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Diversity and Distribution Patterns of Geometrid Moths (Geometridae, Lepidoptera) in Mongolia

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Abstract: Geometrids are a species-rich group of moths that serve as reliable indicators for environmental changes. Little is known about the Mongolian moth fauna, and there is no comprehensive review of species richness, diversity, and distribution patterns of geometrid moths in the country. Our study aims to review the existing knowledge on geometrid moths in Mongolia. We compiled geometrid moth records from published scientific papers, our own research, and from the Global Biodiversity Information Facility (GBIF) to produce a checklist of geometrid moths of Mongolia. Additionally, we analyzed spatial patterns, species richness, and diversity of geometrid moths within 14 ecoregions of Mongolia and evaluated environmental variables for their distribution. In total, we compiled 1973-point records of 388 geometrid species. The most species-rich ecoregion in Mongolia was Daurian Forest Steppe with 142 species. Annual precipitation and maximum temperature of the warmest month were the most important environmental variables that correlated with NMDS axes in an analysis of geometrid assemblages of different ecoregions in Mongolia.

Keywords: beta diversity; ecoregions; environmental variables; location; NMDS; species checklist

1. Introduction

Regarded as disturbing pests or less charismatic than butterflies, moths are nevertheless creatures with an important role in the ecosystem and the potential to serve as environmental indicators [1–4]. Moths are globally distributed and it is estimated that more than 130,000 described species exist [5], far more than the more conspicuous and mostly diurnal butterflies with ca. 20,000 species. Many moths are pollinators, but due to their nocturnal activity they are not well studied [6]. In a recent review from the current literature, Hahn and Brühl reported that in Europe and North America there are 227 moth–plant interactions with 129 moth species involved [6]. Geometrid moths (Geometridae), constituting one of the biggest families of Lepidoptera, are a species-rich and easily recognizable family that have served as indicators for environmental changes in many previous studies [7–10]. These groups also appear to be effective at colonizing habitats after natural or anthropogenic disturbances [11]. There are approximately 24,000 described species of Geometridae worldwide [12]. Although Mongolia is one of the largest countries (rank 19th in size) on Earth, little is known about its moth fauna, and there is no comprehensive review of species richness, diversity, and distribution patterns of geometrid moths in the country. A few researchers attempted to summarize information to mainly confirm this lack of information [13].

Mongolia is a country that encompasses landscapes with a high variety of climatic and geographic features with forest in the north, high mountains in the west, desert in the south, and steppes in the eastern and central parts of Mongolia [14,15]. Altogether, it comprises 16 ecoregions [16] (Figure 1). Ecosystems change along a latitudinal gradient from forest in the north, over steppe and semi-desert to desert in the south [17]. In most areas of the country, livestock herding is a dominant land-use practice, and due to overgrazing, some pasture lands have recently been degraded [18]. With recent discoveries of various mineral resources, mining has become not only the main economic sector, but also the major reason for environmental disturbance in Mongolia. Together with climate change, it is the major driver for habitat loss and environmental changes [14,19]. As a result of these anthropogenic changes, many species are disappearing, but there is little information about which species are at greatest risk of becoming extinct, especially for the less studied taxa.

In order to monitor diversity loss and gain, and to further study the influence of environmental disturbance and climate change on geometrid moths in Mongolia, we need an up-to-date dataset that mirrors the current state of knowledge and that includes all species already recorded. Given this knowledge gap, this study aims to review, summarize, and evaluate the existing knowledge on geometrid moths in Mongolia. It will provide a baseline for further studies, as well as define research priorities in the field. In this study, we aim to: (1) provide a checklist of geometrid moths of Mongolia, setting a baseline for future studies, (2) analyze distribution patterns and species richness and diversity of geometrid moths within ecoregions of Mongolia, and (3) analyze which environmental variables are most important in determining their distribution. We are aware that all results can only give a provisional status due to the data situation, especially the results for Objectives 2 and 3 can only be given with caution; however, our detailed review of the current data will help to define the needs for further research more efficiently.

