and its wasp model *Phimenes flavopictus*

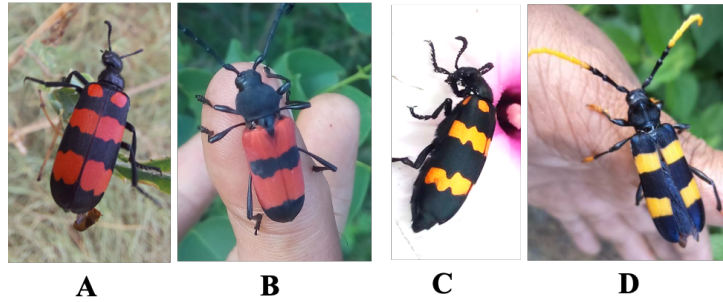
1150 Blanchard, 1845.



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 1152 **Figure 18. Honey bee mimics from Hazaribag Plateau region.** A. *Eristalinus* sp. Linnaeus,
 1153 1758. B. *Stomorhina* sp. Rondani, 1861. C. *Eristalis tenax* Linnaeus, 1758. D. *Mesembrius*
 1154 *bengalensis* Wiedemann, 1819. E. A bee model *Apis cerana indica* Fabricius, 1789.
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 1157 **Figure 19. Bumble bee mimics from Hazaribag Plateau region.** A. *Bombylisoma* sp.
 1158 Rondani, 1856. B. *Bombylella* sp. Greathead, 1995. C. *Cephonodes hylas* Linnaeus, 1771. D.
 1159 *Bombomyia* sp. Greathead, 1995. E. A bumble bee model *Bombus rufofasciatus* Smith, 1852.



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1161 **Figure 20. Blister beetle mimics from Hazaribag Plateau region.** A-B. Model blister beetle

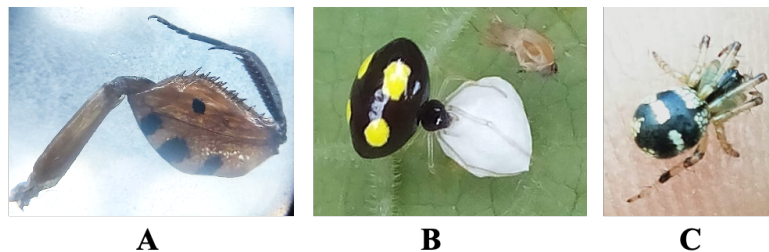
1162 *Hycleus phaleratus* (= *Mylabris phalerata*) Thunberg, 1791 red morph (A) and its mimic

1163 *Purpuricenus sanguinolentus* Olivier, 1795 (B). C-D. Model blister beetle *Hycleus pustulatus*

1164 (= *Mylabris pustulata*) Pallas, 1781 yellow morph (C) and its mimic *Zonopterus flavitarsis*

1165 Hope, 1843.

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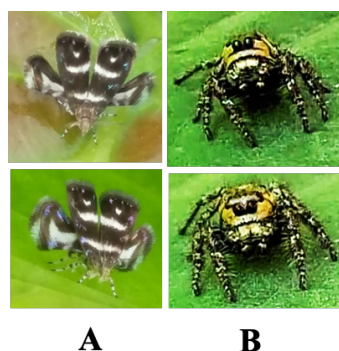
1168 **Figure 21. Ladybird beetle mimics from Hazaribag Plateau region.** A. Forelimb of

1169 *Hestiasula brunneriana* Saussure, 1871 showing the inner face of its flattened oval femur

1170 which mimic pattern and shape of red-black ladybird beetle. B. *Theridula gonygaster* Simon,

1171 1873. C. *Mangora baii* Mi and Li, 2021.

