

Taxonomy and ecology of genus *Phlogophora* Treitschke, 1825 (Lepidoptera: Noctuidae) in Indian Himalaya with description of a new species

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Abstract

The Genus *Phlogophora* Treitschke, 1825 (Noctuidae: Xyleninae), widely distributed in Palaearctic and Oriental realms, is especially diverse within Indian Himalaya with 12 known species till now. Current communication reports three species new to India viz. *P. meticulodina* (Draudt, 1950), *P. nobilis* Hreblay & Ronkay, 1998 and *P. szecsenyii* Hreblay & Ronkay, 1998 and a new species *P. similis* Bandyopadhyay, Mallick, Sanyal & Chandra **sp. nov.**, thus bringing the species number to 16 for the country, along with taxonomic key with morphology and genitalia-based diagnosis for all the Indian/Himalayan species. Out of those species, partial mitochondrial Cytochrome C Oxidase I (COI) sequences were generated for 6 species, of which 5 were novel to the NCBI GenBank. The genus had maximum species richness and abundance in Eastern Himalayan Temperate Forest spanning 1800–2500 m in Central Himalayan landscape of Darjeeling-Sikkim and Nepal. Current Habitat suitability model of six *Phlogophora* species indicated that temperature dependent variables like Temperature Annual Range, Temperature Seasonality and Elevation are the most contributing factors for their predicted distribution range. The genus comprising of both Polycyclic and Monocyclic species became most abundant during Post-monsoon, in cold (9–11 °C) and humid (87–91%) nights, in areas with Annual Mean Temperature ranging within 4.6–19.9 °C and Annual Precipitation of 1000–2800 mm.

Key words: Phlogophorini, Central Himalaya, DNA Barcoding, Himalayan Temperate Forest, Seasonality, Habitat Suitability

Introduction

The genus *Phlogophora* Treitschke, 1825 (Noctuidae, Xyleninae: Phlogophorini) with designated type species *Phalaena meticulosa* Linnaeus, 1758 is widely distributed throughout zoogeographic realms of the world, especially diverse within few specific “centres of diversity”. Within Palaearctic region, Western-Central Europe including Azores group of islands and Japan, Korea extending to South East Siberia are two major centres. In the transition zone of Palaearctic and Oriental realm, another diversity hotspot exists centred around Central/Southern Himalayan

area comprising India, Nepal, Bhutan, Myanmar and extending up to Hengduan Mountains including Sichuan and Yunnan provinces of China. The typical Oriental diversity hotspot includes the Malay Peninsula, comprising Malaysian and Indonesian chain of islands. Few species are known from Afro-tropical region including Madagascar, even fewer from Nearctic region (Fig. 1). At present, 68 species are recognized globally under *Phlogophora* (Poole 1989; Hreblay & Ronkay 1998; Hreblay, Ronkay & Plante 1998; Saldaitis & Ivinskis 2006; Gyulai *et al.* 2015; Gyulai & Saldaitis 2019), with still much scope regarding their biology and ecology. Habitat and larval ecology of the genus are relatively well explored in Bornean islands, where the species are primarily montane (Holloway 1989), and in Azorean islands, where most of the species inhabits humid fern-rich coniferous forests (Wagner 2015). The larvae are generally polyphagous feeding upon multiple plant families of herb and shrubs including a number of economically important plants (Carter 1984).

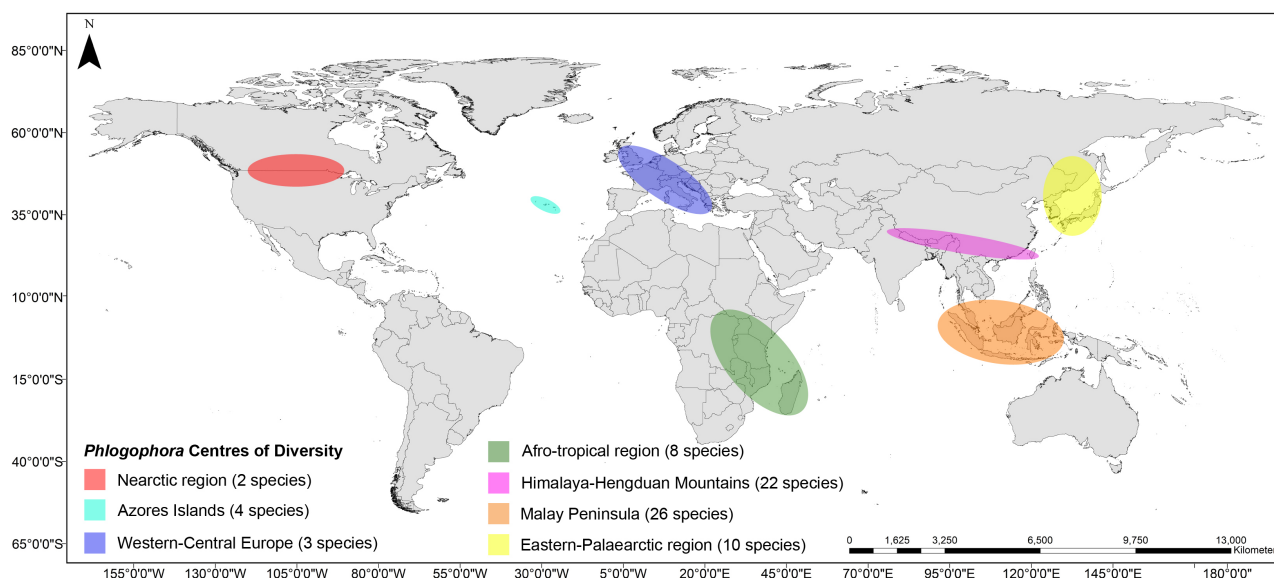


FIGURE 1. Centres of diversity of *Phlogophora* spp. with respective number of species from each centre.

Earlier, most of the presently recognised species of *Phlogophora* were described broadly under the genera *Trachea* Ochsenheimer, 1816, *Euplexia* Stephens, 1829, *Chutapha* Moore, 1882 etc., due to their shared plesiomorphic characters in male genitalia (Holloway 1989). A number of species of this unsettled group was brought under *Euplexia* by Holloway (1976) after examining *E. lucipara* (Linnaeus, 1758) which is the type species of the genus. Subsequently, in 1989 he discussed a set of synapomorphies to establish monophyly of the genus *Phlogophora* by studying male and female genitalia of few Bornean species and transferred 21 species of *Euplexia* and one species of *Trachea* to the genus. He also segregated the Bornean *Phlogophora* into three species groups based particularly on male genitalia characters. However, due to taxonomic complexities and absence of comprehensive revisionary works on the tribe Phlogophorini Hampson, 1918, placement of species among its genera is still far from settled (Gyulai & Ronkay 2018).

Majority of Indian species of *Phlogophora* were described and documented by Moore (1867, 1881, 1882) and Hampson (1894, 1898) under *Euplexia*, with the exception of only three species which were originally described under *Chutapha*, *Trigonophora* Hübner, [1821] and *Dianthoecia* Boisduval, 1834. All Indian *Phlogophora* species being primarily distributed within Himalaya, any mention of Indian/Himalayan *Phlogophora* is always synonymous. The genus lacks any recent comprehensive treatment from Indian subcontinent except Kirti *et al.* 2014, who discussed the genitalic attributes of three species. Twelve valid species have been recognized till date from India, including *P. striatovirens* (Moore, 1867) which has recently been reinstated as a valid species (Gyulai *et al.* 2015). This number (also the global count) does not include *P. sinuosa* (Moore, 1881), described from Darjeeling under the genus *Phalga*, which was later synonymised under *Cosmophila* and subsequently to *Eutelina* (Hampson 1894, Hampson 1908), as the status of the species is still uncertain without any recent voucher material. With a focus on updated taxonomic and ecological account of Indian/Himalayan *Phlogophora*, we attempted to highlight here: wing and genitalia diagnosis with a dichotomous key based on wing pattern for all species, addition of three species to Indian list and description of one new species, thus updating the total number to 16 species from the country. We also

updated the barcode database of the genus by generating partial mitochondrial Cytochrome C Oxidase I (COI) sequences of 6 morphologically identified species. Besides, we also sought to outline crucial ecological characteristics of the Himalayan species highlighting their climatic and habitat specificity, seasonal abundance and environmental variables governing their distribution.

Material and methods

Field Sampling & Identification: Sampling was conducted in a stratified random framework in selected altitudinal gradients spanning from lowest to highest altitudinal points choosing sites at an interval of every 200 m, within representative Protected Areas falling under five major biogeographic provinces of Indian Himalaya, viz. Ladakh Mountains in Ladakh, Trans-Himalaya (1A); Great Himalayan National Park in Himachal Pradesh, North-Western Himalaya (2A); Govind Wildlife Sanctuary, Valley of Flowers National Park and Askot Wildlife Sanctuary in Uttarakhand, Western Himalaya (2B); Khangchendzonga Biosphere Reserve in Sikkim, Neora Valley National Park and Singalila National Park in West Bengal, Central Himalaya (2C); and Namdapha National Park and Dihang Dibang Biosphere Reserve in Arunachal Pradesh, Eastern Himalaya (2D) (Rodgers & Panwar 1988) (Fig.2). All the sampling sites were categorized into different Forest/Habitat Types based on altitude and dominant plant species following Champion & Seth (1968). Sampling effort in 193 sites spanning 30 forest types thus indicated *Phlogophora* presence in 42 sites falling under five major habitat types. Sampling was undertaken in three broad seasons predominant in Himalaya, viz., Pre-monsoon (April–June), Monsoon (July–September) and Post-monsoon (October–December). Specimens were collected in front of white-sheet reflecting light from artificial light-source. In most of the cases as in remote areas, a combination of solar-powered Light-Emitting-Diode (LED) lamp of 48 W with 32 bulbs (1.5 W each) and pressurized-paraffin lamp (petromax) of 80 W with white incandescent light were used. Mercury Vapor (MV) lamp of 160 W was used wherever electricity was available. Garmin Oregon 550 GPS was used to record geographical coordinates and altitude. Temperature and relative humidity at immediate vicinity of the trap site were recorded at every hour using Kestrel 3000 Weather Meter. Moths attracted to light trap were first photographed and then collected in glass bottle with Ethyl Acetate. Collected specimens were curated following standard protocol (Dickson 1976). Voucher specimens were submitted to National Zoological Collection of Zoological Survey of India (ZSI), Kolkata. For studying genitalia morphology, abdominal segments of male specimens were removed and digested in 10% NaOH overnight. Soaked abdominal segments were dissected in 20% Ethanol and studied under Leica S8AP0 HD binocular microscope. Temporary genitalia slides using water as mounting agent were prepared and photographed under Leica MC120 HD camera and dissected genitalia were later stored in 70% Ethanol.

DNA Barcoding: Two or three leg samples were taken out from the morphologically identified specimens with sanitized forceps and stored in molecular grade 70% Ethanol at 4 °C. Genomic DNA was extracted from the leg samples following the standard protocol of Phenol Chloroform-Isoamyl alcohol (Sambrook & Russell 2001). The primer pair, LepF1: 5'-ATTCAACCAATCATAAAGATATTGG-3' and LepR1: 5'-TAAACTTCTGGATGTC-CAAAAATCA-3' (Hebert *et al.* 2004) was used to amplify the 648 bp barcode region of the mitochondrial DNA. The total volume of PCR reaction was 30 µl containing: 20 picomoles of each primer, 20 mM Tris-HCl (pH 8.0), 100 mM KCl, 0.1 mM EDTA, 1 mM DTT, 1.8 mM MgCl₂, 0.25 mM of each dNTP and 1 µl of Taq polymerase (Takara Bio Inc., Shiga, Japan). The Veriti VR Thermal Cycler (Applied Biosystems, Foster City, CA) was used for the amplification with the following thermocycling profile: first cycle of 5 min at 94 °C, followed by 5 cycles of 1 min at 94 °C, 1 min 30 sec at 45 °C, 1 min 30 sec at 72 °C; followed by 30 cycles of 1 min at 94 °C, 1 min 30 sec at 51 °C, 1 min 30 sec at 72 °C, and final extension for 5 min at 72 °C. The PCR products were purified using the QIAquick Gel Extraction Kit (Qiagen Inc., Germantown, MD) following the manufacturer's protocols. The cycle sequencing of the purified PCR products was performed with BigDye® Terminator ver. 3.1 Cycle Sequencing Kit (Applied Biosystems Inc., California, USA) and finally sequenced using 48 capillary ABI 3730 Genetic analyser in ZSI, Kolkata. 13 DNA sequences of 6 morphologically identified species of *Phlogophora* have been generated which were aligned against 56 available sequences of *Phlogophora* retrieved from National Centre for Biotechnology Information (NCBI) and Barcode of Life Database (BOLD). *Acontia marmoralis* (Fabricius, 1794) (NCBI Accession no. KF390949.1) was used as an outgroup. In the final dataset, 70 sequences were aligned using Clustal X (Thompson *et al.* 1997) and finally 507 bp of mtCOI were opted to estimate the genetic divergence and phylogeny. Evolutionary

genetic divergences were calculated with Kimura-2-parameter model and neighbour-joining (NJ) phylogenetic tree was constructed in the software MEGA X with 1,000 bootstraps of replications (Tamura *et al.* 2013).

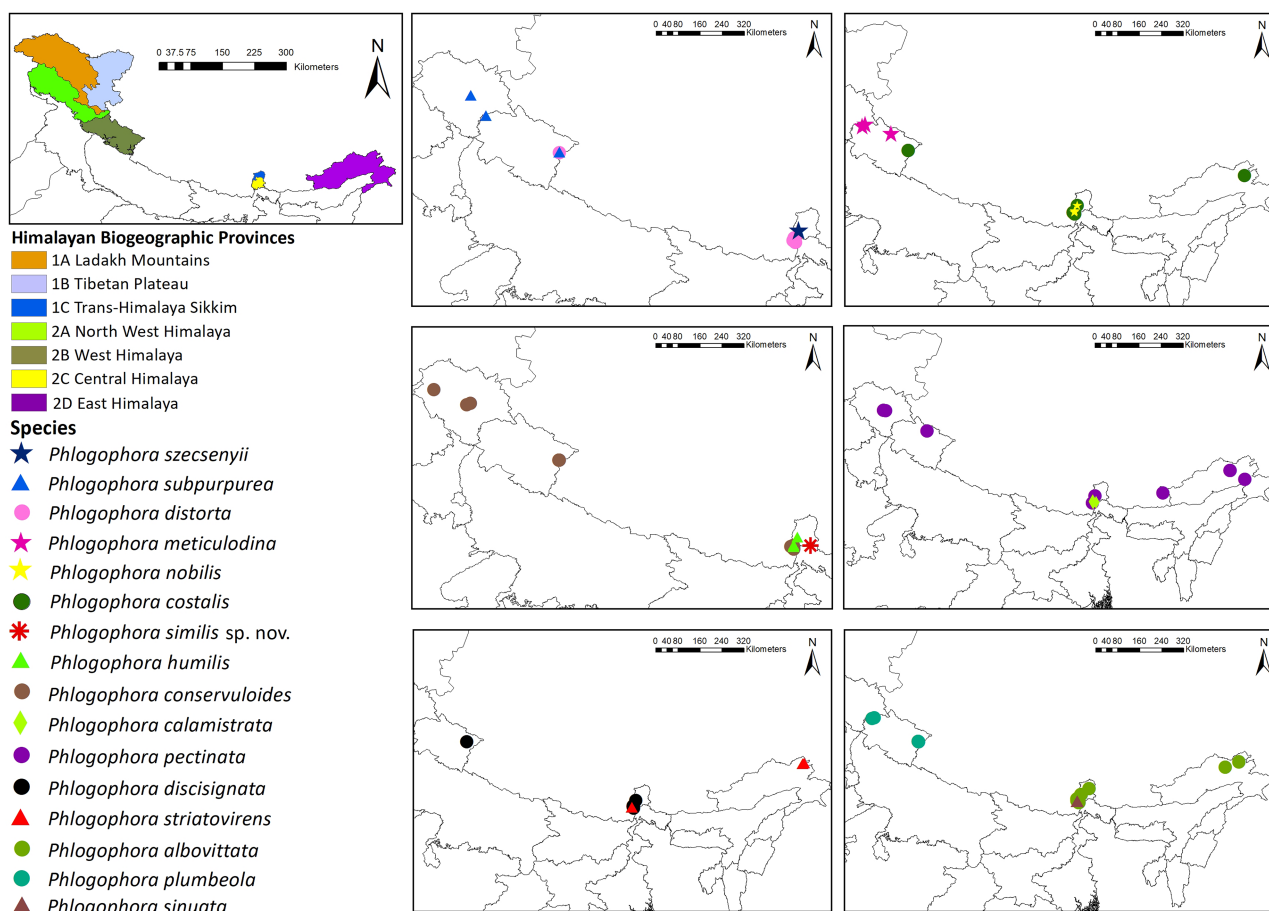


FIGURE 2. Collection localities of *Phlogophora* spp. from Indian Himalaya.

Habitat & Seasonal Preference: Relative Abundance of *Phlogophora* spp. were compared among different Himalayan habitat types and seasons. Seasonal abundance pattern as dependent variable was explored through Canonical Correspondence Analysis (CCA) (ter Braak 1995) to see the effects of major environmental variables including altitude, Normalized Difference Vegetation Index (NDVI), average trap night temperature, average trap night humidity, annual mean temperature and annual precipitation in the programme PAST (Hammer *et al.* 2001).