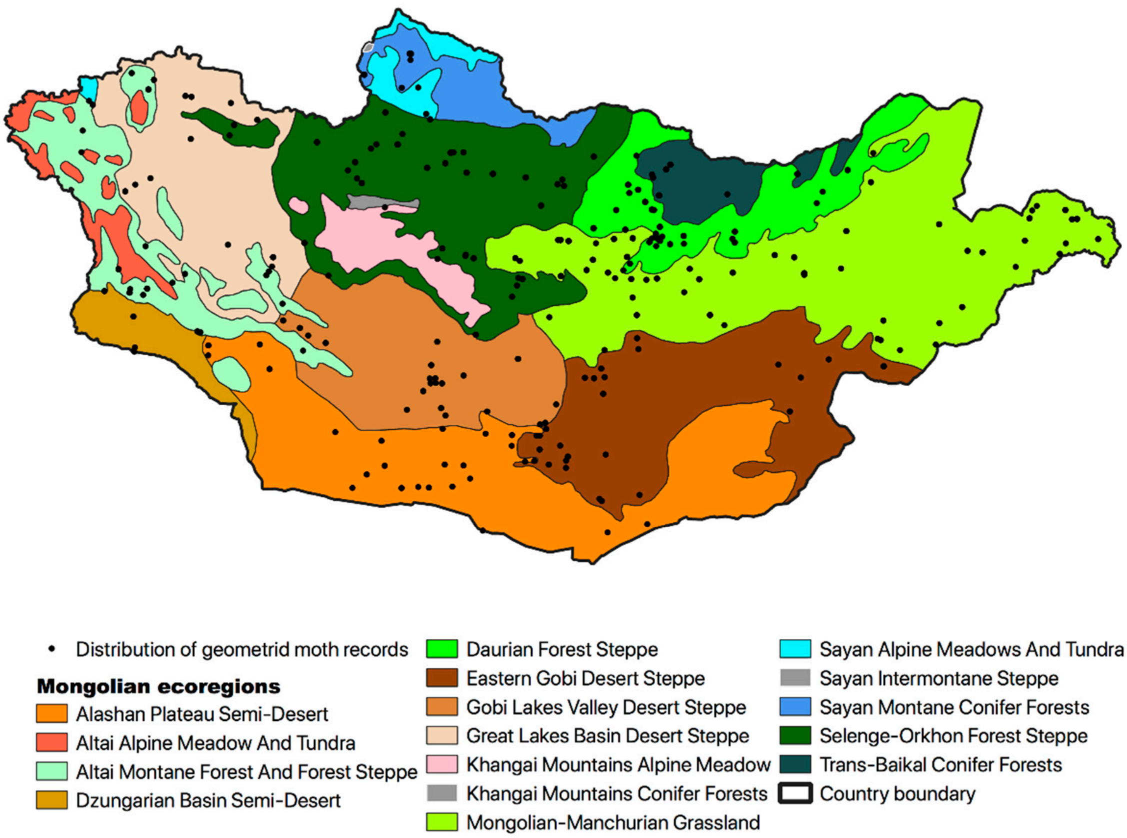

Figure 1. Mongolian 14 ecoregions with distribution of 1557 geometrid moth records (211 of 1973 records are missing exact locations, 205 records were sampled at the same location, but at different time period). For two small ecoregions (marked in gray), there is no scientific knowledge of geometrid moths.

Study Review

Information on the species composition of Macrolepidoptera of Mongolia began to accumulate from the end of the nineteenth century, as a result of the works of collectors such as Fritz Dörries, Hauberhauer and Leder, and others. Otto Staudinger [20] published the first paper on the collection of Fritz Dörries, who made a trip in 1879 to Khentii Mountains to collect Lepidoptera. This resulted in data on the location of 75 species of geometrids in central and western parts of Mongolia [20]. Later, Staudinger published several papers and books on the fauna of Palaearctic Lepidoptera which included some geometrid species from Mongolia [21–23]. In 1964, a Mongolian–German expedition conducted a biological survey, as a result of the expedition 214 Lepidopteran exemplars were sampled. Burchard Alberti later published the results on Lepidoptera and nine geometrid species were listed in the paper [24]. Likewise, Joseph Moucha listed four geometrid species from a Mongolian–Czech entomological–botanical expedition, which was conducted around 1960 [25]. Grigory Grum-Grshimailo found three geometrid species from Selenge Aimag in the collection of M.I. Molleson [26]. Alexander Mikhailovich Djakonov [27,28] recorded a new occurrence of *Horisme scosiata* and described one new species *Scotopteryx transbaicalica* from the family of Geometridae based on old material of Staudinger. Other researchers such as Karl Dietze [29], Eugen Wehrli [30], and Fritz Heydemann [31] also described new species. In the fourth volume and its supplementary of "Die Gross-Schmetterlinge der Erde. Die Spanner des Palaearktischen Faunengebietes" series edited by Adalbert Seitz, 34 geometrid species were listed for Mongolia [32,33].

The most important contribution to the collection and study of Mongolian geometrid moths were made by Russian and Soviet expeditions led by Pyotr Kuzmich Kozlov and later by Soviet–Mongolian expeditions [34–36]. During the survey of Soviet–Mongolian expeditions, Jaan Viidalepp recorded a total of 201 geometrid species.Viidalepp later in 1999 compiled a checklist of geometrid moths of the former U.S.S.R and in this monograph 210 species were included for Mongolia [37]. Particularly rich and diverse material on Lepidoptera (41,000 specimens) were collected by the Hungarian expeditions conducted by Zoltán Kaszab, who made six entomological collecting trips along latitudinal and longitudinal gradients in Mongolia, between 1963 and 1968. András Vojnits published several papers based on the Kaszab's collections dedicated to subfamilies of Geometridae in the period between 1974 and 1979. He recorded 177 species from the whole collection, described 39 species new to the fauna of Mongolia and four species new to science [38–44]. Malcolm J. Scoble [45] presented 66 taxa from Mongolia.

