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COMMUNICATION

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Pritha Dey & Axel Hausmann

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COMMUNICATION

New distribution and range extension records of geometrid moths (Lepidoptera: Geometridae) from two western Himalayan protected areas

Pritha Dey [1] & **Axel Hausmann** [2]

[1] Present address: Centre for Ecological Sciences, Indian Institute of Science, CV Raman Road, Bengaluru, Karnataka 560012, India.
[1] Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand 248001, India
[2] SNSB-Zoologische Staatssammlung München, Münchhausenstr, 21, 81247, Germany.
[1] dey.pritha126@gmail.com (corresponding author), [2] hausmann.a@snsb.de

Abstract: This article presents new distribution and range extension records (including new records from the state of Uttarakhand) of 12 species of the Geometridae family along with their taxonomic records. The records are based on field collections, where sampling was done along elevation and vegetation gradients in the buffer zones of Nanda Devi Biosphere Reserve and Kedarnath Wildlife Sanctuary, two prominent protected areas in the western Himalayan Indian state of Uttarakhand. DNA barcoding was performed for some of the species for confirmation of identification in addition to the morphological identifications. Voucher specimens are deposited in a public repository for future reference.

Keywords: DNA barcoding, Ennominae, Kedarnath Wildlife Sanctuary, Larentiinae, Nanda Devi Biosphere Reserve, Uttarakhand.

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Author details: Pritha Dey is currently a post-doc at the Centre for Ecological Sciences, Indian Institute of Science, Bangalore. Her research interests include taxonomy, diversity - distribution patterns and evolutionary ecology of moths. Axel Hausmann currently leads the Department of Entomology, Zoologische Staatssammlung München and is curator of the Lepidoptera collection. He does research in Entomology, Zoology, Linnaean Taxonomy and DNA Barcoding.

Author contributions: PD secured funding, conceived the study and did the data collection; AH verified the taxonomic details; PD and AH wrote the manuscript.

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INTRODUCTION

Geometridae are the second-largest family of moths, globally distributed, known to include approximately 24,000 species worldwide (Scoble & Hausmann 2007; VanNieukerken et al. 2011), whereas 2,041 species are recorded from India (Kirti et al. 2019). Most species are slenderly built, generally with weak flying ability, and nocturnal or crepuscular. At rest, the fasciae of the wing pattern are continuous. Geometrids are recognised by the presence of paired tympanal organ at the base of the abdomen in adults and the reduced prolegs in the larvae (Minet & Scoble 1999). This group has also been the subject of a number of recent large-scale taxonomic and phylogenetic works (e.g., Sihvonen & Siljander 2005; Sihvonen et al. 2011, 2020; Brehm et al. 2019; Murillo-Ramos et al. 2019). Although the taxonomy of this family is well established for the temperate regions, tropical areas still need large-scale revisions.

Geometrid moths have been established as a model group for biodiversity studies, community analyses, and ecological research in temperate and tropical regions (Axmacher et al. 2004, 2009; Brehm et al. 2013, 2018; Beck et al. 2017). They are sensitive to climate change (Cheng et al. 2018) and environmental conditions, making them an ideal indicator group to monitor forest recovery and habitat disturbance (New 2004; Beck et al. 2017).

The distribution records of this crucial group of moths with vast diversity, however, still remain scattered from India. The comprehensive work on moths of different regions of the biodiverse rough terrains of western Himalaya, a Biodiversity hotspot within the Indian territory, was mostly carried out by Hampson (1892, 1894, 1895, 1896) in his 'Fauna of British India' series and Cotes & Swinhoe (1887) in 'A Catalogue of Moths of India'. Some studies later on focussed on the diversity and taxonomy of geometrid moths from this region, which include: Pajni & Walia (1984a,b), Walia & Pajni (1987), Rose (1986), Walia (1988, 2005), Smetacek (2004), Walia & Anju (2005), Kirti et al. (2007, 2008a,b, 2009, 2011, 2014), and Stüning & Walia (2009).