Distribution Modelling: Species distribution models (SDMs) develop climatically homogenous habitats which are predicted to have similar ecological characters. Combining the species occurrence data (both primary and secondary) along with the spatial environmental variables, the MaxEnt software (Ver: 3.4.1) was used to develop such similar climatic areas to predict and quantify the probability of present distribution of *Phlogophora* species across the Himalayan Biodiversity Hotspot (HBH). Based on highest unique occurrence points, six *Phlogophora* species were chosen to be modelled: *P. pectinata* (15 points), *P. conservuloides* (13 points), *P. costalis* (17 points), *P. distorta* (14 points), *P. albobittata* (30 points) and *P. calamistrata* (5 points). For each species, SDM Toolbox v2.4 (Brown 2014; <http://sdmtoolbox.org>) was used to reduce spatial clustering of location points with a resolution of 1.5 km and to generate a bias file using the Gaussian Kernel Density of sampling localities with a sampling bias distance of 0.14638 degrees. Extent of HBH was downloaded from databasin.org (Mittermeier *et al.* 2004). Nineteen bioclimatic variables used to represent the current climate features (averaged over 1970–2000) with 30 arc seconds resolution were obtained from the WorldClim database Version 2.1 (Fick & Hijmans 2017; www.worldclim.org). All the bioclim data along with 30 arc seconds Digital Elevation Model (DEM) (usgs.gov) was further cropped by the extent of the HBH. After Principal Component Analysis (PCA), bioclimatic variables having strong auto-correlation (correlation coefficient > 0.9) were removed. The final model was developed using the non-correlated bioclimatic variables Mean Diurnal Range (BIO2), Isothermality (BIO3), Temperature Seasonality (BIO4), Temperature Annual Range (BIO7), Precipitation of Driest Month (BIO14), Precipitation Seasonality (BIO15), Precipitation of

Driest Quarter (BIO17) along with the elevation data (DEM). For each species, 10 replicated models were generated by cross validation method with a maximum of 5000 iterations, 10000 background points and MaxEnt cloglog function. Out of the ten generated models, model validation was performed through threshold independent evaluation using Receiver operating characteristics (ROC) from Area under ROC curve (AUC) value ranging from 0 to 1 where 0.5 resembles complete random model predictions (Phillips *et al.* 2006). All the related GIS works were performed using ArcMap 10.4.

Results

Taxonomic account

Key to the species of *Phlogophora* Treitschke, 1825 in India

1. Orbicular and reniform stigma of forewing conjoined along median nervure. 2
 - Orbicular and reniform stigma not conjoined along median nervure. 7
2. Semilunate annuli present below conjoint orbicular and reniform stigma. 3
 - Semilunate annuli absent below conjoint orbicular and reniform stigma. 6
3. Forewing with postmedial band and submarginal line distinct, area between them dark *P. nobilis* Hreblay & Ronkay
 - Forewing without postmedial band and the submarginal line indistinct 4
4. Hindwing with a broad fuscous terminal band from apex to vein 2 5
 - Hindwing without broad terminal band *P. costalis* (Moore)
5. Hindwing golden-ochreous, with an indistinct postmedial line just before the marginal band
 - *P. similis* Bandyopadhyay, Mallick, Sanyal & Chandra **sp. nov.**
 - Hindwing whitish, without postmedial line *P. humilis* Hreblay & Ronkay
6. Forewing with a small dark apical streak just below costa *P. meticolodina* (Draudt)
 - Forewing without dark apical streak *P. conservuloides* (Hampson)
7. Head black 8
 - Head not black 12
8. Thorax with broad white stripes on vertex and patagia *P. distorta* (Moore)
 - Thorax without any stripes. 9
9. Forewing with broad and dark medial band. 10
 - Forewing without medial band. *P. szecsenyii* Hreblay & Ronkay
10. Antemedial band bent outward below cell. *P. sinuata* (Moore)
 - Antemedial band of forewing bent inward below the cell 11
11. Forewing without submarginal line *P. albovittata* (Moore)
 - Forewing with submarginal line. *P. pectinata* (Warren)
12. Upper side of hindwing with medial line 13
 - Upper side of hindwing without medial line 15
13. Ventral side of palpi, thorax and abdomen crimson red. *P. subpurpurea* Leech
 - Ventral side of palpi, thorax and abdomen not red. 14
14. Postmedial line of forewing single. *P. calamistrata* (Moore)
 - Postmedial line of forewing treble *P. plumbeola* (Hampson)
15. Forewing with postmedial line double, black, filled in with golden *P. striatovirens* (Moore)
 - Forewing with postmedial line indistinct. *P. discisignata* (Moore)

Taxonomic check list of *Phlogophora* Treitschke, 1825 species in India

Phlogophora nobilis Hreblay & Ronkay, 1998

[Fig. 3, 23, 24]

Phlogophora nobilis Hreblay & Ronkay, 1998, in Haruta, *Tinea*, **15**: 259.

Type locality: Nangethanti, Annapurna Himal [Nepal].

Material examined: India: 1 ♀, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 088.22087° E, 1879 m, 23. XI. 2019; coll. A. K. Sanyal & team.

1 ♂, West Bengal, Dist. Darjeeling, Singalila National Park, Manedara, 27.1147° N, 088.1000° E, 2168 m, 19.

X. 2018; 1 ♀, 27. X. 2018; 1 ♂, 29. X. 2018; coll. A. K. Sanyal & team; 2 ♀♀, Palamajua, 27.07071° N, 088.09071° E, 1909 m, 03. XI. 2018; coll. K. Bhattacharyya & team.

Diagnosis: Wing expanse: Male: 38–40 mm, female: 40–42 mm. *P. nobilis* differs from *P. costalis* and *P. humilis* in having the typical purplish brown head and thorax, and pinkish costal stripe of the forewing. Moreover, brownish-olive green ground colour of forewing and less sinuous and interrupted submarginal pale line are also diagnostic features.

Male genitalia: Male genitalia of this species is very unique with elongated valva having a constriction below cucullus. Sacculus broad with heavily sclerotised claw-like process, the outer part of which is bifid and the inner part is short, inwardly bent. The clasper of the harpe is relatively less sclerotised, apically long and thumb-like; aedeagus vesica long without any scobination or cornuti.

Distribution: India: Sikkim, West Bengal. **Global:** Nepal (Hreblay & Ronkay 1998).

Note: The species is being reported for the first time from India.

Bionomics: Probably a very rare and range-restricted species known only from Central Himalaya, recorded in an altitudinal zone of 1900–2500 m, preferably in Wet Temperate and Mixed Coniferous Forest. Individuals were active during post-monsoon months of October–November within a very narrow annual mean temperature and annual precipitation range of 14–15 °C and 2300–2500 mm respectively.

NCBI GenBank accession No.: MT219970

Phlogophora costalis (Moore, 1882)

[Fig. 4, 25, 26]

Chutapha costalis Moore, 1882, *Descr. Indian Lep. Atkinson*, (2): 131. [Type species of *Chutapha*]

Euplexia olivacea Leech, 1900, *Trans. Ent. Soc. Lond.*, (1): 84.

Chutapha costalis Moore: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, 7: 495.

Chutapha olivacea (Leech): Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, 7: 496.

Phlogophora costalis (Moore): Yoshimoto, 1992, in Haruta, *Tinea*, 13: 59.

Phlogophora costalis (Moore): Fibiger & Hacker, 2007, *Noct. Eur.*, 9: 186.

Type locality: Darjiling [=Darjeeling, India, West Bengal].

Material examined: India: 3 ♂♂, Uttarakhand, Dist. Pithoragarh, Askot Wildlife Sanctuary, Jimjhini, 29.92121° N, 080.39719° E, 2627 m, 18. VI. 2018; coll. A. K. Sanyal & team.

1 ♂, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 088.22087° E, 1879 m, 19. XI. 2019; coll. A. K. Sanyal & team.

2 ♂♂, 3 ♀♀, West Bengal, Dist. Darjeeling, Singalila National Park, Chitre, 26.99126° N, 088.11189° E, 2295 m, 15. V. 2018; 1 ♂, Meghma, 27.03270° N, 088.08314° E, 2971 m, 18. V. 2018; 6 ♂♂, 1 ♀, Gairibas, 27.05090° N, 088.03360° E, 2494 m, 21. V. 2018; coll. K. Bhattacharyya & team.

1 ♂, Arunachal Pradesh, Dist. Dibang Valley, Dihang Dibang Biosphere Reserve, Anini, Amika, 28.76411° N, 095.96115° E, 3070 m, 05. VI. 2018; coll. S. Gayen & team.

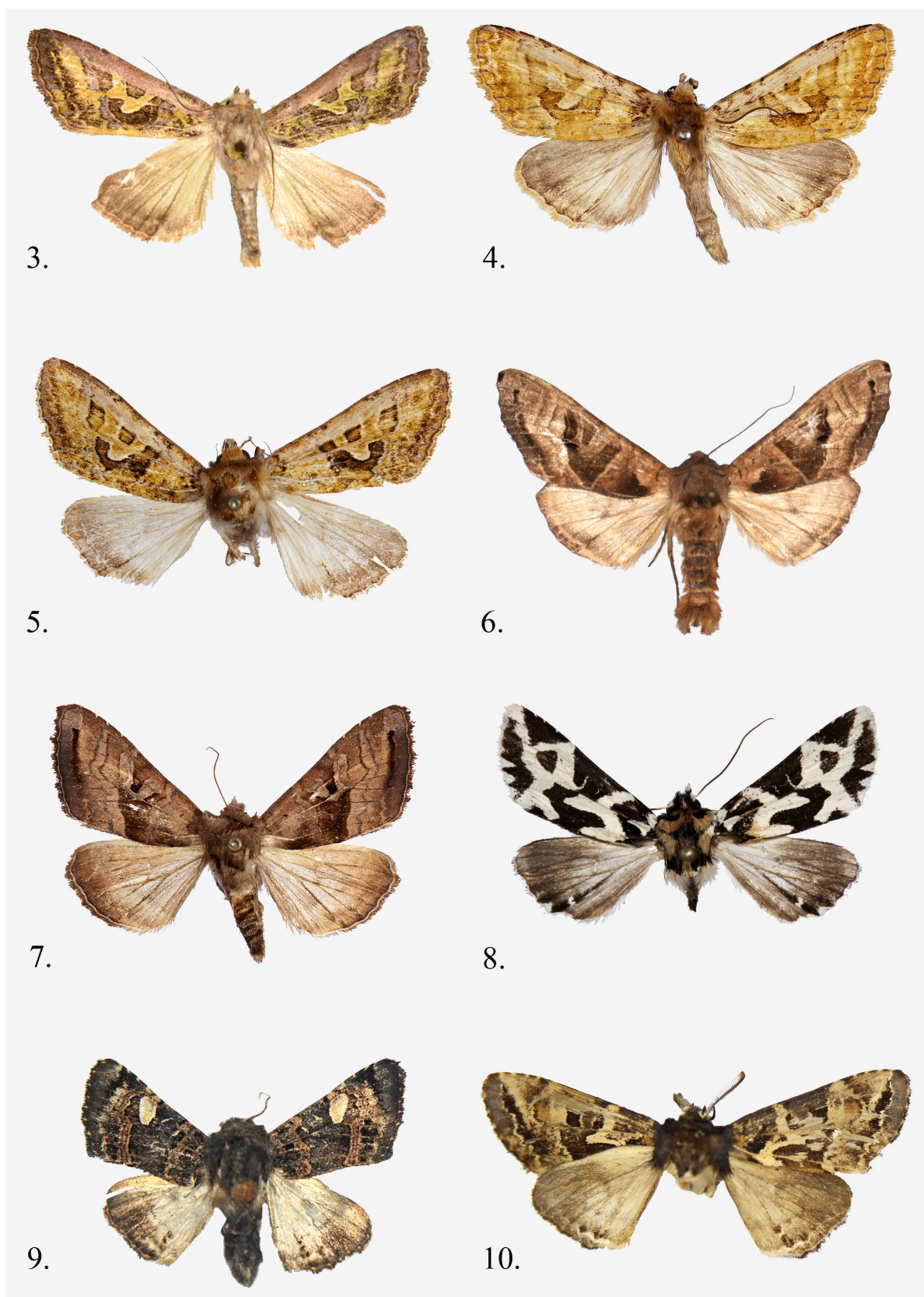
Diagnosis: Wing expanse: Male: 38–40 mm. This species closely resembles *P. humilis* but can be distinguished by relatively less elongated forewing and the pale olive-green forewing ground colour with paler costal border. Fresh specimens are with more prominent olive-green suffusion. However, *P. costalis* can be distinctly told apart from *humilis* by having an indistinct postmedial line just before the marginal dark suffusion of hindwing.

Male genitalia: Uncus narrow, hook shaped; valva spindle shaped with typical harpe-digitus complex which is characterized by a slender, distally bent harpe and a triangular digitus from the middle of valva extended beyond the saccular margin; aedeagus vesica moderately scobinate with a patch of minute cornuti.

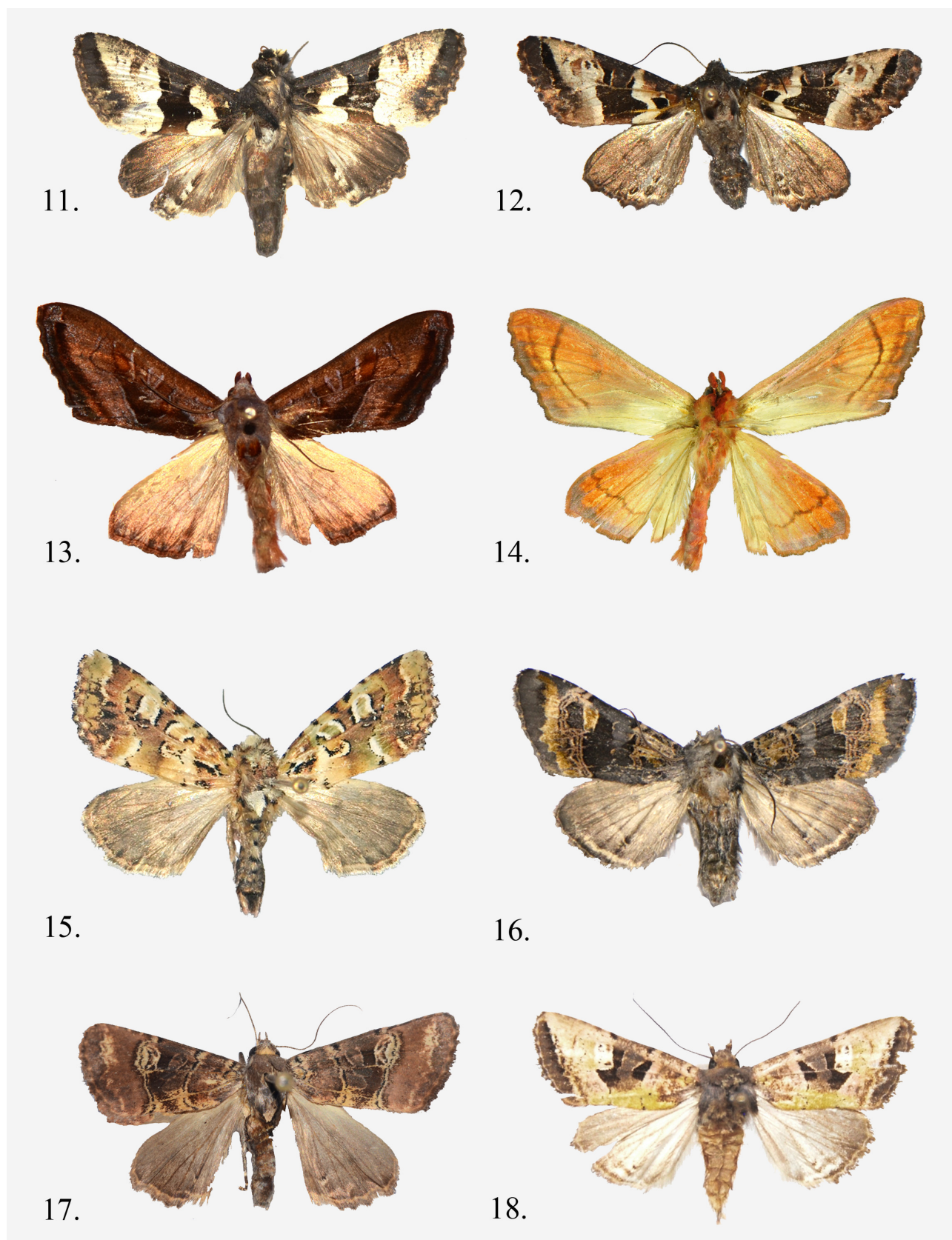
Distribution: India: Uttarakhand, Sikkim, West Bengal, Arunachal Pradesh (Moore 1882; Kirti *et al.* 2014).

Global: Nepal, China (Leech 1900; Yoshimoto 1992).

Bionomics: Distributed from Western to Eastern Himalaya, preferably within a wide altitudinal range of 1500–3000 m with annual mean temperature of 9–16 °C and annual precipitation of 1100–2600 mm. Individuals were active all through the year mainly in Wet Temperate Forest and rarely up to sub-alpine zone in Eastern Himalaya, with population blooms detected in May and October.