Other researchers also contributed to the study of Mongolian geometrid moths. For instance, Gantigmaa Ch. and coworkers recorded 90 species in the West Khentii of Northern Mongolia [46]. In the book "Biodiversity of Sokhondinsky Reserve", 29 geometrid species from Mongolia have been included [47]. Beljaev and Vasilenko [48] noted 29 species of geometrid moths in Mongolia. Vasilenko and colleagues [49–51] recorded eight species and described one new species *Rhodostrophia ustyuzhanini* in Western Mongolia. In 2012 and 2013, we collected 70 geometrid species from central and northern parts of Mongolia [4]. Mironov and Glasworthy [52] reported 57 species with two species (*Eupithecia ankini*, *Eupithecia munguata*) new to science and 12 species new to the fauna of Mongolia. Erlacher et al., studied six geometrid species from Mongolia and described one new species *Charissa beljaevi* [53–55]. In 2019, Makhov and Beljaev [56] studied the geometrid moths of the Baikal Region and recorded 14 species from Mongolia. In six volumes of "The Geometrid Moths of Europe", 117 moth species are listed from Mongolia. We validated our species checklist with these volumes [57–62].

2. Materials and Methods

We compiled geometrid moth records from published scientific papers, from our work [63] (all sample identifications were double checked by curator T. Enkhbayar, Department of Biology, National University of Mongolia), from the collections of the Siberian Zoological Museum (curator - S.V.Vasilenko) [64], and also from the Global Biodiversity Information Facility (GBIF) [65]. Lastly, we checked the "Revised, annotated systematic checklist of the Geometridae of Europe and adjacent areas, Vols 1–6" [62]. From the Museum collections we could only get country-level information, not the exact location. From GBIF data, we included 380 records into our species list [65]. Fourteen specimens of six species were found in the public data of The Barcode of Life Data System (Bold System) [66].

We used Google Scholar to search the literature with following search strings:

- With all of the words: Mongol (in English Mongolia, in German Mongolei, thus it was better to use only Mongol);
- With at least one of the words: Geometrid OR Larentiinae OR Desmobathrinae OR Ennominae OR Archiearinae OR Geometrinae OR Oenochrominae OR Orthostixinae OR Sterrhinae;

As a result of the search, 184 literatures appeared, though many of them were about geometrid moths of Inner Mongolia. These we excluded from our list.

- Without the words: Inner Mongolia.

After excluding Inner Mongolia, 96 results remained and of these, 73 were relevant to our study.

Totally, we compiled 1973-point records of 388 geometrid species (Table S1). Of these records, 87 species were missing information on exact locations, these 87 species are used to estimate species richness and listed in the species checklist but are excluded from other analysis. We georeferenced species locations from literature and generated coordinates of each location with Google Earth [67]. After that we cross-checked each species name in "The Global Lepidoptera Names Index" [68]. Moreover, experts on geometrid moths such as Axel Hausmann, Jaan Viidalepp, Gunnar Brehm, Sven Erlacher, and Pasi Sihvonen validated most species of our checklist and provided further literatures.

In the next step we used the sampled data in order to estimate true species richness, to evaluate the distribution of species within Mongolia, and to identify regions that have been undersampled so far by species rarefaction. For these reasons, we transformed all species locations into $2° \times 2°$ grid cells, resulting in 51 grid cells inhabited by 301 species. Of 301 species, 121 were unique species occuring only once within 51 grids. To estimate species richness we applied Good Turing Theory, which uses unique species for estimation [69]. We used the application SuperDuplicates (https://chao.shinyapps.io/SuperDuplicates/) for the estimation with the following setting: Data type: incidence data; Number of observed species (SOBs): 388; Number of uniques (Q1): 208 (we combined the 121 unique species with the former mentioned 87 species without locations).

Further we calculated rarefaction curves for single ecoregions to assess collection quality in different areas of Mongolia. Four ecoregions (Altai Alpine Meadow and Tundra, Dzungarian Basin Semi-Desert, Khangai Mountains Alpine Meadow and Sayan Alpine Meadows, and Tundra) were strongly under sampled, having species richness below 15, thus we excluded them from the analysis to avoid misleading interpretation.

To estimate the rarefaction curve across grid cells and ecoregions, we calculated interpolation and extrapolation of species richness using the 'iNEXT' package: Interpolation and extrapolation for species richness in R [70,71] with 0.95 confidence interval and prepared the rarefaction plots with 'devtools' package [72] and ggiNEXT function of 'ggplot2' package [73].