From the western Himalayan state of Uttarakhand, where our study was conducted, some prominent work on moth diversity include: Arora (1997), Smetacek (1994, 2008), Sanyal et al. (2011, 2013, 2017), Dey et al. (2015, 2017), Sanyal (2015), Sondhi & Sondhi (2016) and Dey (2019). Sanyal et al. (2011, 2013) and Dey et al. (2015, 2017) looked into the diversity and distribution of moth assemblages. Dey et al. (2019) present a DNA barcode reference library of geometrid species from western Himalaya. Recently, Chandra et al. (2019) included moth diversity in two Protected Areas from Uttarakhand. There is a lot of area still to be studied in this mountainous state to understand the diversity and the underlying patterns in a more comprehensive way.

Our current study was conducted in two western Himalayan protected areas: a) Nanda Devi National Park area which is a part of the Nanda Devi Biosphere Reserve (NDBR). It covers an area of 6,407.03km² (core area: 712.12km², buffer zone: 5148.57km², and transition zone: 546.34km²), with an altitudinal range of 1,800m–7,816m; and b) The Kedarnath Wildlife Sanctuary (KWS) (30.416–30.683 N, 78.916–79.366 E). The altitude ranges 1,160–7,068 m covering an area of 975 km². Both these protected areas are located in the Chamoli-Rudraprayag District in the state of Uttarakhand and are the prominent protected areas in the western Himalaya. The habitats range from mixed oak forests to the lush alpine meadows (Image 1). The combination of human pressure, pristine forest areas and a large altitudinal range make them ideal sites for exploring trends in moth diversity.

Here we present new geographic distribution and range extension records of 12 geometrid species from the state of Uttarakhand which will add to the distribution data of this family from a threatened and fragmented landscape of the western Himalaya.

METHODS

Sampling methodology

Specimens were collected from the buffer regions of two protected areas in the western Himalayan state of Uttarakhand, Nanda Devi Biosphere Reserve (NDBR) and Kedarnath Wildlife Sanctuary (KWS) (Image 2). The study areas were stratified on the basis of elevation and vegetation types to explore the moth diversity along these gradients. Sampling was done at every 200 m along the elevation from 1,500 m to 3,500 m (details of the collection sites in Table 1). Two light-traps with 12W solar lamps were operated for the first 3–4 hours from dusk as this is the time of maximum activity of most geometrid species. Late night sampling was not possible due to logistic constraints. In KWS, we used lepiLED (Brehm 2017) to set up the light-trap.

DNA barcoding

Specimens of some species were DNA barcoded (COI 5' gene aiming at recovering the 658 bp barcode fragment). To do this, one dry leg was removed from