FIGURES 3–10. Habitus images of *Phlogophora* spp. 3. *Phlogophora nobilis* Hreblay & Ronkay, 1998; 4. *Phlogophora costalis* (Moore, 1882); 5. *Phlogophora humilis* Hreblay & Ronkay, 1998; 6. *Phlogophora meticolodina* (Draudt, 1950)*; 7. *Phlogophora conservuloides* (Hampson, 1898); 8. *Phlogophora distorta* (Moore, 1881); 9. *Phlogophora szecsenyii* (Hreblay & Ronkay, 1998); 10. *Phlogophora sinuata* (Moore, 1882). *Image procured from Dr Péter Gyulai, Hungary, through personal correspondence.



FIGURES 11–18. Habitus images of *Phlogophora* spp. 11. *Phlogophora albovittata* (Moore, 1867); 12. *Phlogophora pectinata* (Warren, 1888); 13. *Phlogophora subpurpurea* Leech, 1900 (dorsal); 14. *Phlogophora subpurpurea* Leech, 1900 (ventral); 15. *Phlogophora calamistrata* (Moore, 1882); 16. *Phlogophora plumbeola* (Hampson, 1894); 17. *Phlogophora striatovirens* (Moore, 1867); 18. *Phlogophora discisignata* (Moore, 1867)*. *Image procured from Dr Péter Gyulai, Hungary, through personal correspondence.

***Phlogophora similis* Bandyopadhyay, Mallick, Sanyal & Chandra sp. nov.**

[Fig. 19–22, 51–54]

Type material: Holotype: India: ♂, West Bengal, Dist. Kalimpong, Neora Valley National Park, Rishap, 27.1073° N, 088.6512° E, 2136 m, 05. IX. 2016; coll. K. Bhattacharyya & team.

Paratypes: 3 ♂♂, same locality as holotype.

Type repository: National Zoological Collection (NZC), ZSI (Reg. no. HT: 7591/H10; PT: 7592/H10)

Description: Wing expanse: 38–40 mm. Head and thorax ochreous, tinged with olive-green, vertex and patagia with dark olive green hairs; junction of each segment of legs yellow-ringed; antenna ciliated, overall brown with one-third of dorsal side ochreous, basal segment bright ochreous; palpi porrect, ochreous, dark brown at sides; abdomen ochreous, segments with fuscous suffusion, underside darker; forewing with ground colour olive-green, apically elongated with ochreous costal fascia having prominent markings of transverse lines; subbasal line up to the submedian fold, black, double and crenulate; antemedial line double, oblique, indistinct; an olive-brown triangular patch in area between subbasal and antemedial line not touching inner margin; orbicular and reniform ochreous, inner part with olive scales, upper part open, bordered with black, lower part conjoined to a semilunate ochreous patch below median nervure; ‘U’ shaped dark olive-brown patch below that up to vein 1; area between orbicular and reniform dark olive-brown; area beyond reniform with a kidney shaped black bordered olive patch; postmedial line double, crenulate, indistinct, angled inward and dark brown above vein 7; pale, dark-bordered, olive-brown submarginal line highly angled at vein 7 and vein 2, oblique in between; a marginal black line; area between submarginal and marginal line purplish. Hind wing golden-ochreous with a broad fuscous submarginal band, preceded by indistinct, pale postmedial line. Cilia of both wings olive-brown with a fine white line through them.

Forewing underside dark suffused with traces of postmedial line; inner margin and submarginal line pale ochreous. Hindwing underside pale, costal area black speckled with traces of dark postmedial line which becomes obsolete towards anal angle.

Male genitalia: Uncus long, distally broadened and spatulate; valva medio-ventrally broad with a bulge at the saccular margin and forming a prominent constriction below cucullus, narrow at apex; cucullus with strong corona, costa moderately sclerotised with a medial sharp but small projection dividing the costal margin in to two prominent crescents; terminally slightly bent long harpe, digitus broad, ear-shaped, not exceeding the costal margin, basal plate of harpe moderately sclerotised; vinculum ‘V’ shaped, sacculus bulbous with moderate sclerotization at dorsal margin; juxta pointed with apical sclerotization; aedeagus long, slender, sclerotised carinal region; vesica long with a large conical subterminal diverticulum; a large strongly sclerotised subterminal scobinate area opposite to the diverticulum with numerous minute cornuti.

Female: Unknown.

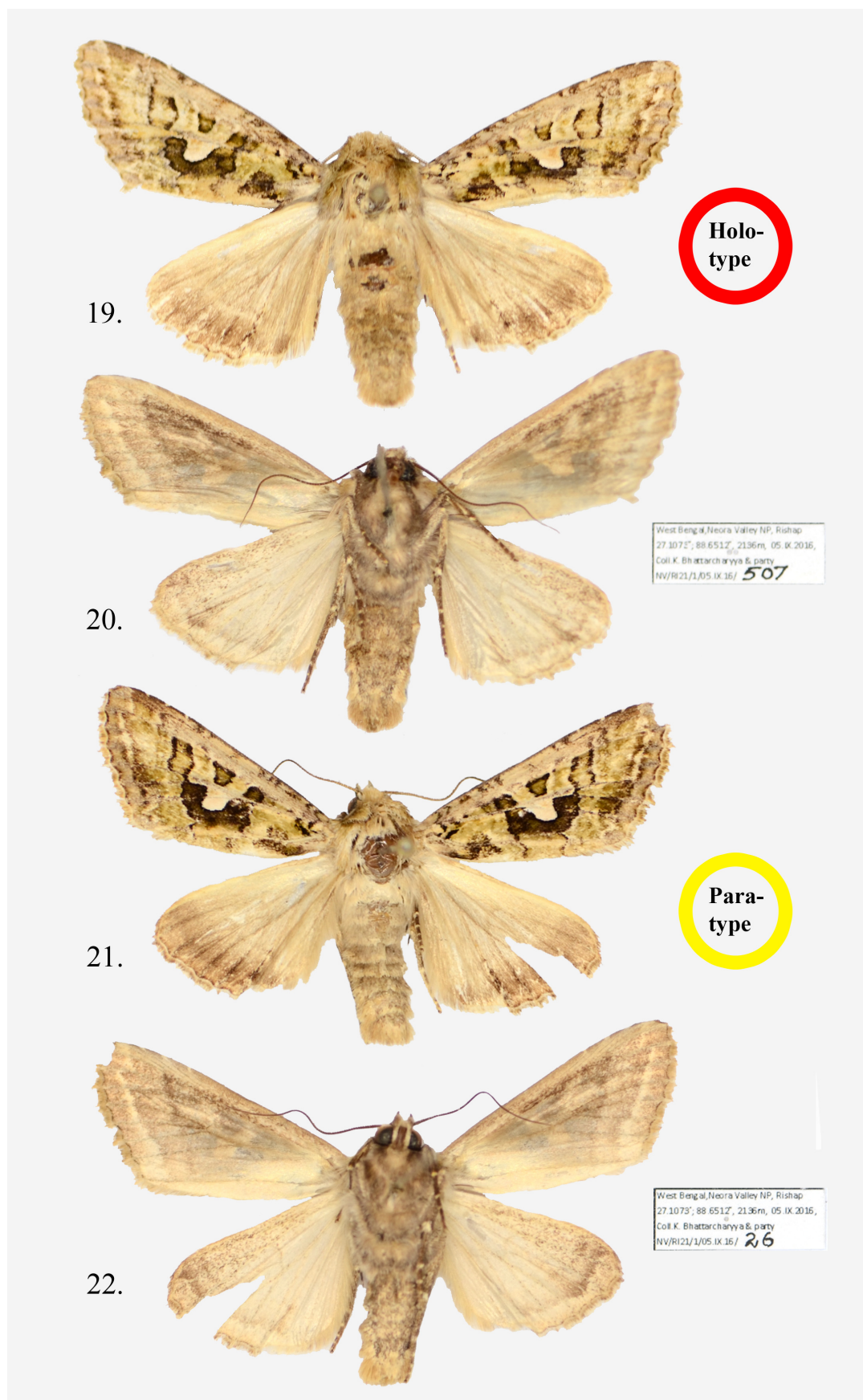
Diagnosis: The new species is definitely allied to *P. costalis* and *P. humilis*. All the three species are apparently indistinguishable in their wing pattern and coloration. The golden-ochreous hind wing with indistinct postmedial line of *P. similis* **sp. nov.** is the only distinguishing feature from its allied species.

In the male genitalia, the new species varies hugely with its siblings. The key features being the distally broad and spatulate uncus where it is narrow in case of both *P. costalis* and *P. humilis*; valva is medio-ventrally broad with narrow cucullus compared to sickle shaped in *humilis* and spindle shaped in *costalis*; the harpe is longer compared to both the siblings and the digitus is ear-shaped compared to triangular in *costalis* and small spine-like in *humilis*; the aedeagus is also comparatively longer and slender. The conical subterminal diverticulum of the vesica of *P. similis* **sp. nov.** is absent in *costalis*, whereas, the minute cornuti of subterminal scobinated patch is lacking in *humilis*.

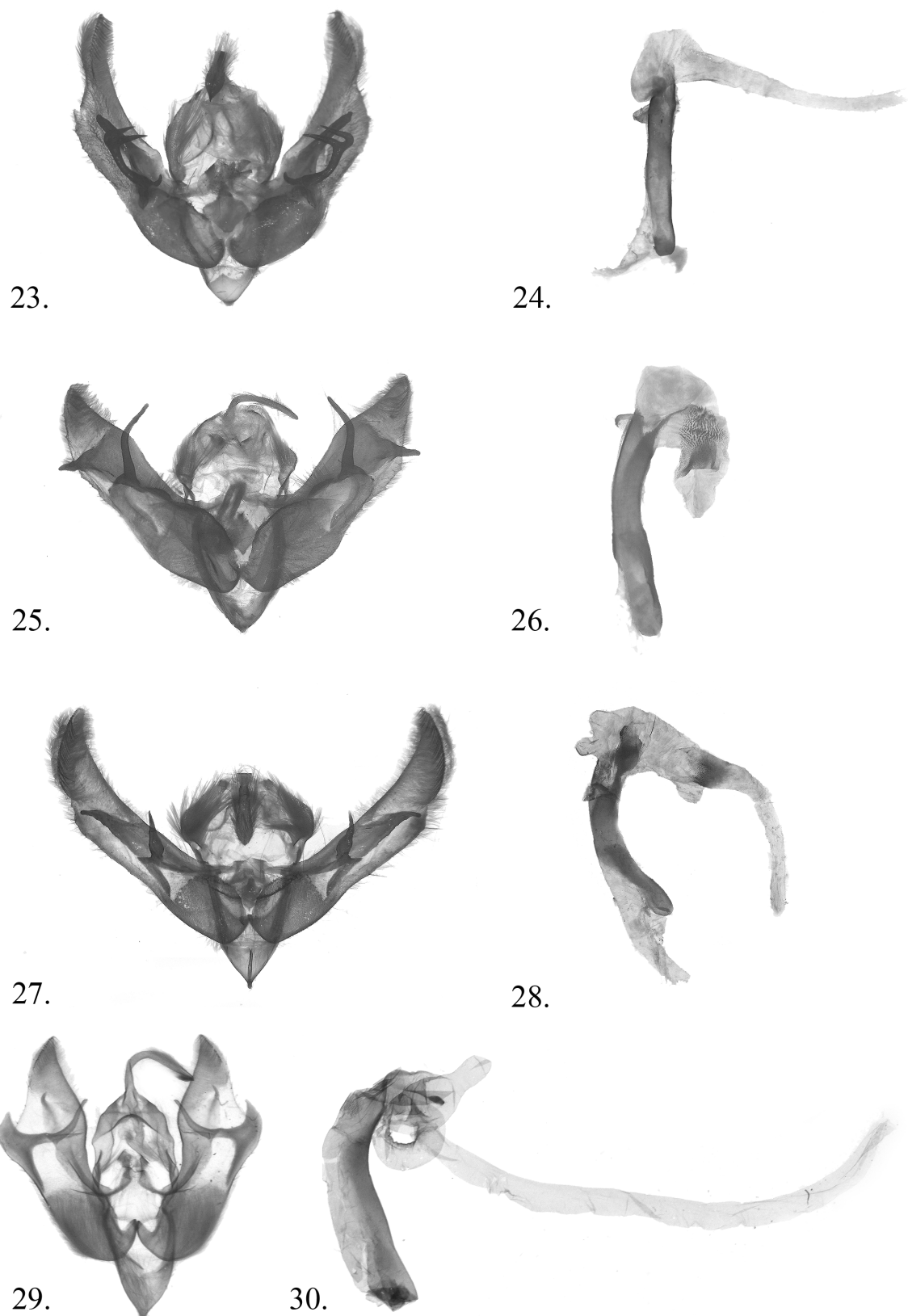
Distribution: India: West Bengal (Dist. Kalimpong).

Bionomics: Probably a very range-restricted species recorded only from Neora Valley National Park at around 2100 m altitude, in Sub-tropical Wet Hill Forest receiving 2600 mm annual precipitation with 14.6 °C annual mean temperature. Individuals were collected in the month of September when the average trap night temperature and average trap night humidity were 17.2 °C and 92.32% respectively.

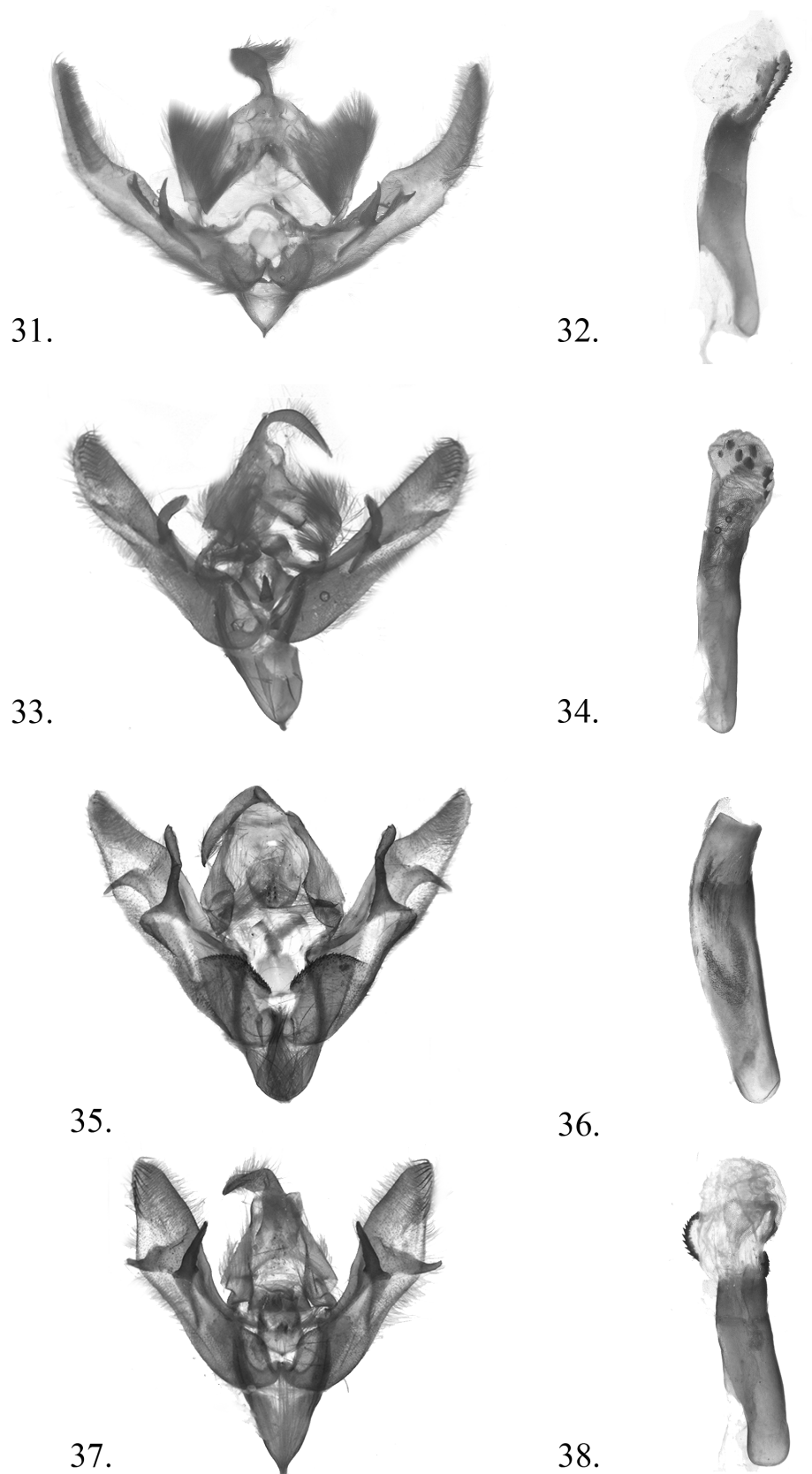
Etymology: The name of the new species refers to its apparently similar wing pattern with the closely allied “*costalis*” group of species, all having names ending with suffix “*lis*” including *P. humilis* and *P. nobilis*.



FIGURES 19–22. Habitus images of *Phlogophora similis* **sp. nov.** 19. *Phlogophora similis* **sp. nov.**, male, HT (dorsal); 20. *Phlogophora similis* **sp. nov.**, male, HT (ventral); 21. *Phlogophora similis* **sp. nov.**, male, PT (dorsal); 22. *Phlogophora similis* **sp. nov.**, male, PT (ventral).