We performed Non-Metric Multidimensional Scaling Analysis (NMDS) to check the dissimilarity of geometrid species composition between ecoregions based on the zero-adjusted Bray–Curtis dissimilarity measure using 'phytomosaic/ecole' and 'vegan' package [74–76]. For estimation of pairwise similarities between ecoregions, we calculated the estimated abundance based Soerensen Index by abundance data using online program SpadeR [77]. We preferred Soerensen Index over Jaccard Index, while the result was a little bit higher than Jaccard. This estimated abundance based index can detect unseen shared species and is appropriate to evaluate beta diversity of samples under sampling bias [78].

We used 19 Bioclim data with 30 arc seconds resolution as climatic variables for the region [79]. We extracted these variables for the fourteen ecoregions. Ecoregion GIS data for Mongolia were downloaded from The Nature Conservancy (TNC) [80]. In two ecoregions no geometrid moths were found, namely, Khangai Mountains Conifer Forests and Sayan Intermontane Steppe (Figure 1). We thus excluded these ecoregions from the further analysis. To check for strong linear dependencies among explanatory variables we computed the variance inflation factor (VIF) for each variable in R package 'vegan'. We excluded variables with VIF values higher than 10 [81] (Table 1). We chose the most significant environmental variables with forward selection method by using vegan's 'ordistep' function [81]. Variables selected by forward selection method were fitted into the ordination plot using vegan's 'entfit' function.

All analysis were performed in R [82] and most graphs were made with package 'ggplot2' [73].

Table 1. List of the environmental [79] variables* for the fourteen ecoregions used in this study. All variables have been entered into forward selection method for selecting most important variables. The selected variables were later fitted in the Non-Metric Multidimensional Scaling Analysis (NMDS). Colors refer to the map in Figure 1.

Ecoregions	Bio1	Bio2	Bio5	Bio6	Bio7	Bio10	Bio11	Bio12	Biome [83]
Alashan Plateau Semi-Desert	5.1	14.1	28.6	−20.3	49	20.6	−11.7	85	Deserts and Xeric Shrublands
Altai Alpine Meadow and Tundra	−4.5	12.3	17.1	−28.1	45.2	10.3	−20.3	199	Montane Grasslands and Shrublands
Altai Montane Forest and Forest Steppe	−1.8	13.1	20.5	−26.8	47.3	13.4	−18.5	148	Temperate Conifer Forests
Dzungarian Basin Semi-Desert	3.9	14	27.4	−23	50.4	19.6	−13.9	91	Deserts and Xeric Shrublands
Daurian Forest Steppe	−1.5	13.9	23.7	−29.1	52.9	16	−21	306	Temperate Grasslands, Savannas and Shrublands
Eastern Gobi Desert Steppe	3.3	13.4	27.6	−22.5	50.1	19.8	−14.7	130	Deserts and Xeric Shrublands
Gobi Lakes Valley Desert Steppe	0.7	14.6	23.8	−24.3	48.1	15.9	−15.5	141	Deserts and Xeric Shrublands
Great Lakes Basin Desert Steppe	−1.6	13.5	24.2	−31.7	55.9	16.6	−23.1	147	Deserts and Xeric Shrublands
Khangai Mountains Alpine Meadow	−5.6	14.3	17.3	−30.5	47.8	9.7	−22.1	261	Montane Grasslands and Shrublands
Mongolian-Manchurian Grassland	0.3	13.6	25.4	−26.4	51.8	17.6	−18.7	224	Temperate Grasslands, Savannas and Shrublands
Sayan Alpine Meadows and Tundra	−8.4	13.6	16.3	−34.9	51.2	8.5	−27.3	355	Montane Grasslands and Shrublands
Sayan Montane Coniferous Forests	−5.1	13.7	19.2	−31.3	50.4	11.4	−23.5	381	Temperate Conifer Forests
Selenge-Orkhon Forest Steppe	−3.2	14.3	20.6	−29.7	50.3	12.9	−21.4	277	Temperate Grasslands, Savannas and Shrublands
Trans-Baikal Coniferous Forests	−3.3	13.4	22.1	−31.1	53.2	14.6	−23.3	366	Boreal Forests/Taiga

* Environmental variables with VIF under 10. Bio1—Annual Mean Temperature [°C]; Bio2—Mean Diurnal Range [°C]; Bio5—Max Temperature [°C]; Bio6—Min Temperature [°C]; Bio7—Temperature Annual Range [°C]; Bio10—Mean Temperature of Warmest Quarter [°C]; Bio11—Mean Temperature of Coldest Quarter [°C]; Bio12—Annual precipitation [mm].

3. Results

Altogether, we recorded 388 geometrid species of six subfamilies: Archiearinae, Desmobathrinae, Ennominae, Geometrinae, Larentiinae, and Sterrhinae (Appendix A Table A1). The most species-rich subfamily was Larentiinae with 203 species, while we recorded only one species in the subfamily Desmobathrinae. For 301 species with exact location data (Table S1), we recorded species richness within $2^\circ \times 2^\circ$ grid cells in whole Mongolia (Figure 2).