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1174 **Figure 22. Jumping spider mimicking moth from Hazaribag Plateau region.** A. *Brenthia*

1175 sp. Clemens, 1860. *Brenthia* sp. mimics sitting posture of a salticid model and creates

1176 impression of a salticid spider through its colour pattern. B. A salticid *Hyllus semicupreus*

1177 Simon, 1885 in characteristic sitting posture of a typical salticid (jumping spider).



A



B



C

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1180 **Figure 23. Sex-limited mimicry.** A-B. Female butterflies of *Papilio polytes* Linnaeus, 1758
1181 form *Stichius* (A) mimic *Pachliopta aristolochiae* Fabricius, 1775 (B). C. *Hyplolimnas*
1182 *misippus* Linnaeus, 1764 male. Female is known to mimic *Danaus chrysippus* Linnaeus, 1758.

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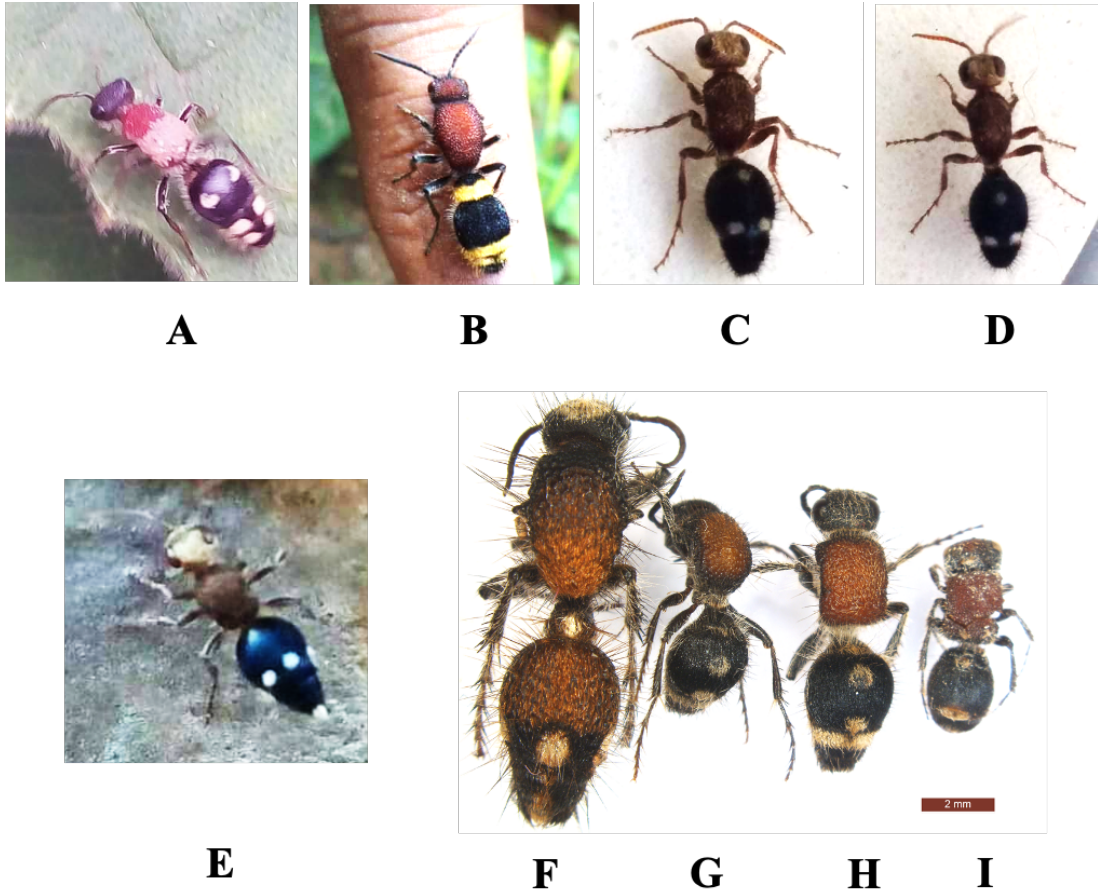
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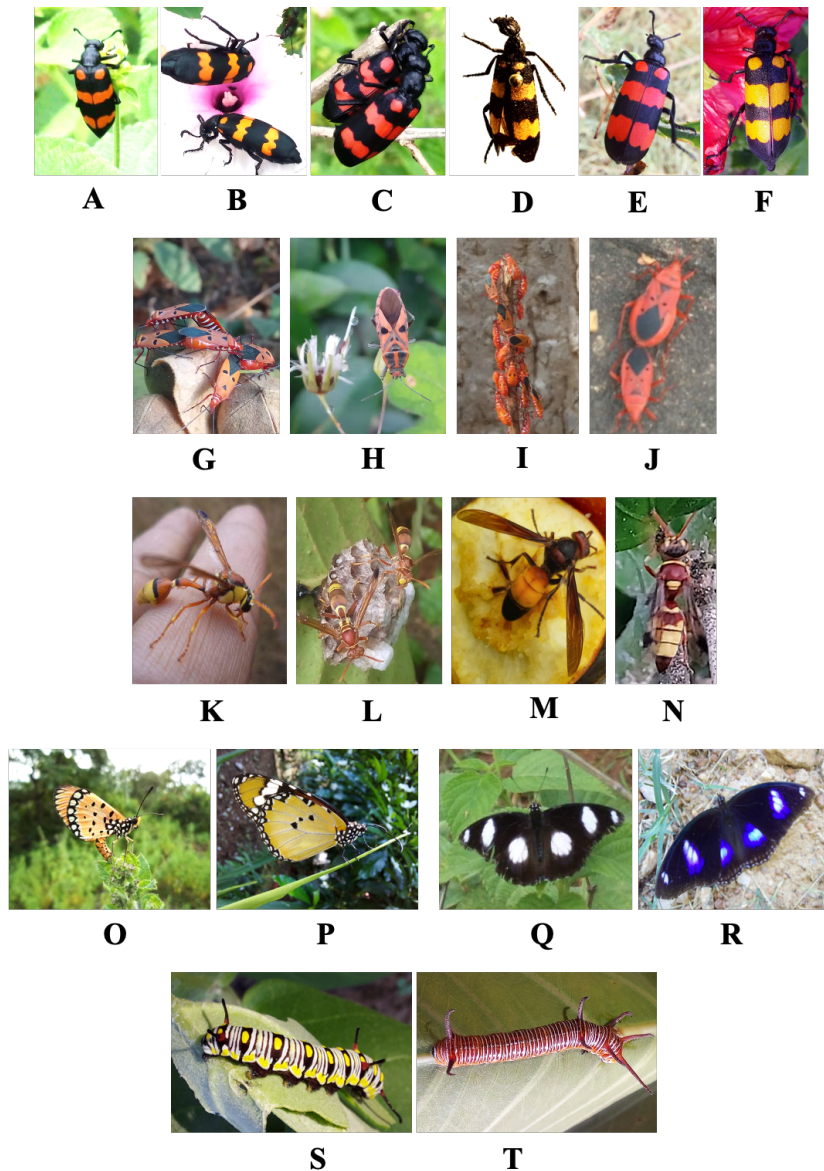
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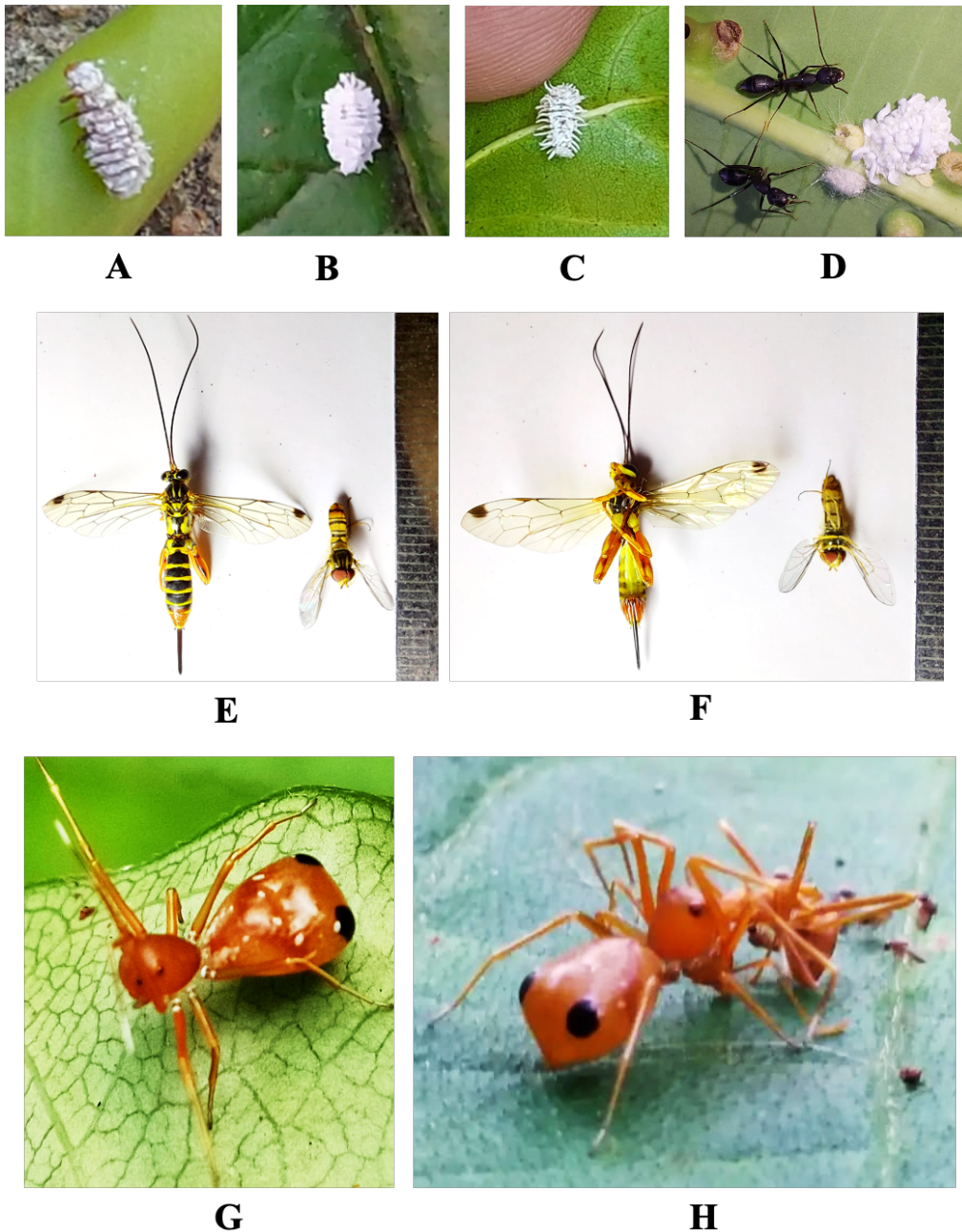