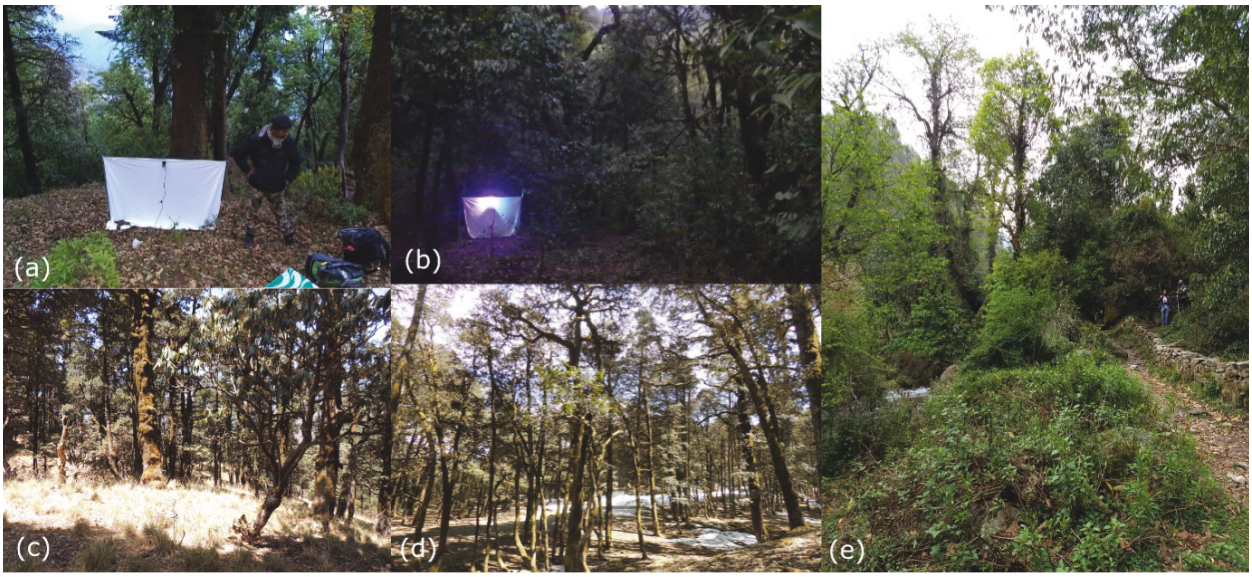

Image 1. Some of forest types where sampling was done within the two protected areas: a—Oak-Maple forest | b—Moru Oak *Quercus floribunda* forest | c—Alpine Rhododendron Forest | d—Kharsu Oak *Quercus semecarpifolia* forest | e—Western mix coniferous forest. © Pritha Dey.

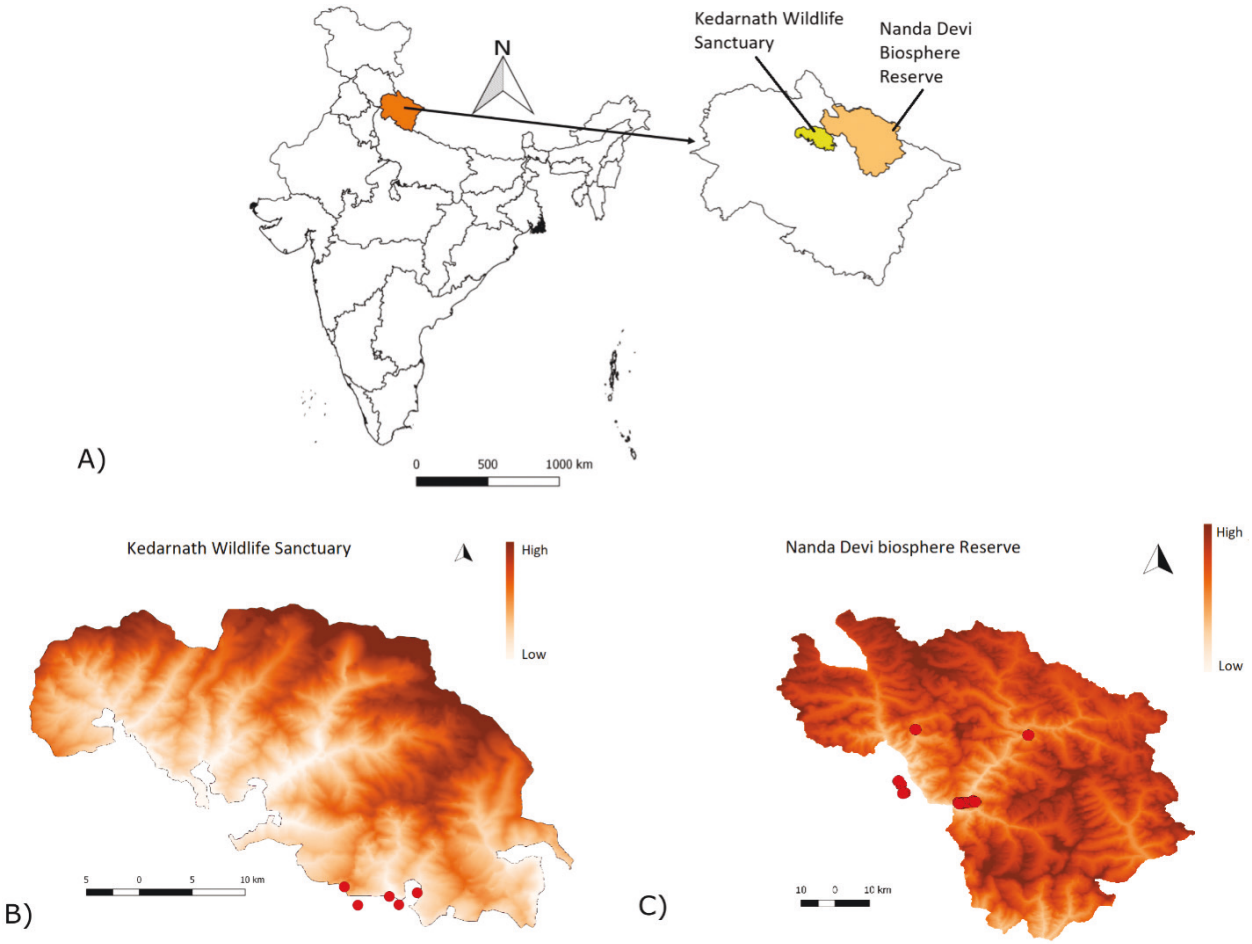

Image 2. Map showing: A—The boundaries of the two protected areas in the west Himalayan state of Uttarakhand | the collection sites (marked in red circles) in B—Kedarnath Wildlife Sanctuary and C—Nanda Devi Biosphere Reserve