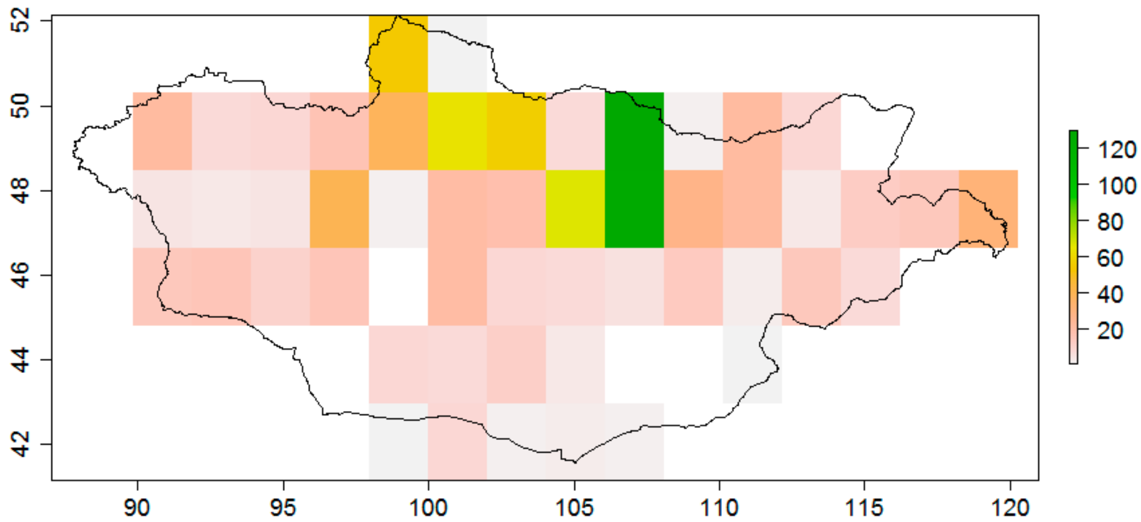

Figure 2. A map of study region (Mongolia) with distribution of 2° × 2° grid cell records. Colors represent the species richness (n = 301) within grid cells.

Species richness was highest in the northern central part of the country, with 133 species recorded near Darkhan-Uul Aimag and the capital Ulaanbaatar. Four most frequently recorded species were *Rhodostrophia jacularia* (in n = 32 grids), *Scopula beckeraria* (n = 18) *Scopula albiceraria* (n = 17), and *Horisme aquata* (n = 17).

As a result of the Good–Turing theory, estimated species richness for whole Mongolia was 663.19 with 0.95 confidence interval (606.80–734.12), which is nearly double the observed species richness (Q2.est = 78.51; se = 32.31; Undetected # species= 275.19; Undetected percentage (%) = 41.49). Also, we constructed a sample-based interpolation and extrapolation curve of 301 species with exact reported location within 51 grids. The interpolated and extrapolated estimators of species richness show similar results (Figure 3), the curve was not asymptotic, indicating under-sampling of the communities.

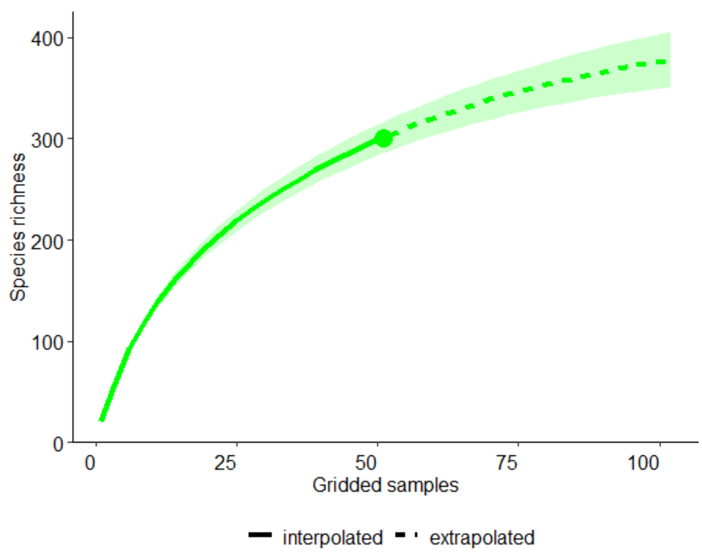

Figure 3. A sample-based interpolation and extrapolation curve of geometrid moths collected from Mongolia with 0.95 confidence interval. 51 grids were sampled with altogether 301 species. Axes X and Y represent the number of gridded samples and species richness, respectively.