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Figure 24. Müllerian mimicry among velvet ants (Mutillidae) from Hazaribag Plateau region. A. *Trogaspidia villosa* Fabricius, 1775. B. *Orientilla* sp. Lelej, 1979. C-D. *Ephucilla* sp. Lelej, 1995. E. *Kurzenkotilla* sp. Lelej, 2005. F. *Dasylabris argentipes* Smith, 1855. G-H. *Physetopoda* sp. Schuster, 1949. I. *Smicromyrme* sp. Thomson, 1870. These velvet ants are Müllerian mimics of one another and are therefore part of a common mimicry ring.



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 1216 **Figure 25. Different Müllerian mimicry rings from Hazaribag Plateau region.** A-F.
 1217 Different colour morphs of blister beetles *Hycleus pustulatus* (= *Mylabris pustulata*) Thunberg,
 1218 1821 (A-D) and *Mylabris phalerata* (= *Hycleus phaleratus*) Pallas, 1781 (E-F). G-J.
 1219 Pyrrhocorid bugs *Dysdercus cingulatus* Fabricius, 1775 (G); *Spilostethus hospes* Fabricius,
 1220 1794 (H); *Dysdercus koenigii* Fabricius, 1775 (I); *Probergrothius nigricornis* Stal, 1861 (J).
 1221 K-N. Wasps *Delta pyriforme pyriforme* Fabricius, 1775 (K); *Rhopalidia fasciata* Fabricius,
 1222 1804 (L); *Vespa tropica* Linnaeus, 1758 (M), *Vespa orientalis* Linnaeus, 1761 (N). O-P.
 1223 Butterflies *Danaus chrysippus* Linnaeus, 1758 (O) and *Acraea violae* Fabricius, 1775 (P). Q-
 1224 R. Butterflies: *Hypolimnna bolina* Linnaeus, 1758 (Q) and *Hypolimnna misippus* Linnaeus,
 1225 1764 (R). S-T. Butterfly caterpillars *Euploea core* Cramer, 1780 and *Danaus chrysippus*
 1226 Linnaeus, 1758.