FIGURES 23–30. Male genitalia images of *Phlogophora* spp. 23–24. *Phlogophora nobilis* Hreblay & Ronkay, 1998, West Bengal, Gen. prep. SN/MND21/1/29.X.18/60; 25–26. *Phlogophora costalis* (Moore, 1882), West Bengal, Gen. prep. SN/GAR24_2/2/21.V.18/37; 27–28. *Phlogophora humilis* Hreblay & Ronkay, 1998, West Bengal, Gen. prep. SN/PAL19_1/1/03. XI.18/166; 29–30. *Phlogophora meticolodina* (Draudt, 1950), Sichuan, China, Gen. prep. GYP 5267*. *Image procured from Dr Péter Gyulai, Hungary, through personal correspondence.



FIGURES 31–38. Male genitalia images of *Phlogophora* spp. 31–32. *Phlogophora conservuloides* (Hampson, 1898), Uttarakhand, Gen. prep. AS/CK26/3/18.VI.18/7; 33–34. *Phlogophora distorta* (Moore, 1881), Uttarakhand, Gen. prep. AS/CK22/3/14.V.18/4; 35–36. *Phlogophora szecsényii* (Hreblay & Ronkay, 1998), Sikkim, Gen. prep. KB/DZ19/1/23.XI.19/203; 37–38. *Phlogophora albovittata* (Moore, 1867), West Bengal, Gen. prep. SN/CH22/2/15.V.18/190.

***Phlogophora humilis* Hreblay & Ronkay, 1998**

[Fig. 5, 27, 28]

Phlogophora humilis Hreblay & Ronkay, 1998, in Haruta, *Tinea*, **15**: 259.

Type locality: Lal Kharka, Taplejung area [Nepal].

Material examined: India: 1 ♂, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 088.22087° E, 1879 m, 23. XI. 2019; coll. A. K. Sanyal & team.

1 ♂, West Bengal, Dist. Darjeeling, Singalila National Park, Manedara, 27.1147° N, 088.1000° E, 2168 m, 19. X. 2018; 3 ♂♂, 1 ♀, 29. X. 2018; coll. A. K. Sanyal & team; 2 ♂♂, Palamajua, 27.07071° N, 088.09071° E, 1909 m, 03. XI. 2018; coll. K. Bhattacharyya & team.

Diagnosis: Wing expanse: Male: 36–40 mm, female: 38–40 mm. Almost similar to *P. costalis* and very difficult to separate from outer morphology. Head, thorax and forewing darker olive-green. The hind wing is much whitish compared to *costalis* and have a prominent submarginal dark band lacking the postmedial line before it.

Male genitalia: In *P. humilis*, the male genitalia differ widely from *costalis* having a much longer and narrower sickle-shaped valva with an acute and curved apex. Shorter, basally inflated harpe and elongated ampulla not crossing the saccular margin are typical to the species. Aedeagus vesica long, with a subterminal scobinated patch.

Distribution: **India:** Sikkim, West Bengal (Hreblay & Ronkay 1998). **Global:** Nepal (Hreblay & Ronkay 1998).

Bionomics: Distribution restricted to Central Himalaya, preferably within an altitudinal range of 1900–2500 m, with an annual mean temperature and annual precipitation range of 9–14 °C and 2300–2500 mm respectively. The species was mainly recorded in wet Temperate and mixed Coniferous forests in the postmonsoon months of October and November.

***Phlogophora meticolodina* (Draudt, 1950)**

[Fig. 6, 29, 30]

Trigonophora meticolodina Draudt, 1950, *Mitt. Münchn. Ent. Ges.*, **40**: 104.

Phlogophora meticolodina (Draudt): Hreblay & Ronkay, 1998, in Haruta, *Tinea*, **15**: 260.

Type locality: Li-kiang [China, Yunnan]

Material examined: India: 1 ♀, Uttarakhand, Dist. Uttarkashi, Govind National Park, Har-Ki-Dun, 31.13592° N, 078.39939° E, 3400 m, 17. VI. 2012; 1 ♂, 31.04347° N, 078.26258° E, 3200 m, 22. VI. 2012; coll. A. K. Sanyal & team; 1 ♀, Dist. Chamoli, Valley of Flowers National Park, Ghangaria, 30.70120° N, 079.59398° E, 3103 m, 15. VI. 2017; coll. S. K. Sajan.

Diagnosis: Wing expanse: Male: 42–44 mm, Female: 40–42 mm. Forewing apically much elongated with pinkish tinge; differs from very similar South-Pacific species *P. beatrix* as forewing with dark brown apical streak instead of marginal dark lunules; submarginal line black filled below vein 7 which is pale in *beatrix*. Hindwing pale with ochreous submarginal line; a prominent black marginal line is present in *beatrix* which is lacking in *meticolodina*.

Male genitalia: Uncus long, beak-shaped; valva moderately developed with sclerotised costal area and membranous saccular margin, presence of long, slender harpe and less developed ampulla, the basal plate of harpe is highly sclerotised, broad with acute apex and fused with distal part of sacculus; aedeagus with long coiled vesica without any scobinations.

Distribution: **India:** Uttarakhand. **Global:** Pakistan, Nepal, China (Draudt 1950; Hreblay and Ronkay 1998; Bálint *et al.* 2014).

Note: This species is being reported for the first time from India.

Bionomics: Probably the rarest among all the Indian *Phlogophora*, the species is altitudinally very restricted, never observed below 3000 m, upper range being 3800 m recorded in Nepal. Collected mostly from sub-alpine and alpine habitats composed of Birch-Fir-*Rhododendron* patches. The seasonality of the species is also very specific, always recorded in the month of June within a narrow range of annual mean temperature and annual precipitation of 4.6–7 °C and 1300–1700 mm respectively.

NCBI GenBank accession No.: MT188152.

Phlogophora conservuloides (Hampson, 1898)

[Fig. 7, 31, 32]

Euplexia conservuloides Hampson, 1898, *J. Bomb. Soc.*, **11**: 443.

Chutapha conservuloides (Hampson): Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 493.

Phlogophora conservuloides (Hampson): Yoshimoto, 1992, in Haruta, *Tinea*, **13**: 59.

Type locality: Sikkim [India]

Material examined: India: 1 ♂, Himachal Pradesh, Dist. Kullu, Great Himalayan National Park, Thathi, 31.73912° N, 077.35873° E, 2917 m, 08. IX. 2016; coll. A. K. Sanyal & team; 1 ♂, Shakti Waterfall, 31.78673° N, 077.47989° E, 2200 m, 27. V. 2018; coll. K. Mallick & team. 1 ♂, Dist. Kangra, Dharamshala, Maniyana, 32.22809° N, 076.28016° E, 995 m, 27. X. 2018; coll. A. Raha & team.

4 ♂♂, Uttarakhand, Dist. Pithoragarh, Askot Wildlife Sanctuary, Gawalghat, 29.91782° N, 080.40010° E, 2462 m, 16. VI. 2018; 2 ♂♂, Jimjhini, 29.92121° N, 080.39719° E, 2627 m, 18. VI. 2018; coll. A. K. Sanyal & team.

2 ♂♂, West Bengal, Dist. Darjeeling, Singalila National Park, Chitre, 26.99126° N, 088.11189° E, 2295 m, 15. V. 2018; 2 ♂♂, Meghma, 27.03270° N, 088.08314° E, 2971 m, 19. V. 2018; 1 ♂, Kalpokhri, 27.07387° N, 088.01698° E, 3000 m, 24. V. 2018; coll. K. Bhattacharyya & team; 1 ♂, Manedara, 27.1147° N, 088.1000° E, 2168 m, 01. XI. 2018; coll. A. K. Sanyal & team.

Diagnosis: Wing expanse: Male: 32–34 mm, female: 30–32 mm. In forewing, a prominent black speck between subbasal and antemedial line; submarginal line dark brown in colour between vein 7 and vein 3 particularly, otherwise indistinct and pale; prominent black postmedial line which is double above vein 4; medial area with a chocolate brown triangular patch conjoining the lower part of orbicular and reniform, continuing up to middle of inner margin; area between orbicular and reniform dark chocolate brown. Hindwing pale; cilia brown preceded by a fine ochreous line; underside of both wings paler with pinkish tinge; visible postmedial lines.

Male genitalia: The main characteristic feature is that the valva is narrow compared to its congeners and is long, pointed, sickle-shaped; harpe short, curved, horn-like, and the digitus small, blunt; aedeagus with two ridges of minute spines in carinal region.

Distribution: India: Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, Arunachal Pradesh (Hampson 1898; Kirti *et al.* 2014). **Global:** Nepal, China, Taiwan (Yoshimoto 1992).

Bionomics: Recorded throughout North-Western to Eastern Himalaya, the species is active in the widest altitudinal range among all the Himalayan *Phlogophora* from 1000–3000 m, in a variety of forested habitats from Chir Pine to sub-alpine. Individuals were active in all the seasons with a peak in the month of May in areas receiving an annual precipitation of 1100–2500 mm and annual mean temperature of 10.1–19.9 °C.

Phlogophora distorta (Moore, 1881)

[Fig. 8, 33, 34]

Euplexia distorta Moore, 1881, *Proc. Zool. Soc.*: 354.

Trachea distorta (Moore): Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 121.

Phlogophora distorta (Moore): Yoshimoto, 1992, in Haruta, *Tinea*, **13**: 59.

Phlogophora distorta (Moore): Kononenko & Pinratana, 2013, *Moths of Thailand*, **3** (2): 328.

Type locality: Darjeeling [India, West Bengal]

Material examined: India: 1 ♂, Uttarakhand, Dist. Pithoragarh, Askot Wildlife Sanctuary, Gawalghat, 29.91398° N, 080.40338° E, 2248 m, 04. VI. 2018; coll. A. K. Sanyal & team;

1 ♀, West Bengal, Dist. Darjeeling, Singalila National Park, Chitre, 26.99126° N, 088.11189° E, 2295 m, 15. V. 2018; 1 ♀, Meghma, 27.01586° N, 088.08993° E, 2733 m, 18. V. 2018; 1 ♀, Gairibas, 27.05090° N, 088.03360° E, 2494 m, 21. V. 2018; 1 ♂, Manebhanjan, 26.9877° N, 088.1194° E, 1975 m, 16. X. 2018; 1 ♂, Sirikhola, 27.13034° N, 088.07441° E, 1914 m, 17. X. 2018; 1 ♀, Rimbik, 27.1141° N, 088.1105° E, 1905 m, 18. X. 2018; 3 ♂♂, Palamajua, 27.07071° N, 088.09071° E, 1909 m, 03. XI. 2018; coll. K. Bhattacharyya & team; 1 ♂, Manedara, 27.1147° N, 088.1000° E, 2168 m, 04. XI. 2018; coll. A. K. Sanyal & team.

Diagnosis: Wing expanse: Male: 32–34 mm, female: 28–30 mm. The species has distinct white tipped palpi,

ciliated antenna with white basal tufts and black collar with continuous outlying patches of broad golden-white hairs. It is distinctly recognizable by its zigzag black patterns on white forewing. A trapezoid black patch on middle of costa minutely conjoined with an irregular black patch starting from lower angle of cell to inner margin; a big black triangular patch on costa just before apex; a submarginal elongated black patch with crenulate outer margin, not touching apex.

Male genitalia: Uncus moderately long, hook-shaped; juxta broad, apically narrow, moderately sclerotised with a small triangular sclerotised projection at the middle; valva long, spindle-shaped with one distally curved harpe, cucullus with prominent corona; aedeagus vesica with scattered patches of small cornuti.

Distribution: **India:** Uttarakhand, Sikkim, West Bengal (Moore 1881). **Global:** Nepal, Thailand (Yoshimoto 1992; Kononenko & Pinratana 2013).

Bionomics: Distributed from Western to Central Himalaya, preferably within altitudinal zone of 1900–2700 m, in Wet Temperate and Mixed Coniferous forests with an annual mean temperature range of 12–16 °C and average annual precipitation of 1700–2700 mm. Individuals were recorded in both pre-monsoon and post-monsoon months.

***Phlogophora szecsenyii* Hreblay & Ronkay, 1998**

[Fig. 9, 35, 36]

Phlogophora szecsenyii Hreblay & Ronkay, 1998, *Esperiana*, **6**: 148.

Phlogophora szecsenyii Hreblay & Ronkay: Kononenko & Pinratana, 2013, *Moths of Thailand*, **3**(2): 327.

Type locality: Anpan, Deorali Tanda [Nepal].

Material examined: India: 1 ♂, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 88.22087° E, 1879 m, 23. XI. 2019; coll. A. K. Sanyal & team.

Diagnosis: Wing expanse: Male: 23–25 mm. A remarkably small species relative to its congeners. The species is readily identifiable by its blackish-grey ground colour of the forewings with distinctive white reniform. Multiple subbasal and postmedial golden transverse lines; the outer margin suffused with grey with prominent golden marginal specks. The species is also very similar to *P. plumbeola* but differs in being much smaller in size and darker in colour.

Male genitalia: Valve spindle-shaped with the clasper being much sclerotised, long thumb-like and a small spine like digitus in the sclerotised costal region; sacculus with a half circular convex ridge of small organized spines instead of multiple irregular ones like *P. plumbeola*.

Distribution: **India:** Sikkim. **Global:** Nepal, Thailand, Vietnam (Kononenko & Pinratana 2013).

Note: This species is being reported for the first time from India.

Bionomics: A rare species in Himalaya, recorded only from Central Himalayan zone of Nepal and Sikkim, in a very narrow altitudinal range of 1800–2000 m, preferably in Wet Temperate Forest. Single individual was observed during post-monsoon month of November with an annual mean temperature of 15.6 °C and an annual precipitation of 2300 mm.

NCBI GenBank accession No.: MT188151

***Phlogophora sinuata* (Moore, 1882)**

[Fig. 10]

Euplexia sinuata Moore, 1882, *Descr. Indian lep. Atkinson*, (2): 125.

Euplexia sinuata Moore: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 220.

Phlogophora sinuata (Moore): Yoshimoto, 1994, in Haruta, *Tinea*, **14**: 110.

Type locality: Darjeeling [India, West Bengal]

Material examined: India: 1 ♂, West Bengal, Dist. Darjeeling, Singalila National Park, Gairibas, 27.05090° N, 88.03360° E, 2494 m, 21. V. 2018; coll. K. Bhattacharyya & team.

Diagnosis: Wing expanse: Male: 34 mm. The species is typically characterized by the distinct whitish sinuous

antemedial band strongly angled outward below the cell, and thus can be differentiated with the closely related *P. albiovittata* and *P. pectinata*, which have the antemedial white band bent inward below the cell. The basal area of forewing is much darker and wider, thus the antemedial band is relatively narrower compared to other two species. A small ochreous patch in the basal area and a distinct large ochreous patch beyond the reniform. Submarginal line sinuous, complete, defined by black in inner side and purplish-grey at outer side as in *pectinata* while *albovittata* lacks the submarginal line.

Male genitalia: Unfortunately, the male genitalia structure could not be examined as the abdomen of the single collected specimen was unavailable.

Distribution: **India:** Sikkim, West Bengal (Moore 1882; Hampson 1908). **Global:** Nepal (Yoshimoto 1994).

Bionomics: A very rare species, restricted to the Central Himalaya and till date only recorded from Nepal on a single occasion after its description. One single individual was captured from the adjacent area of the type locality in the pre-monsoon month of May. The species is only reported around 2500 m altitude in the Wet Temperate forests at an average trap night temperature of 12.24 °C and average trap night humidity of 93.67%.

Phlogophora albiovittata (Moore, 1867)

[Fig. 11, 37, 38]

Euplexia albiovittata Moore, 1867, *Proc. Zool. Soc.*: 57.

Euplexia albiovittata Moore: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, 7: 226.

Phlogophora albiovittata (Moore): Holloway, 1989, *Malay. Nat. J.*, 42 (2–3): 57–225.

Phlogophora albiovittata (Moore): Kononenko & Pinratana, 2013, *Moths of Thailand*, 3 (2): 327.

Type locality: Darjeeling [India, West Bengal]

Material examined: India: 2 ♂♂, 1 ♀, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 88.22087° E, 1879 m, 19. XI. 2019; 1 ♀, 22. XI. 2019; 1 ♂, 1 ♀, 23. XI. 2019; 1 ♂, 1 ♀, Khoyngetey, 27.37947° N, 88.22678° E, 1950 m, 28. XI. 2019; 1 ♀, Begha, 27.25722° N, 88.60463° E, 1596 m, 07. XII. 2019; 2 ♂♂, 1 ♀, Dist. North Sikkim, Khangchendzonga Biosphere Reserve, Rabum, 27.65842° N, 88.60463° E, 2000 m, 13. XII. 2019; coll. A. K. Sanyal & team.