each specimen with sterile forceps and transferred to a 96-well microplate preloaded with one drop of 95% ethanol in each well. DNA extraction and sequencing were performed at the Canadian Centre for DNA barcoding, University of Guelph, with standardized high-throughput protocols for DNA barcode amplification and sequencing (Ivanova et al. 2006; deWaard et al. 2008).

Species identification

Identifications of the species in this paper were done with the help of the literature mentioned in the respective species account and also by comparing with the Geometridae collections of the Zoologische Staatssammlung München, Germany, including the famous collection of Claude Herbulot. Voucher specimens are deposited at the Insect collection section of the Wildlife Institute of India, Dehradun. In some cases, DNA barcodes provided additional information on species identity. DNA barcode data are accessible in the public dataset DS-HIMALGEO on BOLD database (https://doi.org/10.5883/DS-HIMALGEO) (Ratnasingham & Hebert 2007, 2013).

Species Account

Subfamily: Ennominae

1. *Arichanna tramesata* Moore, 1868 (Image 3:1)

Arichanna tramesata Moore, 1868, Proc. zool. Soc. Lond. 1867:658, pl.33, fig.2 [India: Bengal]

Arichanna tramesata: Hampson (1895), Fauna of British India (Moths) 3: 290

Arichanna tramesata: Wehrli (1939), in Seitz Macrolep. World Suppl. IV: 255

Arichanna tramesata: Sato (1993), Moths of Nepal. Part 2. TINEA. Vol. 13 (Supplement 3). The Japan Heterocerists' Society, Tokyo. Pl. 34/11.

Distribution in India: Bengal, Sikkim, Khasis (Meghalaya); new record from the western Himalaya

2. *Arichanna sparsa* (Butler, 1890) (Image 3:2)

Icterodes sparsa Butler, 1890, Entomologist 23:316 [India: Kangra, Dharmsala]

Arichanna sparsa: Prout (1915) in Seitz Macrolep. World IV: 304, pl. 14 b

Arichanna sparsa: Hampson (1895), Fauna of British India (Moths) 3: 294

Arichanna sparsa: Sato (1993), Moths of Nepal. Part 2. TINEA. Vol. 13 (Supplement 3). The Japan Heterocerists' Society, Tokyo. Pl. 34/2.

Distribution in India: Darjeeling (West Bengal), Dharmsala (Himachal Pradesh); new record from the state of Uttarakhand

Genetic data: BIN: BOLD: AAJ8159 (BC ZSM Lep 94382, 94384).

3. *Blepharoctenucha virescens* (Butler, 1880) (Image 4:3)

Hemerophila virescens Butler, 1880, Ann. Mag. Nat. Hist. (5) vi. P.126 [India: Darjeeling]

Boarmia virescens: Hampson (1895), Fauna of British India (Moths) 3: 295

Blepharoctenucha virescens: Yazaki (1992), Moths of Nepal. Part 1. TINEA. Vol. 13 (Supplement 2). The Japan Heterocerists' Society, Tokyo. Pl. 10/10.

Distribution in India: Sikkim, Darjeeling (West Bengal), Arunachal Pradesh; new record from western Himalaya

Remarks: The distal parts of the wings show a paler coloration than in the Nepalese specimen figured in Yazaki (1992).

Subfamily: Larentiinae

4. *Costicoma exangulata* (Warren, 1909) (Image 3:3)

Perizoma exangulata Warren, 1909, Novit. Zool. xvi: 127 [Kashmir: Srinagar]

Thera exangulata: Prout (1914), in Seitz Macrolep. World Suppl. IV: 217, pl. 8 row l, (113)

Costicoma exangulata: Choi (2000), American Museum Novitates, no.3295: 19

Distribution in India: Kashmir: Srinagar; new record from the state of Uttarakhand (Choi 2000 mentions that the species is found in the "northern part of India", but no other record is found from other Northern Indian states)

Genetic data: BIN: BOLD: ADF3000 (BC ZSM Lep 94548, 94549).