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Figure 26. Arthropods exhibiting aggressive mimicry from Hazaribag Plateau region. A- C. Mealybug mimicking larvae of *Scymnus* sp. Kugelann, 1794 (A), *Hyperaspis* Chevrolat in Dejean, 1837 (B) and *Cryptolaemus motrouzeiri* Mulsant, 1850 (C). D. A mealybug is shown as model. Ants and mealybugs share a complex symbiotic relationship called mutualism. E-F. Dorsal (E) and ventral (F) view of *Echthromorpha agrestoria* Swederus, 1787 (left) and *Episyrrhus viridaureus* Wiedemann, 1824 (right). G-H. *Amyciaea forticeps* O. Pickard-Cambridge, 1873 (G). It feeds on its red ant model *Oecophylla smaragdina* Fabricius, 1775 (H).



A



B



C

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1239 **Figure 27. Arthropods exhibiting chemical mimicry from Hazaribag Plateau region. A.**

1240 *Acherontia lachesis* Fabricius, 1798. B. *Acherontia styx* Westwood, 1847. C. *Paussus* sp.

1241 Linnaeus, 1775.

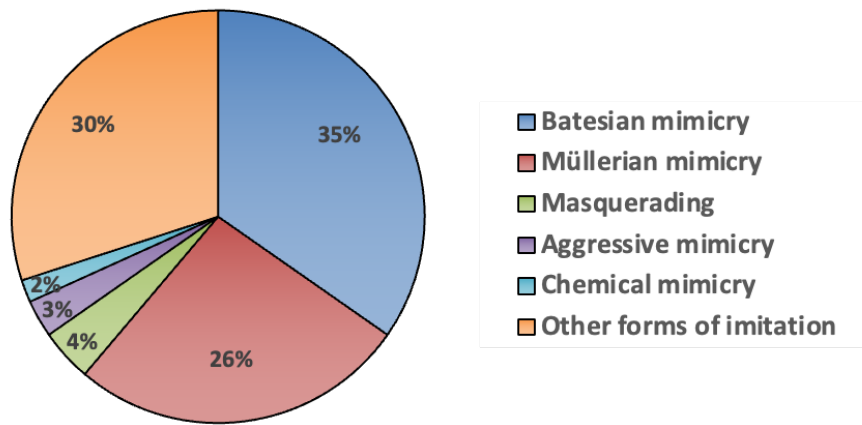
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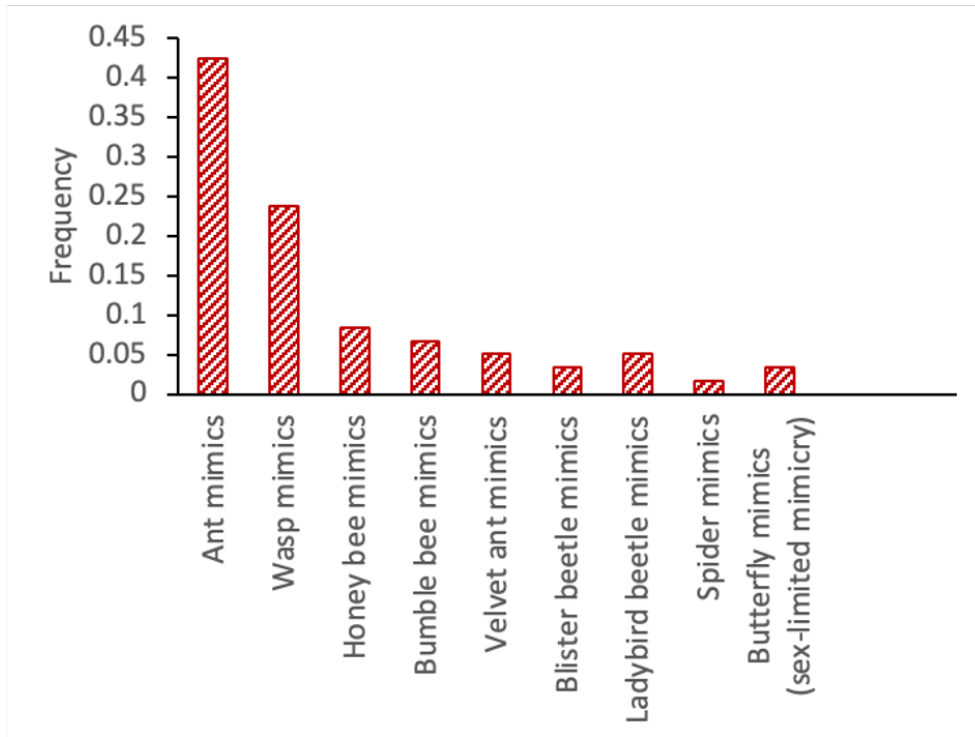
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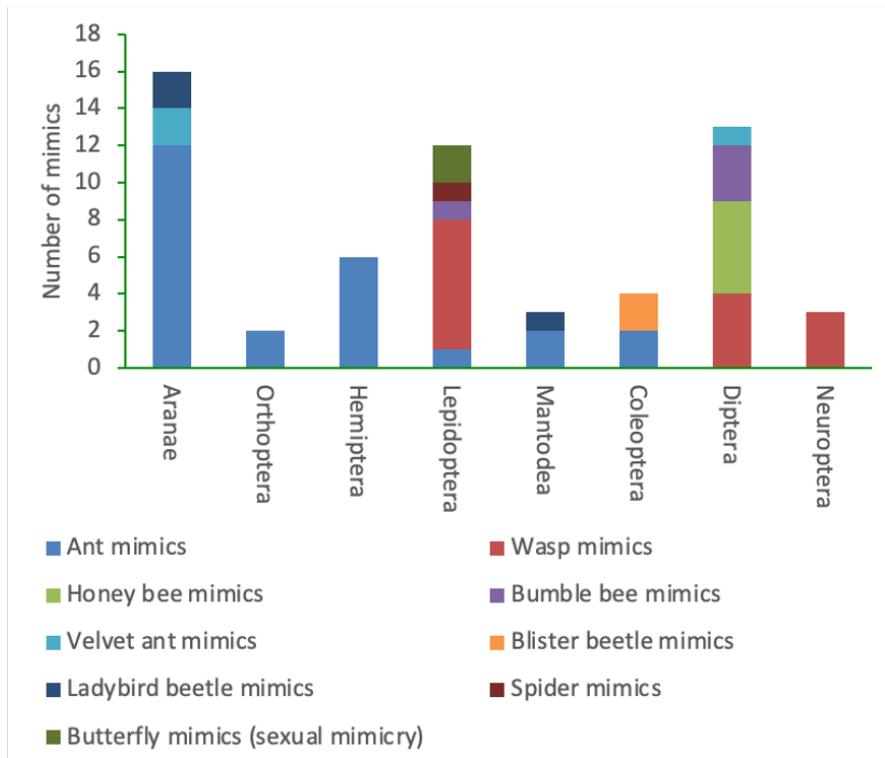
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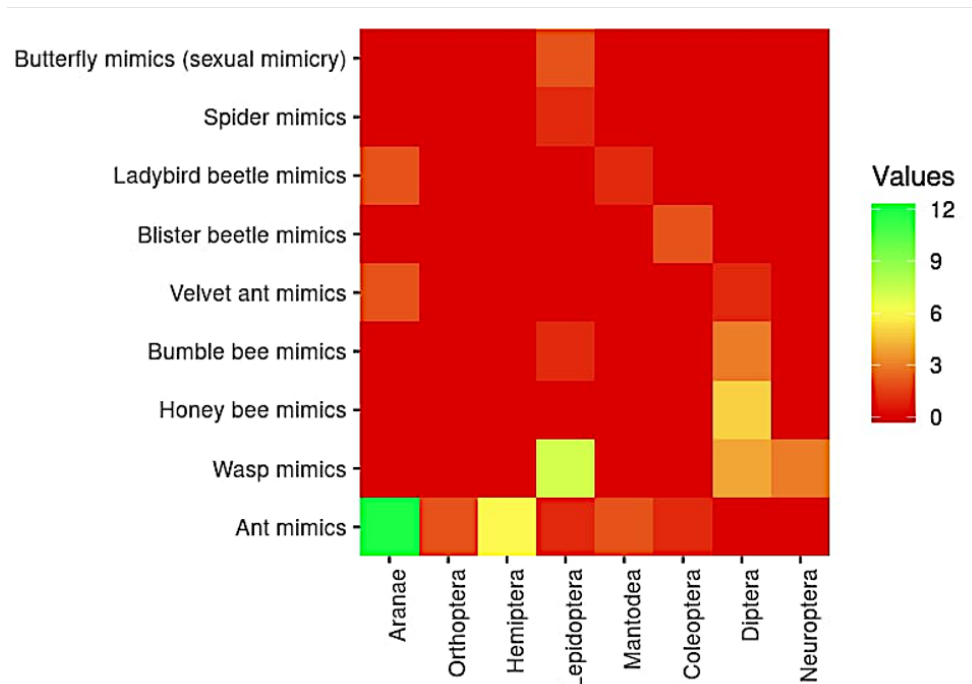
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Figure 28. Different types of mimics from Hazaribag Plateau region. A. Share of different kinds of mimics recorded from Hazaribag Plateau region in terms of percentage. Note that masquerading has been shown separately from other forms of imitation. B. Frequency of Batesian mimics with respect to the model animal.