1 ♂, West Bengal, Dist. Darjeeling, Singalila National Park, Sirikhola, 27.13034° N, 88.07441° E, 1914 m, 12. VIII. 2016; 2 ♂♂, 17. X. 2018; 2 ♂♂, 3 ♀♀, Chitre, 26.99126° N, 88.11189° E, 2295 m, 15. V. 2018; 1 ♂, Meghma, 27.03270° N, 88.08314° E, 2971 m, 19. V. 2018; 1 ♂, 2 ♀♀, Gairibas, 27.05090° N, 88.03360° E, 2494 m, 21. V. 2018; 2 ♀♀, Molley Camp, 27.16998° N, 88.0202° E, 3510 m, 26. V. 2018; 1 ♂, Kalpokhri, 27.07387° N, 88.01698° E, 3000 m, 24. V. 2018; coll. K. Bhattacharyya & team; 1 ♀, Manebhanjan, 26.9877° N, 88.1194° E, 1975 m, 16. X. 2018; 1 ♂, Manedara, 27.1147° N, 88.1° E, 2168 m, 27. X. 2018; 1 ♂, 29. X. 2018; 2 ♂♂, 30. X. 2018; 1 ♂, 31. X. 2018; 1 ♂, 04. XI. 2018; 1 ♀, 07. XI. 2018; coll. A. K. Sanyal & team; 2 ♂♂, 1 ♀, Palamajua, 27.07071° N, 88.09071° E, 1909 m, 03. XI. 2018; 1 ♂, Khopidara, 27.00525° N, 88.1189° E, 2054 m, 06. XI. 2018; coll. K. Bhattacharyya & team.

1 ♂, Arunachal Pradesh, Dist. Dibang Valley, Dihang Dibang Biosphere Reserve, Malini Camp, 28.68275° N, 95.15980° E, 1870 m, 28. X. 2017; 1 ♂, 29. X. 2017; 1 ♂, Mipi, 28.96387° N, 95.80807° E, 1552 m, 31. X. 2017; coll. N. Singh; 1 ♂, Brango, 28.93824° N, 95.81697° E, 1467 m, 09. IV. 2018; coll. R. Ranjan.

Diagnosis: Wing expanse: Male: 38–40 mm, female: 34–36 mm. The species has distinct white tipped palpi, ciliated antenna with white basal tufts and completely blackish-brown thorax. It is characterized by typical silvery-white forewing with chocolate-brown suffusion; basal area irregularly black-brown; a broad antemedial irregular white band dentate inwardly below cell; medial band broad, chocolate-brown; orbicular blackish and reniform white. The species is almost similar to Bornean *P. nigroplumbea* (Warren, 1912) which differs from it by having a continuous dark grey forewing costa extended up to the distal edge of reniform, whereas in *albovittata*, the area is broken above reniform with the extension of white colour of the reniform, leaving only a few dark speckling.

Male genitalia: The male genitalia of the species is characterized by spindle shaped valva with relatively short but strong harpe and less sclerotised digitus; the aedeagus vesica is characterized by one circular ridge of upwardly directed spines. The notable difference with *nigroplumbea* can be observed in the scobinated patch of vesica being present in opposite direction (Holloway 1989).

Distribution: India: Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, Arunachal Pradesh, Meghalaya, Nagaland, Tamil Nadu (Moore 1867; Cotes & Swinhoe 1888; Hampson 1894; Kirti *et al.* 2014). **Global:** Pakistan, Nepal, Bhutan, China, Taiwan, Vietnam, Thailand, Indonesia (Sumatra, Java), Japan, Korea (Cotes & Swinhoe 1888; Leech 1900; Dudgeon 1905; Hampson 1908; Roepke 1948; Lin 1993; Kononenko & Pinratana 2013).

Bionomics: Most widely distributed among all the Indian *Phlogophora*, ranging throughout the Himalayas (except Trans-Himalaya), North-Eastern Hills and Western Ghats, in wide habitat types ranging from Evergreen, Temperate and Coniferous forests. In Himalaya, the species is recorded in the altitudinal zone of 1450–3500 m, receiving annual precipitation of 1300–2700 mm and annual mean temperature of 8–16 °C. The species was recorded in all three major seasons of the year with maximum abundance in October–November.

NCBI GenBank accession No.: MT219962, MT219963, MT219964, MT219967, MT219969

Phlogophora pectinata (Warren, 1888)

[Fig. 12, 39, 40]

Euplexia pectinata Warren, 1888, *Proc. Zool. Soc.*: 308.

Euplexia pectinata Warren: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, 7: 221.

Phlogophora pectinata (Warren): Yoshimoto, 1994, in Haruta, *Tinea*, 14: 110.

Type locality: Thundiani [Pakistan]

Material examined: India: 1 ♀, Himachal Pradesh, Dist. Kullu, Great Himalayan National Park, Dhel, 31.75618° N, 077.46146° E, 3567 m, 29. VIII. 2016; coll. A. K. Sanyal & team; 1 ♀, Ropa FRH, 31.76558° N, 077.35765° E, 1515 m, 19. IX. 2019; coll. K. Mallick & team.

1 ♂, 1 ♀, Uttarakhand, Dist. Chamoli, Valley of Flowers National Park, Ghangaria, 30.70122° N, 079.59402° E, 3128 m, 28. VIII. 2016; coll. H. Kumar.

1 ♀, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 088.22087° E, 1879 m, 20. XI. 2019, 1 ♀, 23. XI. 2019; coll. A. K. Sanyal & team.

1 ♂, West Bengal, Dist. Darjeeling, Singalila National Park, Meghma, 27.01586° N, 088.08993° E, 2733 m, 18. V. 2018; coll. K. Bhattacharyya & team.

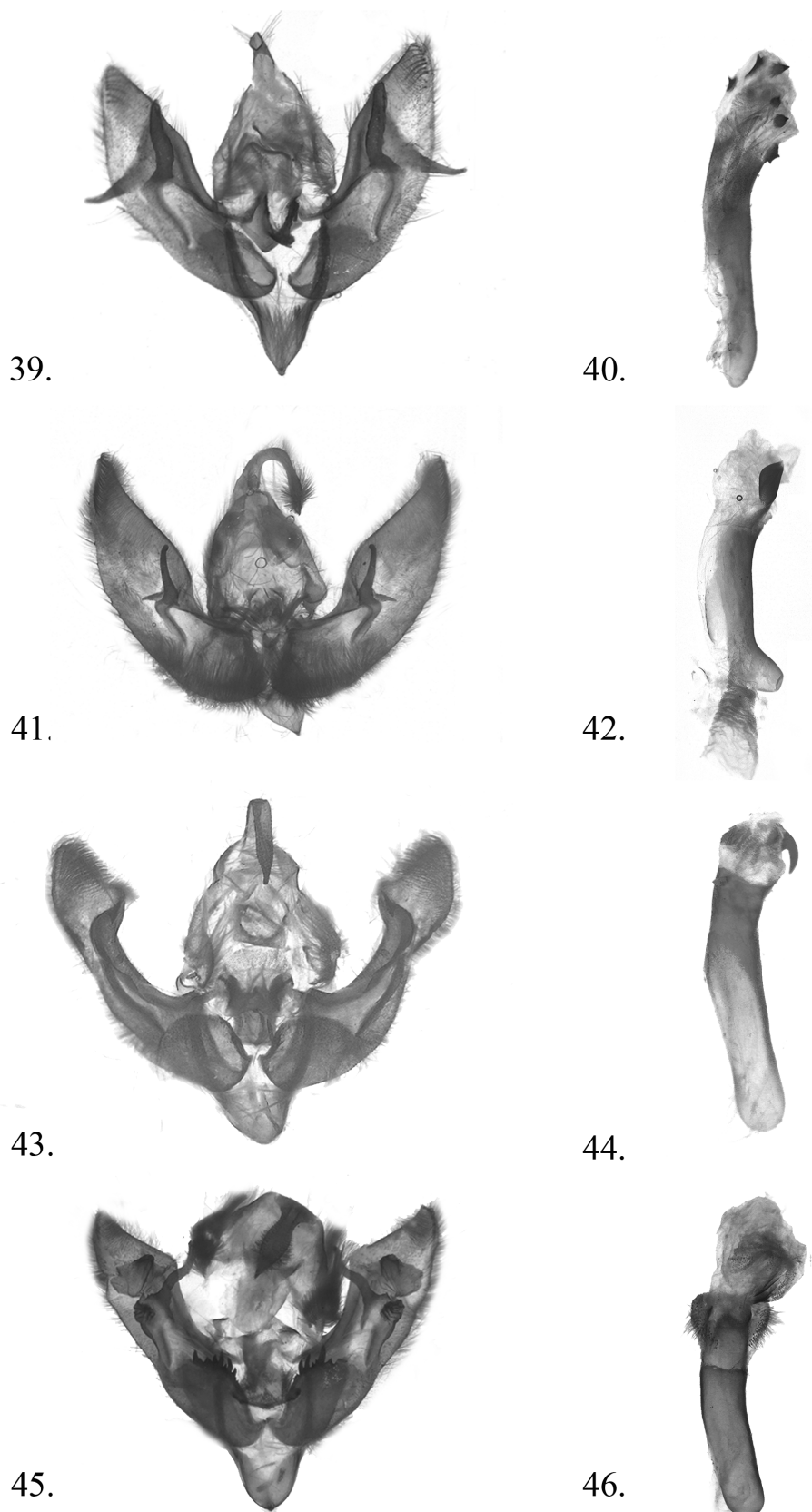
1 ♀, Arunachal Pradesh, Dist. Tawang, Lumla, 27.52915° N, 091.71025° E, 2427 m, 14. IX. 2016; coll. J. Saini; 2 ♀♀, Dist. Dibang Valley, Dihang Dibang Biosphere Reserve, Mayodia, 28.23309° N, 095.90814° E, 2463 m, 29. XII. 2016; coll. S. Gayen; 3 ♂♂, Malini Camp, 28.68275° N, 095.15980° E, 1870 m, 27. XI. 2017; 1 ♂, 28. XI. 2017; coll. N. Singh.

Diagnosis: Wing expanse: Male: 32–34 mm, female: 34–36 mm. *P. pectinata* is typically identified by the pectinated antenna in males, whereas in female it is filiform. It closely resembles *P. albovittata* in outer morphology. The major differences are observed in the forewing of the two species having a distinct black spot conjoined with the basal patch in case of *albovittata* whereas it is disjunct from the basal area in *pectinata*; the submarginal sinuous line is distinctly defined in *pectinata* whereas it is completely absent in *albovittata*. Hindwing completely fuscous unlike *albovittata* where the basal and inner area are whitish.

Male genitalia: Uncus short; valva spindle shaped; harpe and digitus longer compared to *albovittata*; the vesica is typically characterized by well distributed patch of small cornuti.

Distribution: India: Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, Arunachal Pradesh, Haryana, Tamil Nadu (Hampson 1908). **Global:** Pakistan, Nepal (Warren 1888; Yoshimoto 1994).

Bionomics: Widely distributed species ranging throughout Himalayas from North-Western to Eastern Himalaya, Western Ghats and Semi-Arid region, preferably in the altitudinal zone of 1500–3500 m in Himalaya, in wide ranging habitat types from Chir Pine Forest to sub-alpine Birch-*Rhododendron* Forest. The species was recorded from a comparatively broad range of mean annual temperature from 4.6–16 °C and an annual precipitation range of 1000–2300 mm. Although recorded throughout the year, maximum abundance was detected mainly in the month of November.



FIGURES 39–46. Male genitalia images of *Phlogophora* spp. 39–40. *Phlogophora pectinata* (Warren, 1888), Uttarakhand, Gen. prep. WHLEP_133; 41–42. *Phlogophora subpurpurea* Leech, 1900, Uttarakhand, Gen. prep. AS/CK31/3/03.VI.18/8; 43–44. *Phlogophora calamistrata* (Moore, 1882), Sikkim, Gen. prep. KB/DZ19/1/24.XI.19/11; 45–46. *Phlogophora plumbeola* (Hampson, 1894), Uttarakhand, Gen. prep. GLA_4.2.

Phlogophora subpurpurea Leech, 1900

[Fig. 13, 14, 41, 42]

Phlogophora subpurpurea Leech, 1900, *Trans. Ent. Soc.*, **48**: 71.

Trigonophora subpurpurea (Leech): Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 490.

Phlogophora subpurpurea Leech: Yoshimoto, 1994, in Haruta, *Tinea*, **14**: 110.

Type locality: Ta-Chien-lu [China, Sichuan]

Material examined: India: 1 ♀, Himachal Pradesh, Dist. Kullu, Great Himalayan National Park, Shakti, 31.78847° N, 077.49486° E, 2258 m, 30. VIII. 2016; coll. A. K. Sanyal & team;

1 ♀, Uttarakhand, Dist. Uttarkashi, Govind Wildlife Sanctuary, Changsil, 31.12172° N, 077.99303° E, 3200 m, 15. VII. 2012; 3 ♂♂, Dist. Pithoragarh, Askot Wildlife Sanctuary, Vayman, 29.92711° N, 080.38988° E, 3065 m, 03. VII. 2018; coll. A. K. Sanyal & team.

Diagnosis: Wing expanse: Male: 58–60 mm, female: 46–48 mm. Similar to *P. meticolodina* but easily distinguishable by the scarlet red coloration of underside of palpi, thorax and abdomen; forewing much darker, rufous brown with purplish suffusion, markings dark chocolate brown; orbicular, reniform and lower half of postmedial line marked with purplish white; a narrow silvery-grey line originating from a same coloured apical patch along outer margin which becomes obsolete in the middle. Hindwing pale brown with flesh coloured tinge; outer margin greyish; underside of both wings crimson red with prominent postmedial lines.

Male genitalia: Uncus hook shaped; valva apically narrow, medio ventrally broadened; basal plate of harpe moderately sclerotised; clasper long, blunt, round-tipped; ampulla very small, less sclerotised; in aedeagus, carina region with a thumb like sclerotised plate; vesica without any scobination.

Distribution: **India:** Himachal Pradesh, Uttarakhand (Hampson 1908). **Global:** Pakistan, Nepal, China (Tibet) (Leech 1900; Yoshimoto 1994; Bálint *et al.* 2014).

Bionomics: Distributed in North-Western and Western Himalaya and mostly active in altitudinal range of 3000–3200 m, covering sub-alpine and alpine habitats. Seasonal window is also very narrow, activity recorded mostly during transition of pre-monsoon and monsoon, in the months of July–August within an average trap night temperature range of 7–11 °C and annual precipitation range of 1100–1700 mm.

Phlogophora calamistrata (Moore, 1882)

[Fig. 15, 43, 44]

Dianthecia calamistrata Moore, 1882, *Descr. Indian lep. Atkinson*, (2): 124.

Euplexia calamistrata (Moore): Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 230.

Phlogophora calamistrata (Moore): Fibiger & Hacker, 2007, *Noct. Eur.*, **9**: 186.

Type locality: Darjeeling [India, West Bengal].

Material examined: India: 1 ♀, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 88.22087° E, 1879 m, 22. XI. 2019; 1 ♂, 24. XI. 2019; 1 ♀, Khoyngetey, 27.37947° N, 88.22678° E, 1950 m, 27. XI. 2019; 1 ♀, Sachen, 27.41380° N, 88.19749° E, 2193 m, 01. XII. 2019; 3 ♀♀, Dist. North Sikkim, Khangchendzonga Biosphere Reserve, Rabum, 27.65842° N, 88.60463° E, 2000 m, 13. XII. 2019; coll. A. K. Sanyal & team.

1 ♂, West Bengal, Dist. Darjeeling, Darjeeling, 27.0402° N, 88.268° E, 2119 m, 15. X. 2018; 2 ♂♂, Singalila National Park, Manedara, 27.1147° N, 88.1000° E, 2168 m, 27. X. 2018; 6 ♂♂, 29. X. 2018; 1 ♂, 30. X. 2018; 8 ♂♂, 31. X. 2018; coll. A. K. Sanyal & team; 2 ♂♂, Palamajua, 27.07071° N, 88.09071° E, 1909 m, 03. XI. 2018; 4 ♂♂, Dhotrey, 27.0499° N, 88.1093° E, 2531 m, 05. XI. 2018, 2054 m; 8 ♂♂, Khopidara, 27.00525° N, 88.1189° E, 2054 m, 06. XI. 2018; coll. K. Bhattacharyya & team.

Diagnosis: Wing expanse: Male: 36–38 mm. The species is unmistakable with white head and thorax, forewing ground colour being pale olive to ochreous-brown. A white-bordered black streak between subbasal and antemedial line below median nervure. Orbicular and reniform black and white-bordered and filled in with olive; distinct black-centred claviform present; postmedial and submarginal lines whitish, defined by black and the latter originating from an olive apical patch. Hindwing pale fuscous, underside with distinct cell spot and postmedial line.

Male genitalia: Uncus long; elongated valva with bulbous cucullus, a distinct costal flap and broad sacculus. Aedeagus with two tiny carinal spines and vesica with robust claw-like cornutus.

Distribution: **India:** Sikkim, West Bengal (Moore 1882; Hampson 1908). **Global:** Bhutan (Dudgeon 1905).

Bionomics: A very restricted-range species known mainly from Central Himalaya, within a narrow altitudinal range of 1900–2500 m, preferably in Wet Temperate Forest, and active only during post-monsoon months of October–December. The species was only observed in areas having annual precipitation and annual mean temperature range of 2400–2800 mm and 14–16 °C respectively.

NCBI GenBank accession No.: MT219965, MT219966, MT219968

***Phlogophora plumbeola* (Hampson, 1894)**

[Fig. 16, 45, 46]

Euplexia plumbeola Hampson, 1894, *Fauna Brit. Ind.*, **2**: 217.

Euplexia plumbeola Hampson: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 235.