5. *Dysstroma planifasciata* (Prout, 1914) (Image 3:4)

Cidaria planifasciata Prout, 1914, in Seitz Macrolep. World IV: 220; pl.13 e [d]; Vol. XII: pl. 32 i [Kashmir: Koksar]

Dysstroma planifasciata: Yazaki (2000), Moths of Nepal. Part 6. TINEA. Vol. 16 (Supplement 1). The Japan Heterocerists' Society, Tokyo: 10; Pl. 162/8.

Distribution in India: Kashmir: Koksar (now in Himachal Pradesh); new record from the state of Uttarakhand

Genetic data: BIN: BOLD:ADF3836 (BC ZSM Lep 94515, 94516).

Remarks: Further research is required to clarify distribution and species delimitation of the species

Table 1. List of species with details of the collection location and the type of forest.

Subfamily	Genus	Species	Author	Location	Lat.	Long.	Elevation (in m)	Forest type
Ennominae	*Arichanna*	*tramesata*	Moore, 1868	NDBR (Lata vill.), KWS (Kanchula, Jatholi	30.492	79.714	2399	MO
Ennominae	*Arichanna*	*sparsa*	Butler, 1890	NDBR (Lata)	30.494	79.713	2320	WMC
					30.494	79.713	2339	WMC
					30.495	79.721	2544	WMC
Ennominae	*Blepharoctenuc-ha*	*virescens*	Butler, 1880	KWS (Anasuya, Jatholi, Kanchula, Mandal)	30.472	79.288	1766	MO
					30.460	79.230	2636	OM
					30.460	79.270	1617	MO
Larentiinae	*Costicoma*	*exangulata*	Warren, 1909	NDBR (Lata gradient)	30.495	79.721	2526	WMC
					30.495	79.727	2913	WMC
					30.496	79.738	2905	WMC
					30.499	79.743	3310	WHBF
Larentiinae	*Dysstroma*	*planifasciata*	Prout, 1914	NDBR (Joshimath, Lata)	30.554	79.547	2107	LLBP
					30.546	79.554	2414	WMC
					30.520	79.559	3141	KO
					30.521	79.559	3152	KO
					30.495	79.727	2913	WMC
					30.496	79.738	2905	WMC
					30.499	79.743	3310	WHBF
					30.499	79.743	3327	WHBF
Larentiinae	*Cidaria*	*basharica*	Bang-Haas, 1927	NDBR (Malari village)	30.684	79.889	3042	Inside village
Larentiinae	*Trichoplites*	*lateritata*	Moore, 1888	NDBR (Lata gradient)	30.495	79.722	2553	WMC
					30.495	79.721	2544	WMC
Larentiinae	*Rheumaptera*	*melanoplagia*	Hampson, 1902	NDBR, KWS	30.522	79.564	2977	WHUOF
					30.520	79.559	3141	KO
Larentiinae	*Photoscotosia*	*dejuncta*		NDBR (Lata, Ghangariya)	30.494	79.728	2766	WMC
					30.500	79.744	3373	WHBF
					30.497	79.749	3775	WHBF
					30.497	79.749	3768	WHBF
					30.699	79.592	3213	Inside village
Larentiinae	*Perizoma*	*conjuncta*	Warren, 1893	NDBR (Joshima-th, Lata)	30.555	79.547	2108	LLBP
					30.495	79.705	2126	LLBP
					30.494	79.705	2152	LLBP
					30.494	79.705	2164	LLBP
					30.495	79.705	2143	LLBP
					30.495	79.727	2913	WMC
					30.496	79.738	2905	WMC
					30.499	79.743	3310	WHBF
Larentiinae	*Perizoma*	*plumbeata*	Moore, 1888	KWS (Gondi)	30.468	79.261	1638	MO
Larentiinae	*Perizoma*	*hockingii*	Butler, 1889	KWS (Shokharak)	30.478	79.216	3067	AR
					30.545	79.554	2433	WMC

NDBR—Nanda Devi Biosphere Reserve | KWS—Kedarnath Wildlife Sanctuary | MO—Mixed Oak | WMC—Western Mix Coniferous | OM—Oak-Maple | WHBF—Western Himalayan Birch-Fir | LLBP—Low level blue Pine | WHUOF—Western Himalayan upper oak-fir | AR—Alpine rhododendron.

pair *Dysstroma planifasciata* and *D. dentifera* (Warren, 1896), the latter described from India/Darjeeling.