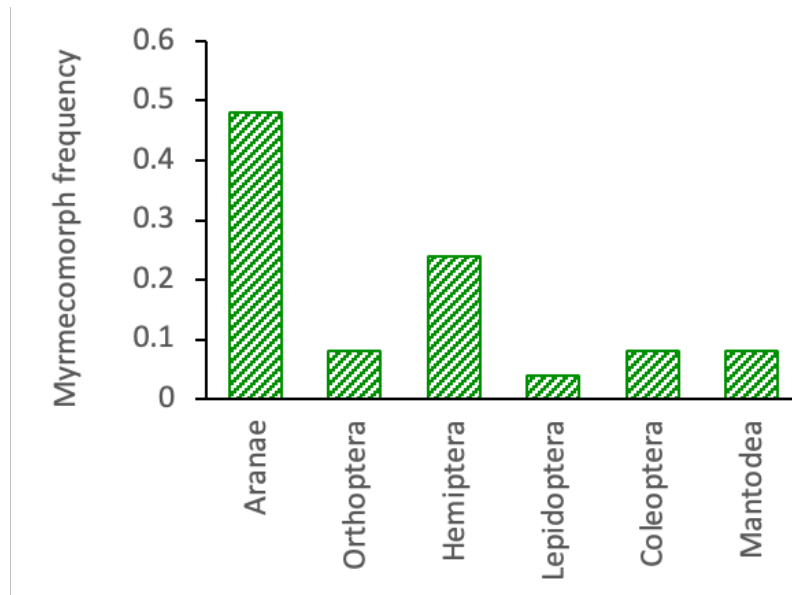


A



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1258 **Figure 29. Batesian mimics from Hazaribag Plateau region.** A. Proportion of different
 1259 orders of mimics *vis-à-vis* their models. B. Heat map representing abundance of different
 1260 subtypes of Batesian mimics.



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1263 **Figure 30. Frequency of myrmecomorphs belonging to different orders as recorded from**
 1264 **Hazaribag Plateau region.** Note that the largest number of ant mimics are spiders.