Phlogophora plumbeola (Hampson): Yoshimoto, 1994, in Haruta, *Tinea*, **14**: 111.

Type locality: Sikkim [= Sikkim, India]

Material examined: India: 1 ♂, Uttarakhand, Dist. Uttarkashi, Govind National Park, Taluka, 31.06264° N, 078.26350° E, 2900 m, 14. VI. 2012; 1 ♂, Govind Wildlife Sanctuary, Kedarkanta, 31.02863° N, 078.16183° E, 2800 m, 29. V. 2012; 2 ♂♂, Dist. Pithoragarh, Askot Wildlife Sanctuary, Gawalghat, 29.91398° N, 080.40338° E, 2248 m, 14. VI. 2018; 5 ♂♂, Gawalghat, 29.91782° N, 080.40010° E, 2462 m, 16. VI. 2018; 1 ♂, Jimjhini, 29.92121° N, 080.39719° E, 2627 m, 18. VI. 2018; 4 ♂♂, Vayman, 29.92711° N, 080.38988° E, 3065 m, 03. VII. 2018; coll. A. K. Sanyal & team.

Diagnosis: Wing expanse: Male 36–38 mm. The plumbeous/slaty blue-grey colour of the head, thorax and forewing is typical to *P. plumbeola* which also justifies the species name. Bunch of golden hairs present at the end of thorax. The golden pattern on the forewing is distinct on plumbeous background; reniform spot distinctly golden; a submarginal golden band with three prominent outward dentations between veins 2 and 4. Hindwing fuscous with a distinct whitish marginal line not reaching the costa and an indistinct medial line. Underside of forewing pale slaty-grey; hindwing white and grey suffused, with black cell spot and prominent waved postmedial line.

Male genitalia: Male genitalia is characterized by moderately broad uncus with lanceolate apex; broad valva with acute cucullus and a long medially bent harpe; the basal plate of harpe with apical sclerotization and presence of short digitus; sacculus with presence of multiple irregular spines in the dorsal margin.

Distribution: **India:** Uttarakhand, Sikkim (Hampson 1898). **Global:** Nepal (Yoshimoto 1994).

Bionomics: Although, known till date only from Central Himalayan landscape of Sikkim and Nepal, our current record extends its distribution west-ward up to north-western Uttarakhand. Currently the species is found to fly within an altitudinal range of 2200–3000 m, preferably in Oak-Fir dominated Temperate Forest patches within an annual mean temperature of 8–12 °C and annual precipitation of 1400–1700 mm. Individuals were found to be active in a very narrow seasonal window, mainly in the transition of pre-monsoon and monsoon.

***Phlogophora striatovirens* (Moore, 1867)**

[Fig. 17, 47, 48]

Euplexia striatovirens Moore, 1867, *Proc. Zool. Soc.*: 58.

Euplexia discisignata Moore: Hampson, 1894, *Fauna Brit. Ind.*, **2**: 213.

Euplexia striatovirens Moore: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 233.

Phlogophora striatovirens (Moore): Yoshimoto, 1994, in Haruta, *Tinea*, **14**: 111.

Type locality: Darjeeling [India, West Bengal]

Material examined: India: 1 ♂, West Bengal, Dist. Darjeeling, Singalila National Park, Gairibas, 27.05090° N, 088.03360° E, 2494 m, 21. V. 2018; coll. K. Bhattacharyya & team.

1 ♀, Arunachal Pradesh, Dist. Dibang Valley, Dihang Dibang Biosphere Reserve, Anini, Patharnallah, 29.10532°

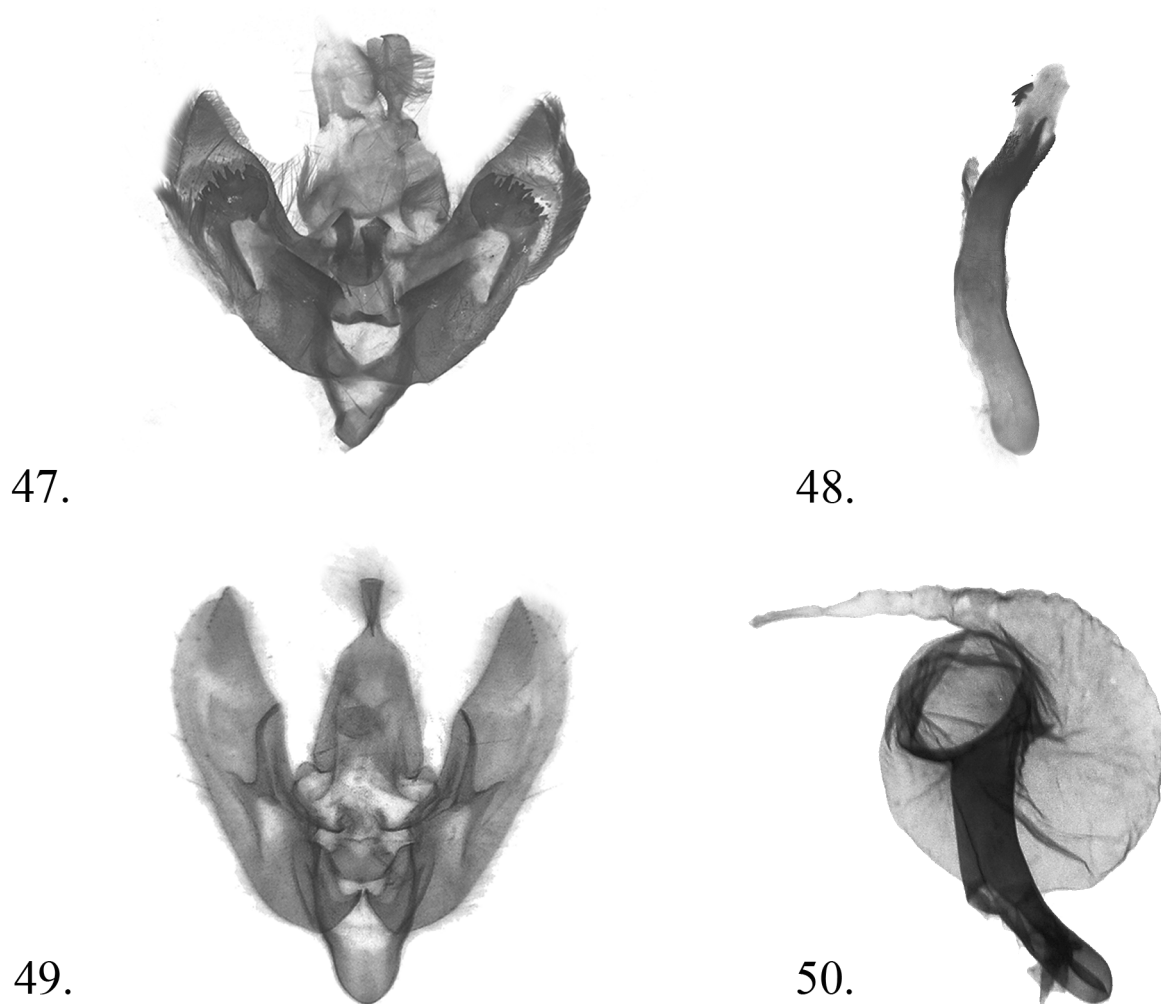
N, 096.08074° E, 2029 m, 19. IV. 2017; 1 ♀, Bruni, 29.15354° N, 096.14857° E, 2436 m, 20. IV. 2017; coll. S. Gayen.

Diagnosis: Wing expanse: Male: 28–30 mm, female: 30–32 mm. Although being very distinctive morphologically, it was earlier considered as a junior subjective synonym of *P. discisignata* by Hampson (1894). In 1908, he treated both the species as different which was confirmed recently as Gyulai *et al.* (2015) discussed significant differences in morphology between the two species. *P. striatovirens* differs mainly in the ground colour of forewing being rusty brown to greenish in fresh or live specimens. Presence of a double, sinuous basal line with black inner edge and an antemedial double line with black outer edge; postmedial line double, sinuous, black-edged enclosing the reniform mark which is partly filled with black on inner half; submarginal line pale yellowish-green, highly dentate with a pale patch on its inner edge between veins 7 and 4; marginal area dark purplish fuscous.

Male genitalia: Uncus spatulate, valva broad with strongly sclerotised harpe bearing multiple irregular spines; the dorsal margin of sacculus also heavily sclerotised but lacks spines; aedeagus slender, carinal region sclerotised with minute spines; vesica long with small cornuti in the basal part.

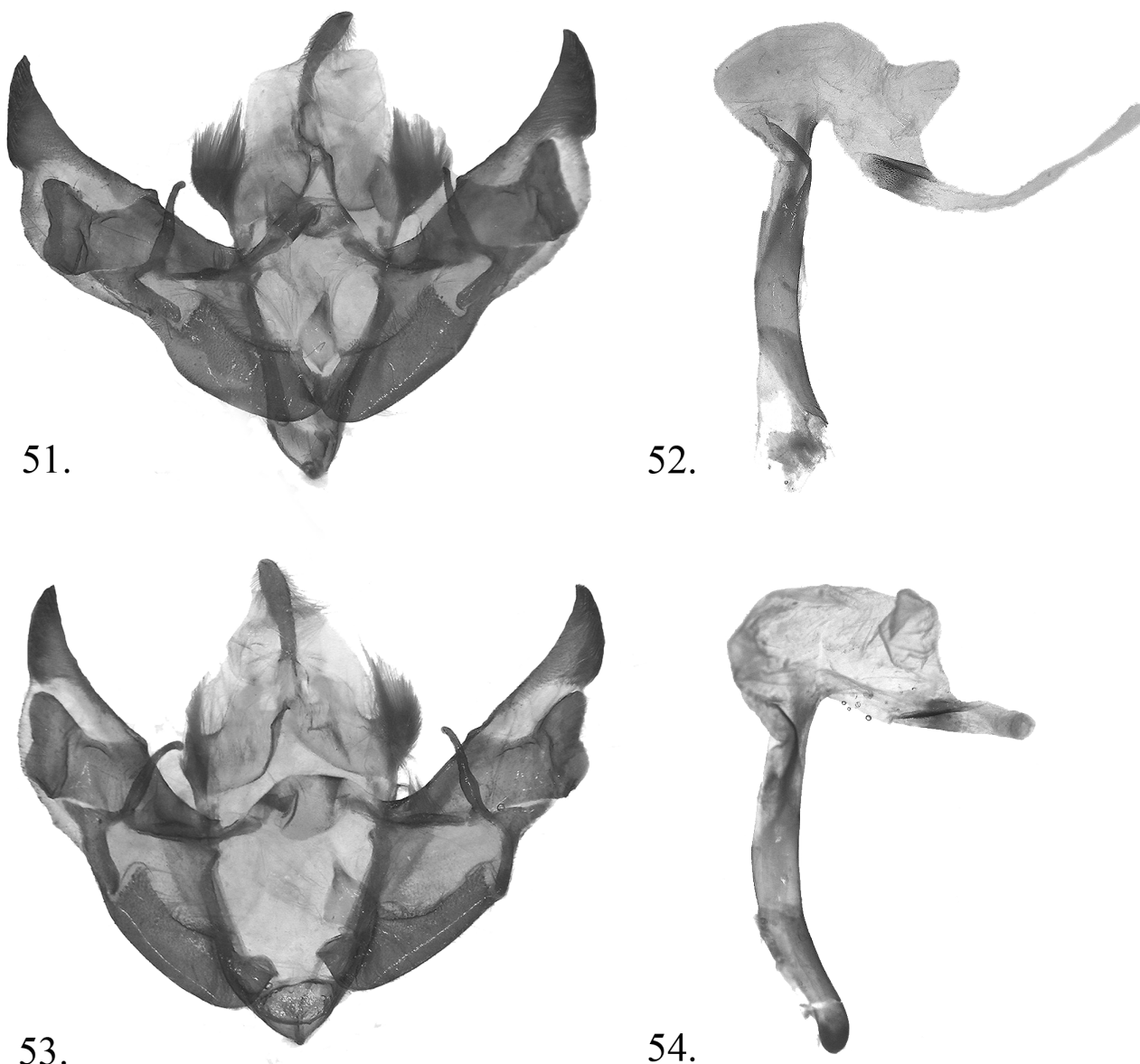
Distribution: **India:** Sikkim, West Bengal, Arunachal Pradesh, Nagaland (Moore 1867; Hampson 1908). **Global:** Nepal, China (Yoshimoto 1994; Han *et al.* 2008).

Bionomics: Distributed in Central to Eastern Himalaya and North-Eastern Hills, the species was recorded to fly within altitudinal zone of 2000–2500 m, preferably in Temperate and Coniferous forests. Individuals were found to be active in early pre-monsoon months of April–May in a narrow range of average trap night temperature at 9–11 °C and an annual precipitation range of 1200–2200 mm.



FIGURES 47–50. Male genitalia images of *Phlogophora* spp. 47–48. *Phlogophora striatovirens* (Moore, 1867), West Bengal, Gen. prep. SN/GAR24_2/2/21.V.18/42; 49–50. *Phlogophora discisignata* (Moore, 1867), Mechi, Nepal, Gen. prep. GYP 3412*.

* Image procured from Dr Péter Gyulai, Hungary, through personal correspondence.



FIGURES 51–54. Male genitalia images of *Phlogophora similis* **sp. nov.** 51–52. *Phlogophora similis* **sp. nov.**, male, HT, West Bengal, Gen. prep. NV/RI21/1/05.IX.16/507; 53–54. *Phlogophora similis* **sp. nov.**, male, PT, West Bengal, Gen. prep. NV/RI21/1/05.IX.16/26.

***Phlogophora discisignata* (Moore, 1867)**

[Fig. 18, 49, 50]

Euplexia discisignata Moore, 1867, *Proc. Zool. Soc.*: 57.

Euplexia discisignata Moore: Hampson, 1894, *Fauna Brit. Ind.*, **2**: 213.

Euplexia discisignata Moore: Hampson, 1908, *Cat. Lepid. Phalaenae Br. Mus.*, **7**: 232;

Phlogophora discisignata (Moore): Kononenko & Pinratana, 2013, *Moths of Thailand*, **3** (2): 328.

Phlogophora discisignata (Moore): Gyulai *et al.*, 2015, *Zootaxa*, **3949** (4): 589.

Type locality: Darjeeling [India, West Bengal].

Material examined: India: 1 ♀, Uttarakhand, Dist. Pithoragarh, Askot Wildlife Sanctuary, Chilamdhar, 30.13751° N, 080.24781° E, 1714 m, 09. X. 2017; coll. A. K. Sanyal & team.

1 ♂, Sikkim, Dist. West Sikkim, Khangchendzonga Biosphere Reserve, Yuksom, 27.37864° N, 088.22087° E, 1879 m, 23. XI. 2019; coll. A. K. Sanyal & team.

1 ♀, West Bengal, Dist. Darjeeling, Singalila National Park, Rimbik, 27.1141° N, 088.1105° E, 1905 m, 18. X. 2018; 1 ♂, Manedara, 27.1147° N, 088.1000° E, 2168 m, 30. X. 2018; 1 ♀, 31. X. 2018; 1 ♂, 04. XI. 2018; coll. A. K. Sanyal & team; 2 ♀♀, 2 ♂♂, Palamajua, 27.07071° N, 088.09071° E, 1909 m, 03. XI. 2018; 1 ♂, Khopidara, 27.00525° N, 088.1189° E, 2054 m, 06. XI. 2018; coll. K. Bhattacharyya & team.

Diagnosis: Wing expanse: Male: 28–30 mm, female: 30–32 mm. Forewing ground colour of male is whitish pale yellow which is often greenish in fresh specimens; for females the ground colour of forewing more suffused with darker brown. The basal and postmedial area of forewing paler with few blackish streaks; medial area having ashy-brown patch from costa to submedian fold the lower part of which is sap green; reniform white with few brown specks; inner side of orbicular and reniform black; the marginal area suffused with purplish-grey with a black submarginal line.

Male genitalia: Uncus narrow, hook-shaped, valva spindle shaped with presence of a slender less-sclerotised harpe; aedeagus vesica broad, spherical.

Distribution: **India:** Uttarakhand, Sikkim, West Bengal, Nagaland (Moore 1867; Hampson 1908). **Global:** Nepal, Bhutan, Thailand, Vietnam (Dudgeon 1905; Yoshimoto 1994; Kononenko & Pinratana, 2013; Gyulai *et al.* 2015).

Bionomics: Distributed in Western to Central Himalaya and North-Eastern Hills, the species was found to be active within a narrow altitudinal range of 1700–2100 m, preferably in Wet Temperate and Mixed Coniferous Forest. Individuals were recorded only in the post-monsoon months of October–November within a narrow average trap night temperature range of 15–16 °C and annual precipitation range of 1800–2600 mm.

DNA Barcode: The generated 13 DNA barcodes can be accessed in NCBI with respective accession numbers, as novel submissions of *P. distorta*, *P. albovittata*, *P. calamistrata*, *P. nobilis*, *P. meticolodina* to the database with first submission of *P. subpurpurea* from India.