6. *Cidaria basharica* Bang-Haas, 1927 (Image 3:5)

Cidaria basharica Bang-Haas, 1927, Horae. Macrolep.1: 93, pl. XI: 20 [India: Poo-Bashahr State, Schipki-la]

Cidaria basharica: Prout (1914), in Seitz, Macrolep. World IV. Suppl (110), pl. 11 b

Cidaria basharica: Yazaki (2000), Moths of Nepal. Part 6. TINEA. Vol. 16 (Supplement 1). The Japan Heterocerists' Society, Tokyo. Pl. 162/16.

Distribution in India: Himachal Pradesh; new record from the state of Uttarakhand

Remarks: Further research is required to clarify distribution and species delimitation of the species pair *Cidaria basharica* and *C. antauges* Prout, 1938, the latter described from Kashmir/Kokser. Wing pattern of our record from Uttarakhand is well matching the figure for a Nepalese specimen in Yazaki (2000), whilst the type of *C. basharica* shows a much narrower medial area. It is not excluded that the populations of Uttarakhand and Nepal belong to *C. antauges*.

7. *Trichoplites lateritiata* (Moore, 1888) (Image 3:6)

Anticlea lateritiata Moore, 1888, in Hewitson & Moore, Descr. new Indian lepid. Insects Colln late Mr Atkinson: 273. [India: Darjeeling]

Trichoplites lateritiata: Yazaki (1993). Moths of Nepal. Part 2. TINEA. Vol. 13 (Supplement 3). The Japan Heterocerists' Society, Tokyo. Pl. 60/2.

Distribution in India: Darjeeling (West Bengal), new record from western Himalaya

8. *Rheumaptera melanoplagia* (Hampson, 1902) (Image 3:7)

Scotosia melanoplagia Hampson, 1902, J. Bombay Nat. Hist. Society 14: 512 [Tibet: Yatong; Sikkim]

Calocalpe melanoplagia: Prout (1941), in Seitz, Macrolep. World XII, pl. 33 h

Calocalpe melanoplagia: Fletcher (1961), Veröff. Zool. Staatssamml. München 6: 171.

Rheumaptera melanoplagia: Yazaki (1995), Moths of Nepal. Part 4. TINEA. Vol. 14 (Supplement 2). The Japan Heterocerists' Society, Tokyo. Pl. 97/20.

Triphosa melanoplagia: Scoble (ed., 1999). Geometrid Moths of the World, a Catalogue.

Distribution in India: Sikkim (Dudgeon); new record from western Himalaya

Genetic data: BIN: BOLD:ADF3132 (BC ZSM Lep 94404)

Remarks: Sanyal et al. 2017 mentions this record by PD. A long series of this species from Western Nepal province shows a broader forewing costal spot in almost all of the >200 specimens.

9. *Photoscotosia dejuncta* Prout, 1937 (Image 3: 8)

Photoscotosia dejuncta Prout, 1937: in Seitz, Macrolep. World IV, Suppl.: 103, pl. 10 d [Kashmir: Gulmarg]

Distribution: Kashmir, Himachal Pradesh, Spiti Valley (Herbulot Collection, ZSM), new record from the state of Uttarakhand

Genetic data: BIN: BOLD:AAE6530 (BC ZSM Lep 94391), BIN-sharing with nominotypical *P. dejuncta*, but slightly diverging.

Remarks: Identified in the collection Herbulot in Zoologische Staatssammlung Munich, Germany, as "*Photoscotosia dejuncta occidens* Herbulot" which apparently is an unpublished manuscript name intended for the populations from Himachal Pradesh which differ from nominotypical *P. dejuncta* by a more greyish coloration and the missing pale costal spot near the forewing apex. This name was used in Dey et al. (2019) without description (nomen nudum). Yazaki (1995) described *Photoscotosia pallidimacula* based on specimens from central Nepal, showing paler forewings and a broadly white hindwing costa. More research is needed to clarify the taxonomy and species delimitation in this group.