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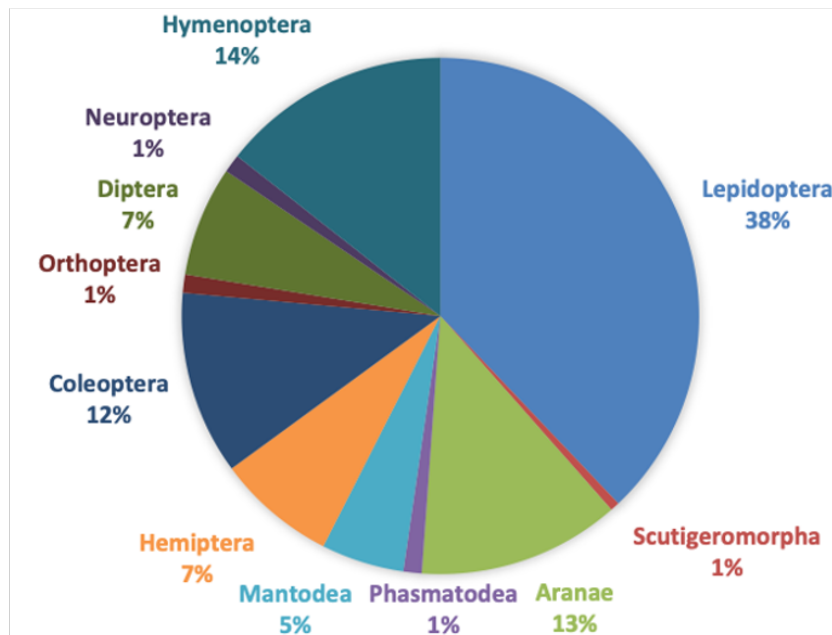
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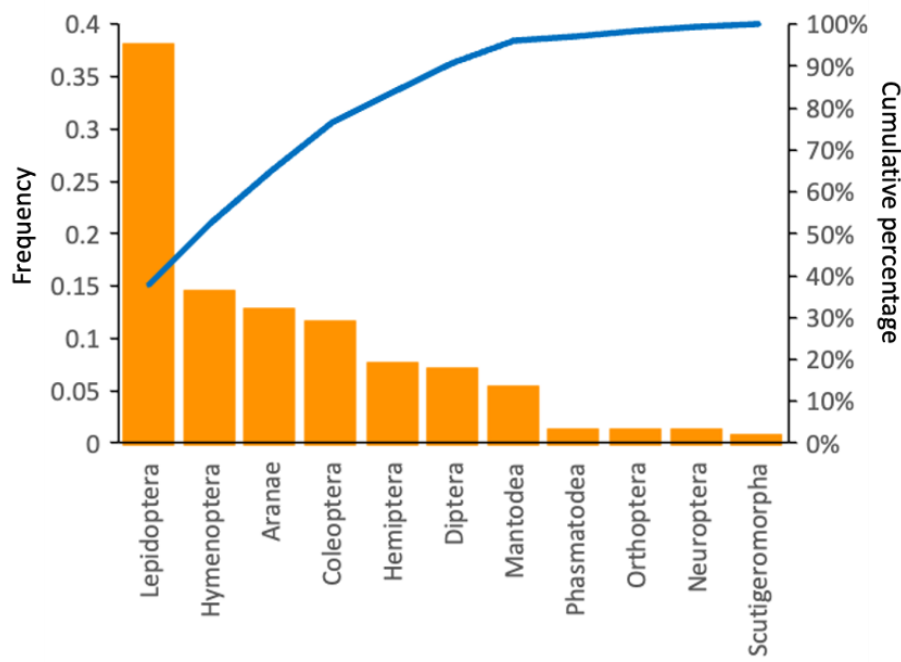
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A



B

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1283 **Figure 31. Diversity of terrestrial arthropods exhibiting mimicry from Hazaribag Plateau**

1284 **region.** A. Order-wise percentage of different arthropod taxa exhibiting mimicry. B. Pareto

1285 chart displaying frequency of different mimics and their share in the mimic diversity. Note that

1286 Lepidoptera, Hymenoptera, Aranae, Coleoptera, Hemiptera and Diptera together account for

1287 more than 90% of the mimics.