In the next step we used the fourteen Mongolian ecoregions (Figure 1) to investigate the distribution of the sampled geometrid species in more detail. The most species-rich ecoregion was Daurian Forest

Steppe with 142 species, while Khangai Mountains Alpine Meadow was the lowest in species richness with only three species of geometrid moths (Figure 4). One species (*Rhodostrophia jacularia*) occurred in 10 ecoregions, there were five further generalist species (*Euphyia unangulata, Eupithecia nephelata, Scopula albiceraria, Scopula beckeraria*) that occurred in eight to nine ecoregions. In contrast, 126 species were recorded only in one ecoregion. Four ecoregions were clearly under-sampled (Altai Alpine Meadow and Tundra, Dzungarian Basin Semi-Desert, Khangai Mountains Alpine Meadow, Sayan Alpine Meadows and Tundra) thus to avoid misleading interpretation, we excluded those ecoregions from further analysis.

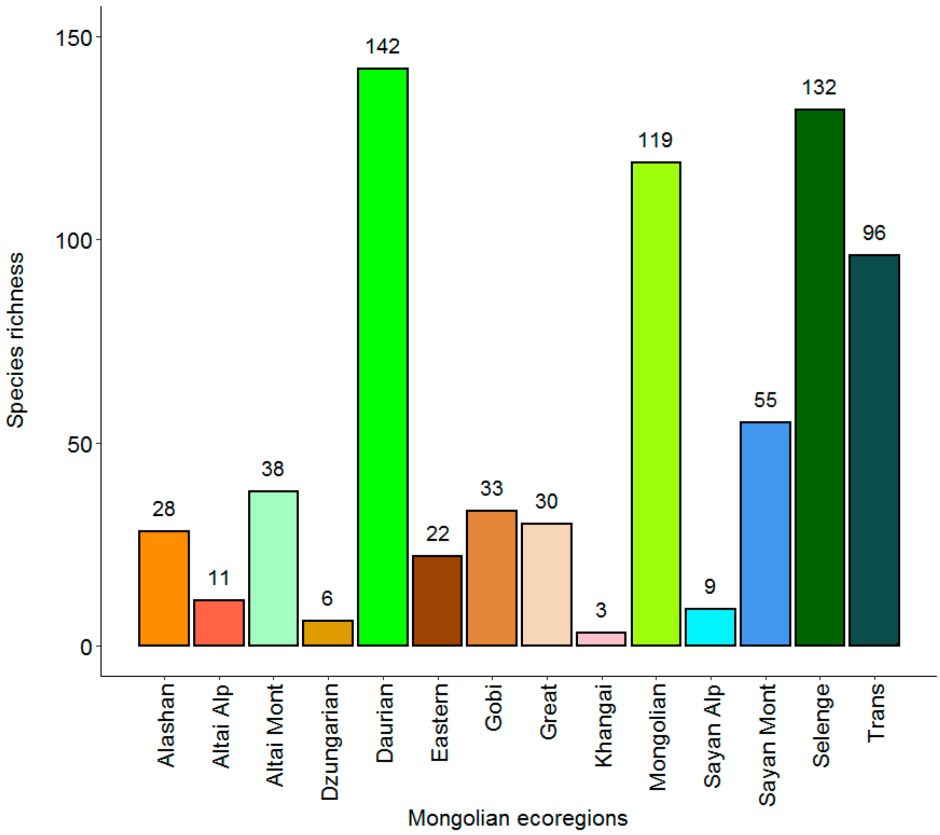

Figure 4. Geometrid moth species richness of 14 ecoregions of Mongolia. Under-sampled ecoregions are Altai Alp, Dzungarian, Khangai, and Sayan Alp. Colors refer to the map in Figure 1. Ecoregion abbreviations: Alashan: Alashan Plateau Semi-Desert, Altai Alp: Altai Alpine Meadow and Tundra, Altai Mont: Altai Montane Forest and Forest Steppe, Dzungarian: Dzungarian Basin Semi-Desert, Daurian: Daurian Forest Steppe, Eastern: Eastern Gobi Desert Steppe, Gobi: Gobi Lakes Valley Desert Steppe, Great: Great Lakes Basin Desert Steppe, Khangai: Khangai Mountains Alpine Meadow, Mongolian: Mongolian-Manchurian Grassland, Sayan Alp: Sayan Alpine Meadows and Tundra, Sayan Mont: Sayan Montane Coniferous Forests, Selenge: Selenge-Orkhon Forest Steppe, Trans: Trans-Baikal Coniferous Forests.

Interpolation and extrapolation curves of particular ecoregions differ in their shapes, thus indicating different "sample quality". Curves of Alashan Plateau Semi-Desert, Altai Montane Forest and Forest Steppe, Eastern Gobi Desert Steppe, Gobi Lakes Valley Desert Steppe, and Great Lakes Basin Desert Steppe are not asymptotic, only half of the estimated maximum species richness is sampled; while curves of Daurian Forest Steppe, Mongolian-Manchurian Grassland, Selenge-Orkhon Forest Steppe and Trans-Baikal Coniferous Forests are half asymptotic, thus tending to increase, while the curve of Sayan Montane Coniferous Forests is flattening, thus pointing to complete sampling of the moth community (Figure 5).