10. *Perizoma conjuncta* Warren, 1893 (Image 3:9)

Perizoma conjuncta Warren, 1893: Proc. Zool. Soc. Lond.: 381. [Burma: E Pegu]

Larentia conjuncta: Hampson (1895), Fauna of British India (Moths) 3: 374.

Perizoma conjuncta: Prout (1939), in Seitz, Macrolep. World XII: 279

Perizoma conjuncta: Inoue (2000), Moths of Nepal. Part 6. TINEA. Vol. 16 (Supplement 1). The Japan Heterocerists' Society, Tokyo. Pl. 166/20.

Distribution in India: Khasis (Meghalaya), new record from western Himalaya

Genetic data: BIN: BOLD:ADF4467 (BC ZSM Lep 94466, 94484).

11. *Perizoma plumbeata* (Moore, 1888) (Image 4:1)

Anticlea plumbeata Moore, 1888, Descr. new Indian lepid. Insects Colln. Late Mr. W.S. Atkinson (3): 273.

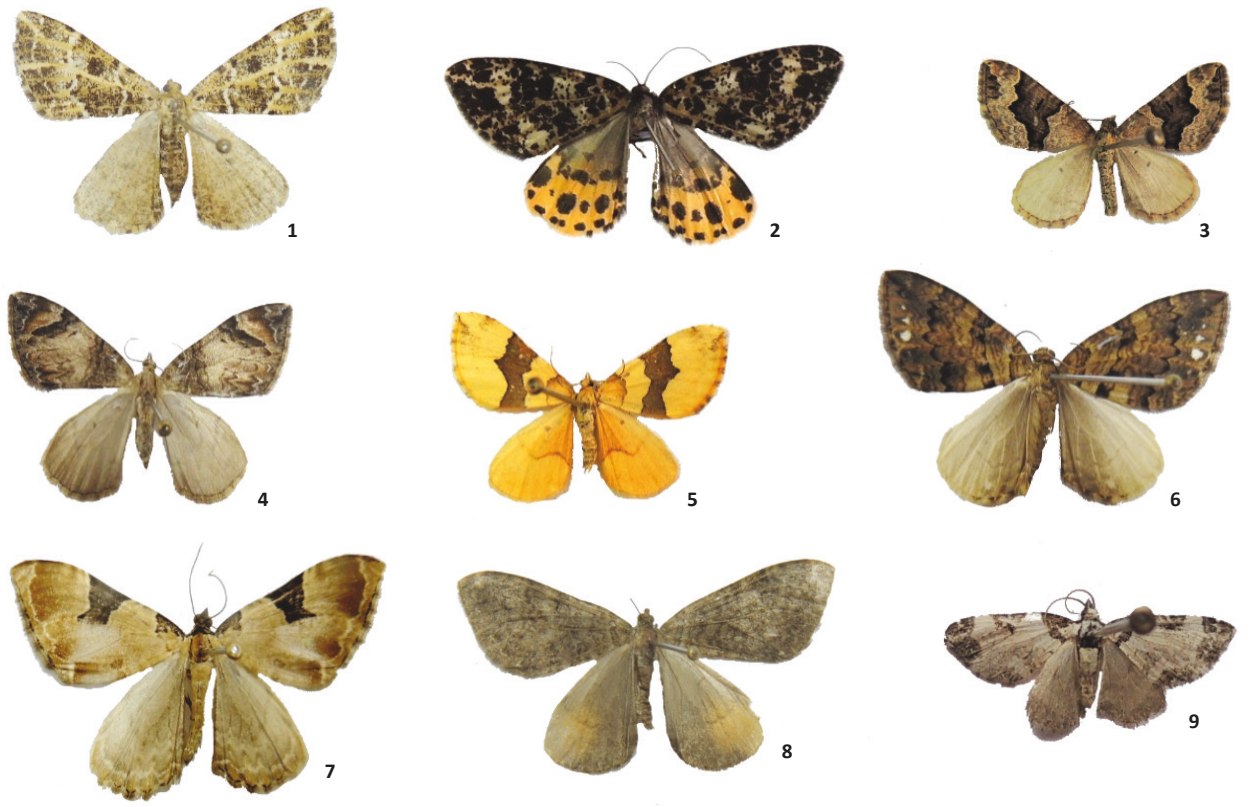

Image 3. Moth species recorded and collected from Nanda Devi Biosphere Reserve: 1—*Arichanna tramesata* | 2—*Arichanna sparsa* | 3—*Costicoma exangulata* | 4—*Dysstroma planifasciata* | 5—*Cidaria basharica* | 6—*Trichoplites lateritata* | 7—*Rheumaptera melanoplagia* | 8—*Photoscotosia dejuncta* | 9—*Perizoma conjuncta*. © Pritha Dey