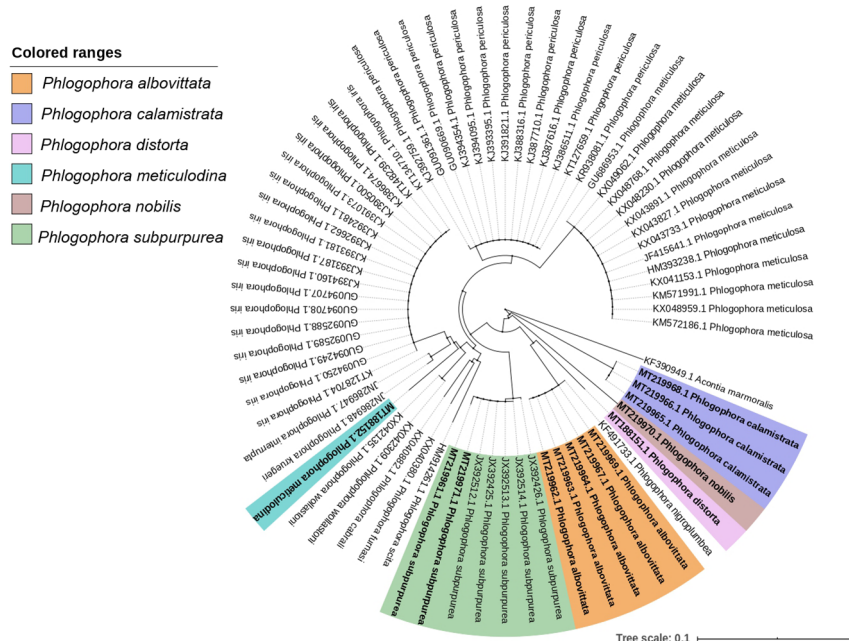


FIGURE 55. Neighbour-joining (NJ) tree of the *Phlogophora* spp. with bootstrap supports.

The overall mean distance in the final dataset comprising of the generated sequences aligned with all the available sequences of *Phlogophora* (14 species) from global database was found to be 4.8% (Fig. 55). The mean within-species distance of the dataset was 0.6% with highest of 2.5% in *P. subpurpurea*. Whereas, the highest interspecific genetic distance was resulted between *P. calamistrata* and *P. meticolosa* (11.8%). The sequences of *P. subpurpurea* was represented by a single clade with 4.5–11.1% of interspecific divergence (lowest with *P. periculosa*, *P. iris* and highest with *P. calamistrata*). *P. albovittata* and *P. calamistrata* formed two separate clades with 9.5% genetic divergence between them. *P. calamistrata* showed high divergences with all the other species used in the analysis (9.5–11.8%). *P. distorta* formed sister clades with *P. albovittata* with interspecific divergence of 5.4%. All the 14

species showed cohesive clustering as per the NJ Tree except the 4 sequences generated for *P. albovittata* which clustered with the unpublished sequence of *P. nigroplumbea* taken from BOLD database. As the two species are very similar in their outer morphology and genitalia structure, and *P. nigroplumbea* being typically distributed in Indonesia and Philippines (Holloway 1989), the identity of the BOLD sequence of the same remains doubtful.

Ecological account

Habitat Preference: Along the length and breadth of Indian Himalaya, *Phlogophora* species were recorded from a total of 15 sub-categories of forest types, which were further grouped into 5 major habitat/forest types, from low to high altitude, which are: Sub-tropical Wet Hill forest encountered in Central and Eastern Himalaya, covering 1400–2000 m altitudinal band in states of West Bengal, Sikkim and Arunachal Pradesh with an average NDVI of 0.2483; Western Himalayan Temperate forest with average NDVI of 0.2999, encountered in Uttarakhand and Himachal Pradesh within the altitudinal range of 1500–2600 m; Eastern Himalayan Temperate forest distributed in states of West Bengal, Sikkim and Arunachal covering 1800–2500 m altitudinal range with an average NDVI of 0.297; Eastern Himalayan Mixed Coniferous forest with average NDVI of 0.2556, encountered in West Bengal covering altitudinal range of 1900–3000 m and sub-alpine forest consisting of Birch-Fir, Birch-*Rhododendron* and alpine pastures, encountered in 2800–3500 m altitudinal band in Uttarakhand and Himachal Pradesh with an average NDVI of 0.1158.

Among these 5 Forest types, species richness was highest in Eastern Himalayan Temperate Forest followed by Eastern Himalayan Mixed Coniferous Forest with record of 11 and 10 species respectively, whereas the relative abundance was notably high in Eastern Himalayan Temperate Forest compared to all the other habitats (Fig. 56). Western Himalayan Temperate Forest yielded 7 species with relatively medium abundance. The two lowest and highest altitudinal forests of Sub-tropical and sub-alpine zone revealed low *Phlogophora* activity with records of 4 and 6 species respectively. Among the total 16 species recorded, 4 species, viz. *P. costalis*, *P. discisignata*, *P. pectinata* and *P. conservuloides* showed wide range in habitat preference, being recorded from Subtropical, Temperate, Coniferous and sub-alpine zones, whereas, *P. meticolodina* and *P. subpurpurea* showed very restricted presence only in Western Himalayan Sub- Alpine Forest. Interestingly, *P. subpurpurea* was the only Himalayan *Phlogophora* which was recorded from alpine scrub habitat. *P. humilis*, *P. nobilis* and *P. striatovirens* were mainly active in Eastern Himalayan Temperate Forest with moderate activity in Mixed Coniferous Forest, while *P. plumbeola* was continuously active from 2200–3100 m in Wet Temperate Forest up to subalpine Birch-Fir Forest. *P. calamistrata* and *P. albovittata* were abundant in lower altitudinal habitat of Sub-tropical Wet Hill Forest and Wet Temperate Forest. Relative abundance of *Phlogophora* species was detected to be high within NDVI range of 0.255 to 0.299.

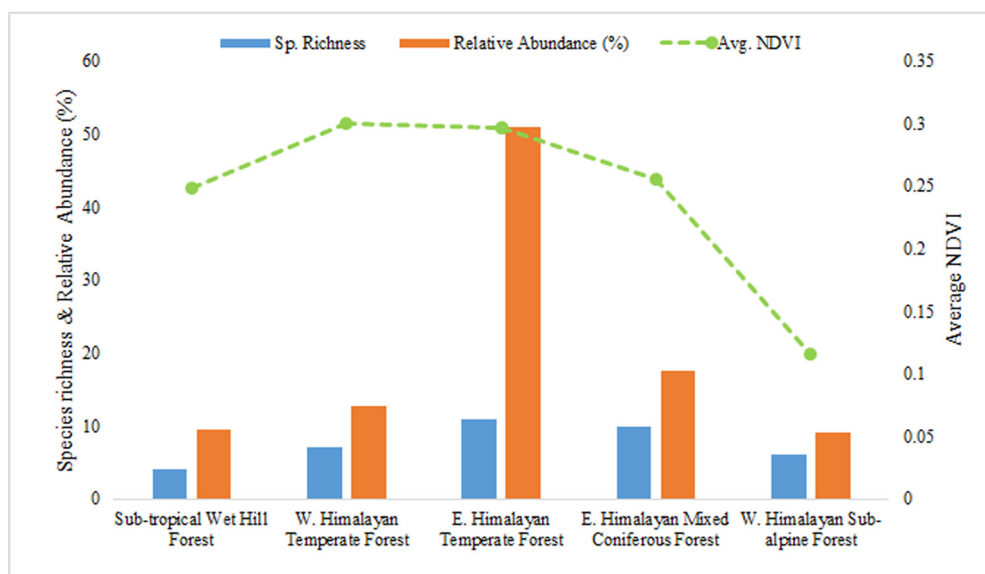


FIGURE 56. Species richness and Relative abundance of *Phlogophora* spp. among five major Himalayan Forest types and average NDVI values.

Among the 16 species of Himalayan *Phlogophora*, 3 species viz. *P. meticolodina*, *P. plumbeola* and *P. subpurpurea* were recorded only from Western sector of Himalaya whereas *P. calamistrata*, *P. nobilis* and *P. humilis* were distributed only in Central Himalaya. *P. striatovirens* was never recorded beyond Central and Eastern Himalaya. Among the other 8 species, *P. costalis* and *P. pectinata* were truly generalist species recorded from all three sectors of Himalaya in all the major habitats.

Climatic suitability & key Environmental factors: All the six climatic suitability models generated for the *Phlogophora* species *P. pectinata*, *P. conservuloides*, *P. costalis*, *P. distorta*, *P. albovittata* and *P. calamistrata* showed AUC value above 0.9 indicating a good model (Thuiller *et al.* 2005). The major factors contributing to the potential habitat distribution of the six aforesaid species were found to be Temperature Annual Range (BIO7), Temperature Seasonality (BIO4) and Elevation (DEM) (Table 1).

TABLE 1. Contributing Bioclimatic Variables and area of suitable habitats of selected *Phlogophora* spp.

Species	AUC value	Contributing Bioclimatic Variables			Area of suitable habitats (sq. Km)		
		Variable	% Contribution	Range	Very high	High	Moderate
<i>P. pectinata</i>	0.955	BIO7	40.5	1.5–3.1 °C	29.9 X 10 ³	51.1 X 10 ³	80.8 X 10 ³
		DEM	30.6	1100–3700 m			
		BIO4	17.7	2.8–4.7 °C			
<i>P. conservuloides</i>	0.913	BIO7	72.2	1.5–3.1 °C	108.8 X 10 ³	134.1 X 10 ³	188.7 X 10 ³
		DEM	7.1	400–3600 m			
		BIO2	16.5	0.7–1.6 °C			
<i>P. costalis</i>	0.972	BIO7	38.2	1.0–2.8 °C	20.3 X 10 ³	23.8 X 10 ³	52.7 X 10 ³
		DEM	24.5	800–2700 m			
		BIO4	21.6	2.5–5.9 °C			
<i>P. distorta</i>	0.966	BIO7	61.3	1.2–3.6 °C	16.3 X 10 ³	19.7 X 10 ³	32.8 X 10 ³
		BIO15	13.9	20–155 mm			
		DEM	13.4	600–3200 m			
<i>P. albovittata</i>	0.960	BIO4	45.1	3.1–4.5 °C	22.4 X 10 ³	29.4 X 10 ³	54.1 X 10 ³
		DEM	20.4	400–2300 m			
		BIO3	17.5	2.8–4.7%			
<i>P. calamistrata</i>	0.981	BIO7	62.1	1.3–2.1 °C	4.4 X 10 ³	5.5 X 10 ³	10.9 X 10 ³
		DEM	12.2	1200–3500 m			
		BIO14	10.6	3–25 mm			

The following areas were taken into account for discussing the predicted suitable habitats of the 6 species along the entire Himalayan Biodiversity Hotspot region: **Western Himalaya** comprising of Indian states Himachal Pradesh and Uttarakhand; **Central Himalaya** comprising of Far-Western Nepal (Province Mahakali: Darchula and Baitadi districts; Province Seti: Banjura, Bajhang and Doti districts), Mid-Western Nepal (Province Rapti: Pyuthan, Rolpa, Rukum and Salyan districts; Province Bheri: Jajarkot district; Province Karnali: Dolpa, Jumla and Kalikot districts), Western Nepal (Province Dhaulagiri: Baglung, Myagdi and Parbat districts; Province Gandaki: Gorkha, Kaski, Lamjung and Manang districts; Province Lumbini: Gulmi and Palpa districts), Central Nepal (Province Bagmati: Sindhuupalchok, Kavrepalanchok, Nuwakot, Rasuwa and Dhading districts; Province Janakpur: Ramechhap and Dolakha districts; Province Narayani: Makwanpur district), Eastern Nepal (Province Mechi: Taplejung, Panchthar and Ilam districts; Province Koshi: Bhojpur, Sankhuwasabha and Dhankuta districts; Province Sagarmatha: Solukhumbu, Okhaldhunga and Khotang districts), few areas of China and Indian states Sikkim and districts of West Bengal; **Eastern Himalaya** comprising of Western Bhutan (districts Haa, Samtse, Thimphu, Paro and Chhukha), Central Bhutan (districts Dagana, Punakha, Tsirang and Wangdue Phodrang), Southern Bhutan (districts Sarpang, Trongsa and Zhemgang), Eastern Bhutan (districts Lhuntse, Mongar, Pemagatshel, Samdrup Jongkhar and Trashigang), few areas of Myanmar and Indian states of Arunachal Pradesh, districts of Assam and Nagaland (Fig. 57).

Based on the response curves, areas with Annual Temperature range of 1.5–3.1 °C is suitable for *P. pectinata*. The probability of the species occurrence gradually increases from 1100 m with rising altitude till 2450 m, beyond which it decreases. Very high suitable areas occupying 2.3% of the extent (HBH) falls under the Indian states of Himachal Pradesh (districts Kullu, Shimla and Kinnaur), Uttarakhand (districts Tehri Garhwal, Chamoli, Pauri Garhwal, Almora, Bageshwar, Pithoragarh and Nainital), Sikkim, West Bengal (district Darjeeling), Arunachal Pradesh (districts Tawang, West Kameng, Changlang and Tirap) along with Eastern, Central, Western and Mid-western Nepal and Western, Central, Southern and Eastern Bhutan. Himachal Pradesh (districts Mandi and Kangra), Uttarakhand (districts Dehradun and Uttarkashi), West Bengal (district Jalpaiguri), Arunachal Pradesh (districts East Kameng, East Siang, Kurung Kumey, Lohit, Papum Pare, Lower Dibang Valley, Lower Subansiri, Upper Siang, Upper Subansiri and West Siang) along with Mid-western and Far-western Nepal, Central, Eastern and Western Bhutan occupies the high suitable areas of the species accounting for 4.18% of HBH.

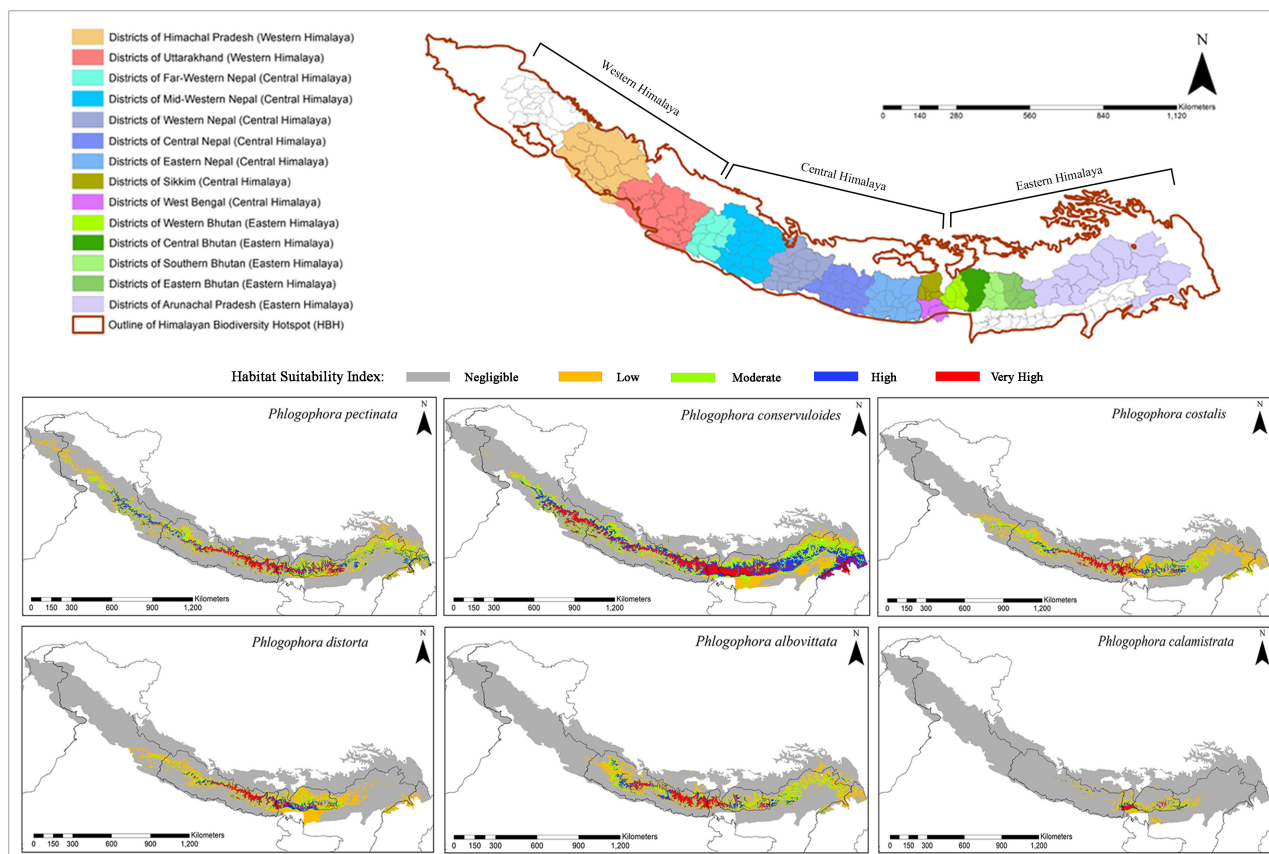


FIGURE 57. Predicted suitable areas for six *Phlogophora* spp. in the Himalayan Biodiversity Hotspot under current climatic condition

For *P. conservuloides*, very high and high suitable areas were predicted to cover 8.9% and 13.49% of the extent respectively. The distribution of the species was seen to be almost continuous along the Himalayan Range, starting from Chamba district of Himachal Pradesh till West Kameng of Arunachal Pradesh, extending up to northern parts of Kachin State and Sagaing Division of Myanmar. Temperature annual range was same as of *P. pectinata*. Suitable elevation for the species spanned widely from 400–3600 m peaking at 2200 m.