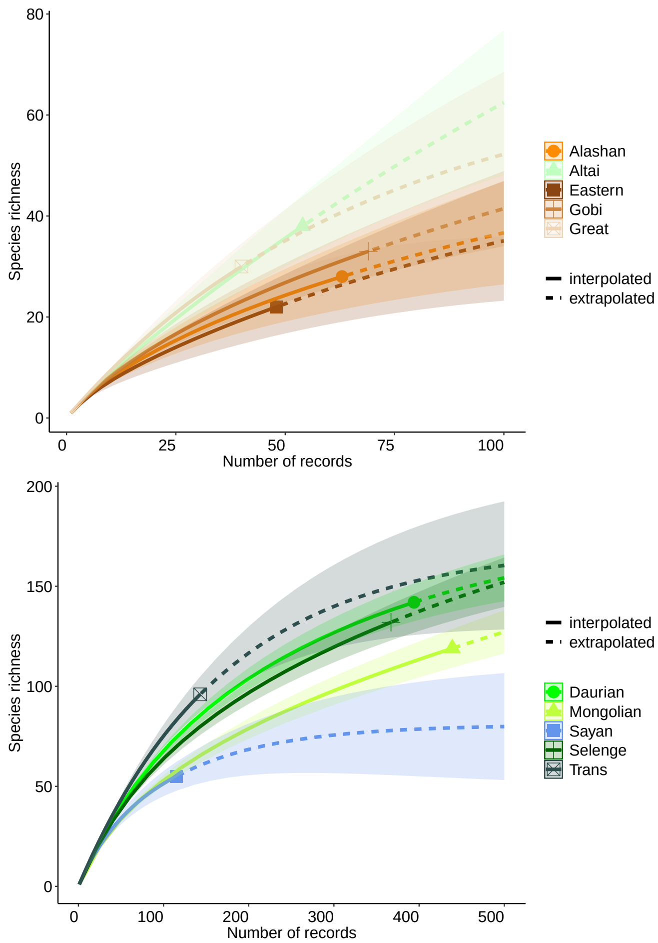

Figure 5. Sampling unit-based interpolation and extrapolation curves of ecoregions with 0.95 confidence interval. Axes *X* and *Y* axes represent the number of records and species richness, respectively. Ecoregions are jointly drawn on plots according to their grouping in the NMDS graph (Figure 6). Colors refer to the map in Figure 1. Ecoregion abbreviations as in Figure 4.

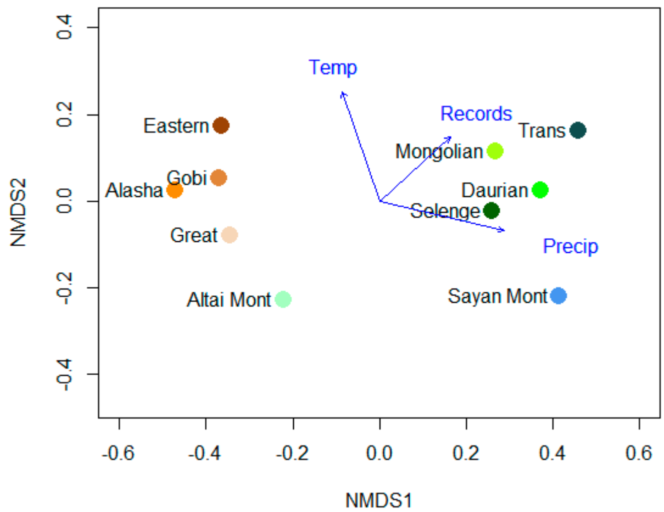

Figure 6. Non-metric multidimensional scaling (NMDS) ordination of 10 ecoregions of Mongolia according to their dissimilarity in geometrid moth species assemblage (zero-adjusted Bray-Curtis dissimilarity index for presence-absence data; stress 0.05). Significant variables are drawn in blue arrows. Temp: Maximum temperature of warmest month, Precip: Precipitation, Records: Number of records of geometrid moths. Colors refer to the map in Figure 1. Ecoregion abbreviations as in Figure 4.

For assessment of beta-diversity, we calculated estimates of the abundance-based Sorensen Index between ecoregions (Table 2). We excluded ecoregions with fewer than 20 species to avoid sampling bias in similarity analysis. The highest pairwise estimated Sorensen Similarity Index was between Eastern Gobi Desert Steppe and Gobi Lakes Valley Desert Steppe ($\beta_s = 0.942$), while the lowest were between Trans-Baikal Coniferous Forests and both of Gobi Lakes Valley Desert Steppe, Great Lakes Basin Desert Steppe ($\beta_s = 0.076$).

Table 2. Pairwise estimates of similarity between ecoregions with online tool Spade [69]. Shown is the estimated abundance-based Sorensen Index. Colors refer to the map in Figure 1. Ecoregion abbreviations as in Figure 4. Highest and lowest values in bold.