Image 4. Moth species recorded from Kedarnath Wildlife Sanctuary. 1—*Perizoma plumbeata* | 2—*Perizoma hockingii* | 3—*Blepharoctencha virescens*. © Pritha Dey

[India: Darjeeling]

Larentia plumbeata: Hampson (1895), Fauna of British India (Moths) 3: 376

Perizoma plumbeata: Inoue (2000), Moths of Nepal. Part 6. TINEA. Vol. 16 (Supplement 1). The Japan Heterocerists' Society, Tokyo. Pl. 166/23.

Distribution in India: Himachal Pradesh, Bengal, Sikkim, Arunachal Pradesh; new record from the state of Uttarakhand

12. *Perizoma hockingii* (Butler, 1889) (Image 4: 2)

Eupithecia hockingii Butler, 1889: Illust. typical lepid. Heterocera Colln Br. Mus. 7: 115, pl. 137: 12. [India: Kangra, Dharmsala]

Larentia hockingii: Hampson (1895), Fauna of British India (Moths) 3: 376

Perizoma hockingii: Inoue (2000), Moths of Nepal. Part 6. TINEA. Vol. 16 (Supplement 1). The Japan Heterocerists' Society, Tokyo. Pl. 166/28.

Distribution in India: Sikkim, Dharmsala (Himachal Pradesh); new record from the state of Uttarakhand.

DISCUSSION

Our study clearly highlights the gaps in the existing distributional data for moths, especially in western Himalaya and reiterates the effectiveness of an integrative biodiversity assessment in a hyper-diverse taxon. So far, the moth diversity of the western Himalayan state of Uttarakhand has just been investigated sporadically. Roonwal et al. (1963), a report of the entomological collections of the Forest Research Institute, Dehradun was among the first publications recording moths from this state. Later on, several other publications, as mentioned in the introduction have contributed to the understanding of the diversity and distribution of moths from this western Himalayan state. Sanyal (2015), Sanyal et al. (2017), Dey (2019), and Dey et al. (2019) have focussed on the diversity and distributions of geometrid moths specifically; however, serious gaps still remain as these studies could not cover the entire elevational/habitat range, which would provide a more comprehensive understanding of the diversity and the ecological processes governing their distributions. Recently, global insect decline has been in the spotlight (Hallmann et al. 2017; Lister & Garcia 2018) and it is time that concerted efforts towards documenting and monitoring insect populations are set in place, specifically in the global biodiversity hotspots. Rapid deforestation and urbanization magnify the problem, whereby we might lose critical habitats for the survival of specialised species. Such declines are a sober warning of wider environmental changes, and new distribution records will increase the biological knowledge required to understand the wider impact of such changes. Also, it will work towards fostering increased interest towards moths, which is critical in this endeavour. Some new records reported in this paper from the surroundings of Kedarnath Wildlife sanctuary were a part of a moth-survey project (https://www.rufford.org/projects/pritha-dey/high-altitude-moth-lepidoptera-heterocera-assemblages-assessing-the-diversity-and-potential-bio-indicator-species-in-kedarnath-wildlife-sanctuary-india/) which simultaneously allowed us (a) to document moths from a hitherto unexplored area and (b) to conduct citizen-science workshops to spread awareness on moths. Our findings highlight the need for more such surveys to document the moth diversity across the wide elevation and habitat gradients in the western Himalayan region, where the Oriental and Palearctic biogeographic elements overlap, and which is home to unique biodiversity (Meinertzhagen 1928). Future endeavours of such kind will not only add to the current database, but will help in bringing the spotlight on the need for moth conservation in a fragmented, threatened landscape, in the largest mountain system in the world.

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