Very high suitable predicted distribution (1.66% of the extent) of *P. costalis* is concentrated mainly across Central Himalaya extending up to Western Bhutan. High suitable areas for the species were predicted in a few scattered locations of districts Almora, Bageshwar, Chamoli, Nainital, Pauri Garhwal, Pithoragarh of Uttarakhand, Far-western and Mid-western Nepal, Central, Eastern and Southern Bhutan up to districts Tawang, West Kameng and Papum Pare of Arunachal Pradesh. Species occurrence was predicted to be highest between a temperature annual range of 1.0–2.2 °C with a gradual decline till 2.8 °C after which the species will be hard to find. A steady increase in the species occurrence was predicted between 800–2700 m of altitude.

Temperature annual range of 1.2–3.6 °C and precipitation seasonality of 20–155 mm contributes towards the very high high distribution of *P. distorta* in the states of Sikkim (districts West, South, East Sikkim), West Bengal (dis-

tricts Darjeeling, Kalimpong, Jalpaiguri) along with Eastern, Central, Western, Mid-Western Nepal and Eastern, Western, Central Bhutan accounting for 1.34% of the total extent. The high suitable areas were predicted to cover 1.61% of the HBH comprising of Indian states of Uttarakhand (districts Bageshwar, Pithoragarh and Nainital), Arunachal Pradesh (district West Kameng) along with Mid-western and Far-western Nepal and Southern, Western and Central Bhutan.

Based on the response curves, *P. albovittata* was predicted to occur in areas with Temperature Seasonality of 3.1–4.5 °C and elevation ranging from 400–2300 m. Covering 1.84% of the total extent, very high suitable areas for the species were predicted to be concentrated in the Indian states of Sikkim, West Bengal (districts Darjeeling, Kalimpong) together with Central, Eastern and Western Nepal and Central, Eastern and Western Bhutan. Accounting for 2.4% area of HBH, the high suitable areas for the species were predicted to fall under the Indian states of West Bengal (districts Darjeeling and Kalimpong), Arunachal Pradesh (districts East Kameng, Kurung Kumey, Lohit, Lower Dibang Valley, Lower Subansiri, Papum Pare, Tawang, Tirap, Upper Dibang Valley, Upper Subansiri and West Kameng), Nagaland (district Mon) together with Central and Mid-Western Nepal and Central, Eastern, Southern and Western Bhutan.

The predicted very high potential habitat distribution of *P. calamistrata* covering only 0.44% of the extent was restricted majorly to the Indian states of Sikkim, West Bengal (district Darjeeling), Assam (district Dhuburi), Arunachal Pradesh (district West Kameng) together with Eastern and Western Nepal, Southern and Eastern Bhutan, China (very few localities in districts Nyalam, Tingri and Yadong). 0.54% of the extent accounts for the predicted high suitable areas of the species comprising of West Bengal (district Darjeeling), Assam (districts Dhuburi and Bongaigaon), Arunachal Pradesh (district East Kameng) along with Eastern, Central and Western Nepal, Central, Eastern, Southern and Western Bhutan, China (very few localities in districts Dinggye, Lhozang). The major factor affecting the distribution of the species was found to be Temperature annual range which shows a sharp decrease in the species occurrence after 1.8 °C till 2.1 °C beyond which, the species occurrence will be very rare. Also, areas within an elevation range of 1200–3500 m was predicted to be suitable for the species.

Seasonal Abundance: *Phlogophora* abundance and richness were strongly influenced by seasonality and associated average trap night temperature and humidity (Fig. 58). Among the three prominent Himalayan seasons, abundance trend showed two peaks, a moderate one spanning the pre-monsoon season of April–June with a peak in the month of May and a stronger one in post-monsoon season spanning October–December with a peak in the month of November. Abundance was certainly low in monsoon season. According to the seasonal activity, two phenological trends were observed: the polycyclic group of species consist of *P. albovittata*, *P. conservuloides*, *P. costalis*, *P. distorta* and *P. pectinata* and the monocyclic group of species consisting *P. calamistrata*, *P. discisignata*, *P. nobilis*, *P. subpurpurea* and *P. plumbeola*. Among the polycyclic group, *P. albovittata* showed highest activity in the pre-monsoon month of May and post-monsoon months of October–November indicating two non-overlapping generations with no activity in between. *P. costalis*, showing multiple generations, were observed throughout the year with highest abundance peak in May and moderate in June and September–November. *P. conservuloides* were mainly active during May–June and moderately all through the year. *P. distorta* and *P. pectinata* were abundant in all three seasons, however, *P. pectinata* is the only polycyclic Himalayan *Phlogophora* which showed distinct monsoon population.

In case of monocyclic species group, *P. calamistrata*, *P. discisignata* and *P. nobilis* were mainly captured during the post-monsoon months whereas, *P. plumbeola* were only active in the months of June–July. *P. subpurpurea* was unique only being active during the monsoon season. Inverse relationship between average trap night temperature and *Phlogophora* abundance was obvious as number of individuals were always high around 9–11 °C, whereas it dropped to negligible count as temperature rose above 12 °C. Maximum number of individuals were reported at a narrow range of average trap night Humidity of 87–91%, whereas, it started to decrease whenever the humidity went down below 82% or above 92%.

For the CCA of Seasonal Abundance-Environmental factors data matrix, the first two axes explained 63.5% cumulative variation in the data with a significance level of <0.01. For variability in seasonal abundance, the first CCA axis is positively influenced by Annual Mean Temperature (Bio1) ($r = 0.73$) and Annual Precipitation (Bio12) ($r = 0.63$). This axis was most negatively influenced by altitude ($r = -0.48$). Average trap night temperature ($r = -0.25$) and average trap night humidity ($r = -0.14$) and NDVI ($r = -0.11$) had negative influence on axis 1 (Fig. 59). In case of individual species, the first CCA axis was highly positive for *P. calamistrata* ($r = 1.06$), *P. humilis* ($r = 0.92$), *P. nobilis* ($r = 0.88$), *P. discisignata* ($r = 0.85$) and *P. distorta* ($r = 0.38$) which indicates a positive influence of the environment factors Bio1 and Bio12. The axis was also highly negative for *P. meticolodina* ($r = -2.77$), *P.*

striatovirens ($r = -2.34$), *P. subpurpurea* ($r = -2.02$), *P. plumbeola* ($r = -1.91$), *P. conservuloides* ($r = -0.64$) and *P. pectinata* ($r = -0.40$). The second CCA axis was most positively influenced by average trap night temperature ($r = 0.42$), depicting association of *P. striatovirens* ($r = 0.16$), *P. distorta* ($r = 0.85$) and *P. costalis* ($r = 0.51$). The CCA diagram clearly indicates that sites sampled in post-monsoon were most uniquely different from other two seasonal ensembles, showing minimum overlap with pre-monsoon and monsoon clusters. The post-monsoon sites were mainly clustered among positive values of both the axes, depicting major influence of annual mean temperature and annual precipitation, whereas the pre-monsoon sites were majorly clustered in positive value of axis 2, depicting moderate influence of average trap night humidity and average trap night temperature. Altitude and NDVI negatively influenced the species assemblage.

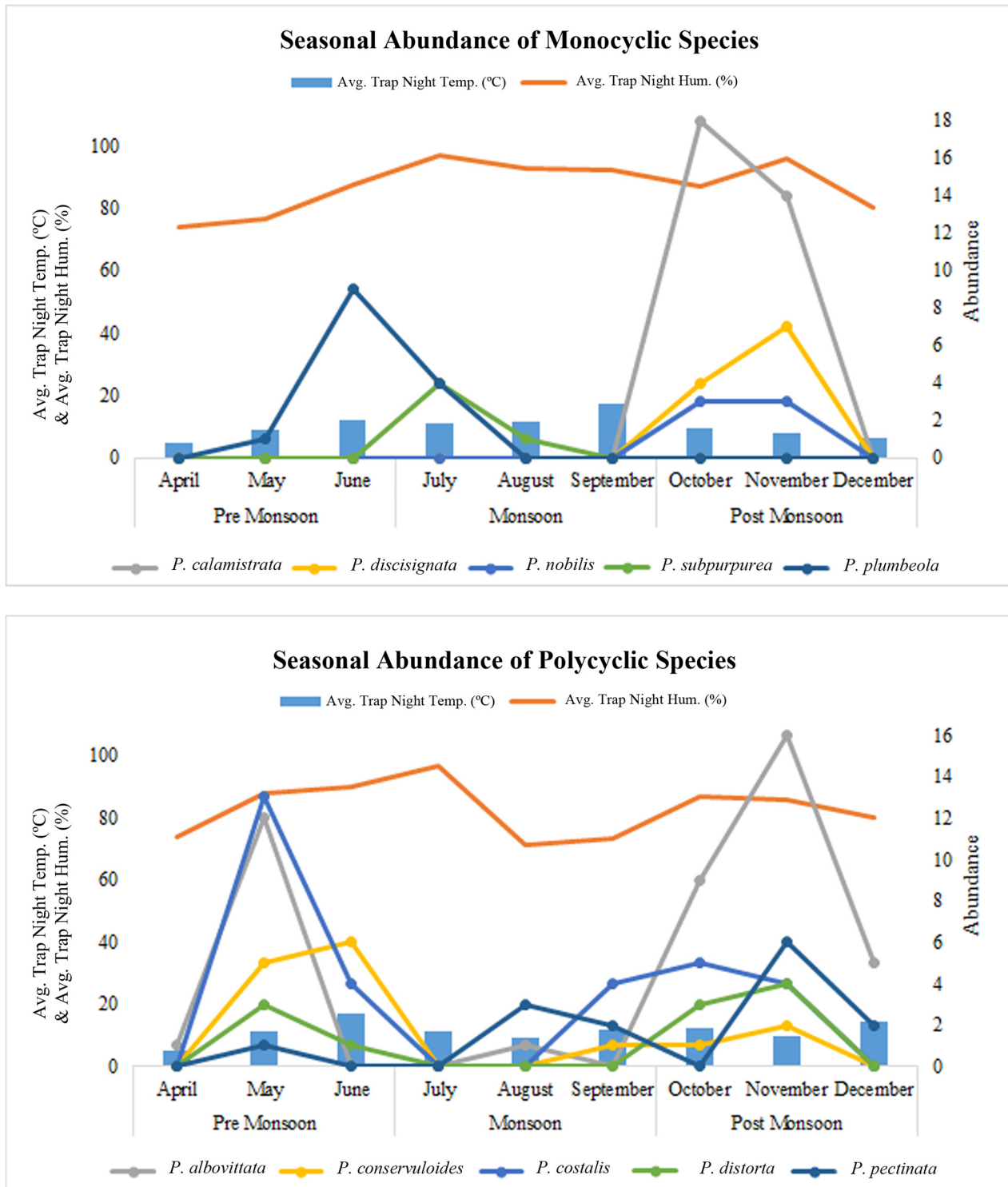


FIGURE 58. Seasonal Abundance of *Phlogophora* spp. along with abundance fluctuations with average trap night temperature and average trap night humidity.

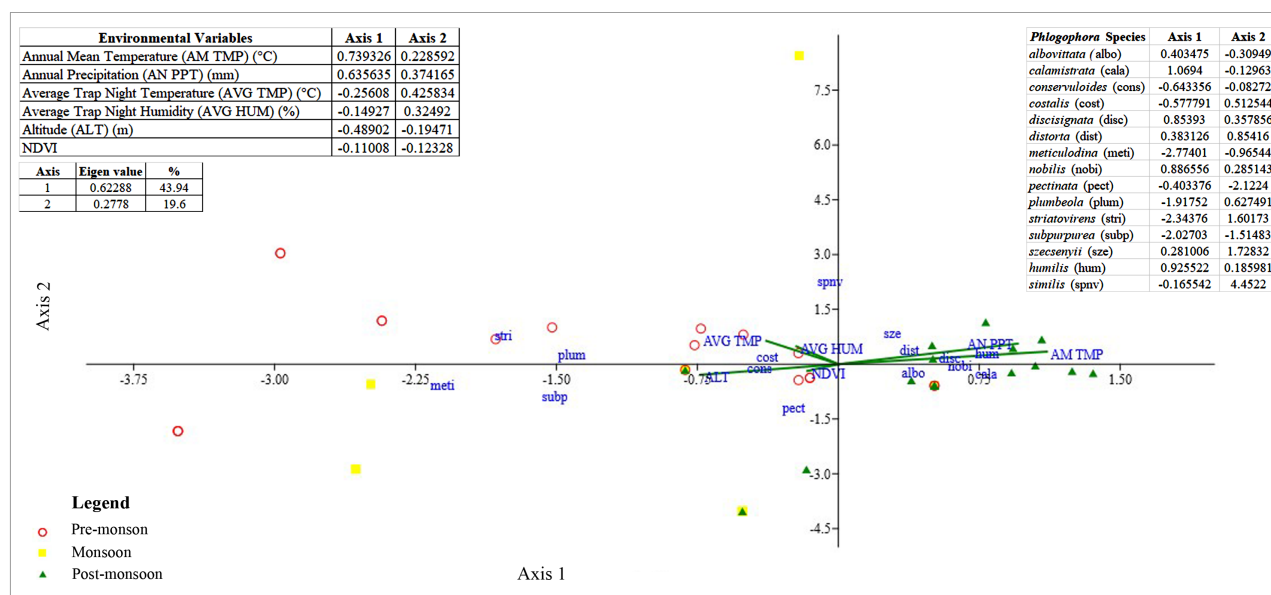


FIGURE 59. CCA biplot based on *Phlogophora* seasonal abundance and major predictor variables with sites (summary table & intraset correlations between species, explanatory variables and ordination axes are shown in inset).

Discussion and conclusion

The species of the genus *Phlogophora* being adapted to multitude of habitat types owing to their apparently wide choices in larval food plants, are very diverse and species-rich within Indian Himalaya, which itself due to their biogeographically transition position between Palaearctic and Oriental realms and wide latitudinal-altitudinal extent, harbours multitudes of micro-habitats with varying plant species composition. The species inventory thus currently updated to include 16 species, with three species, *P. meticulodina*, *P. nobilis* and *P. szecsenyii* known till date from Nepal, China, Thailand and Vietnam, as new inclusion to the Indian fauna. Description of a new species which is certainly a member of the “*costalis*” group points to the fact that diversification within this group of species is relatively high in the humid and monsoonal Central Himalayan zone spanning around Darjeeling-Sikkim and contiguous habitats of Nepal, from where till date an overwhelming number of 11 *Phlogophora* species have been described. Though there is still no record of the genus from Indian Trans-Himalayan zone, high abundance of different species is quite evident among all the major altitudinal zones of Himalaya spanning from Sub-Tropical to sub-alpine habitats. Among all the studied habitats of Himalaya, East Himalayan Wet Temperate Forest spanning 1800–3000 m altitudinal band stood out as the major activity hub. Although the genus was not much well represented in Sub-Tropical and sub-alpine zones, these specialized habitats are evidently inhabited by specialized set of species. Seasonality, temperature and humidity/precipitation were found to influence the *Phlogophora* species in a significant way and our findings show that the predicted distribution range for most of the species are majorly governed by temperature dependent variables. The values of these governing variables were more or less similar to that of the collected field data temperature and elevation. Approximately, 2.3 °C variation in annual temperature range accompanied by a moderate variation in temperature seasonality shows that these species exist in an even and mild climatic range. The genus comprising of both polycyclic and monocyclic species typically became most abundant during the post-monsoon. Their activity reaches the peak in especially cold (9–11 °C) and humid (87–91%) nights. In this context, Azorean endemic species can be mentioned with larval population bloom in December–March indicating that species overwinters in larval stage and adults becoming active mainly in summer (Wanger 2015). Although larval ecology is not much known for Himalayan *Phlogophora* species, our data suggests that the adults were typically captured in May–June and October–November and ensemble composition greatly varies between three prominent seasons, with pre-monsoon and post-monsoon ensembles most distinct. In the typical Himalayan forests, monsoon favours luxuriant development of undergrowth herbs and shrub layers offering wide availability of larval food plants, thus favouring high adult activities in post-monsoon months. On the other hand, spring snow

melting in high altitude pastures triggers the bloom in flowering shrubs in summer or pre-monsoon, thus favouring typical sub-alpine or Alpine species like *P. meticolodina* or *P. subpurpurea*.

In the backdrop of current knowledge, future research should focus on establishing synapomorphies involving the species groups of the tribe Phlogophorini, especially the genera *Phlogophora* and *Euplexia*, optimizing the character states like structures of harpe-digitus complex, cucullus and aedeagus vesica to establish the monophyly within the group. A thorough cladistic analysis involving molecular approaches targeting set of nuclear genes should be a realistic answer. The study being the first attempt to present a baseline information on the distribution range of different *Phlogophora* species and set of bioclimatic variables contributing towards the same, in future, this information will be helpful to narrow down the areas for sampling localities and also compare range shrinkage or range expansion of the species, thus establishing proper management and conservation plans concerning the group. As the genus has wide altitudinal and habitat specificity consisting of characteristic species adapted to particular habitat and climatic regime, they can be suitable candidate for choice of taxa for long-term monitoring to enumerate the effect of global climatic idiosyncrasies impacting Himalayan ecosystems and inhabiting faunal groups.

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