$C_{12(i,j)}$	Alashan	Altai	Daurian	Eastern	Gobi	Great	Mongoli	Sayan	Selenge	Trans
Alashan	1	0.504	0.184	0.595	0.716	0.446	0.433	0.097	0.206	0.244
Altai		1	0.451	0.64	0.742	0.702	0.523	0.311	0.594	0.445
Daurian			1	0.188	0.324	0.267	0.669	0.499	0.769	0.685
Eastern				1	**0.942**	0.644	0.533	0.127	0.424	0.141
Gobi					1	0.8	0.679	0.14	0.371	**0.076**
Great						1	0.497	0.301	0.544	0.139
Mongolian							1	0.417	0.719	0.522
Sayan								1	0.631	0.447
Selenge									1	0.606
Trans										1

An NMDS ordination biplot (stress = 0.05) shows two separate groups of geometrid species communities within ecoregions (Figure 6). Altai Montane Forest and Forest Steppe, Alashan Plateau Semi-Desert, Eastern Gobi Desert Steppe, Gobi Lakes Valley Desert Steppe, and Great Lakes Basin Desert Steppe are clustered in the first group, Sayan Montane Coniferous Forests, Mongolian-Manchurian Grassland, Daurian Forest Steppe, Selenge-Orkhon Forest Steppe, and Trans-Baikal Coniferous Forests are grouped in the second group. Precipitation was positively correlated with NMDS1, while temperature was positively correlated with NMDS2, both correlations were highly significant ($p < 0.01$). Number of records was positively correlated with both axes but was not significant (Table 3).

Table 3. NMDS vector fitted values. Temp: Max temperature of warmest month, Precipitation: Annual precipitation, Records: Number of records of geometrid moths.

Variable	NMDS1	NMDS2	r^2	Pr (> 0)
Temperature	−0.32277	0.94648	0.7473	0.009
Precipitation	0.97252	−0.23281	0.9183	0.001
Records	0.73924	0.67344	0.5096	0.095

4. Discussion

In this study, we compiled a geometrid species checklist for Mongolia, examined species richness and diversity of geometrid communities among ecoregions. In addition, we investigated which environmental variables impact the distribution of geometrid moths. Compiling a species checklist on geometrid moths from a variety of sources published since 1892 was quite challenging, as names of species and locations were changing over the years, while sample efforts in different studies and areas differed considerably. Despite all our efforts we may not have included all species recorded in Mongolia in our list.

In total, we found 1973 records of 388 geometrid species of six subfamilies, but these records were not evenly sampled. The sample-based interpolation and extrapolation curve of gridded sample was not asymptotic, indicating that our records do not represent the whole potential geometrid fauna in Mongolia (Figure 3). Species richness for whole Mongolia was estimated as 663.19 species with Good–Turing theory and this estimated species richness was nearly double the observed species richness. These results confirm the rarefaction analysis and show that our inventory of geometrid moths in Mongolia is still incomplete, with less than 60% of the estimated species being recorded. The fact that countrywide diversity was highest in the grid cell of the capital draws further attention towards an obvious sampling bias with undersampling for the rest of the country. Moreover, we expect to find species of two other subfamilies, Orthostixinae and Alsophilinae in Mongolia. Species of these subfamilies were recorded in adjacent areas, such as in Kazakhstan and in China [37]. However, according to Müller et al. Alsophilinae is transferred to Ennominae, while the subfamily status of Orthostixinae is still not clear [62].

Given the huge size of Mongolia the estimated richness of 663 geometrid species for the whole country seems to be not high. But we wanted to compare the species richness of Mongolia with species richness of other countries similar in size. Norway + Sweden + Finland (1,173,940 km^2) together are similar in size to Mongolia (1,564,000 km^2). Altogether, for these countries, 341 geometrid species are recorded [84]. If we compare observed species richness (388) of Mongolia with the richness of those countries, it is almost similar; if we compare estimated species richness (663), it is almost double.

However, Scandinavia is an area at high latitudes, with harsh climate, not really suited for an ectotherm group like moths. Further south, Iberian Peninsula and Balearic Islands together, have 589 geometrid species (According to a personal information of Javier Gastón, one of the authors of the paper, due to scientific efforts the total number of Geometridae recorded on Iberian Peninsula and the Balearic Islands is now 605 species.) [85] and their areas (596,740 km^2 + 4564 km^2) are almost three times smaller than the landlocked area of Mongolia, which is situated at higher latitude. Comparisons between distant countries are always somewhat lacking, but no figures on geometrid species richness are available for the countries in Inner Asia (e.g., Kazakhstan).

The most frequently recorded species, which occurred in 10 ecoregions of Mongolia, was *Rhodostrophia jacularia*, an inhabitant of steppe and semi-desert [34,86]. Sihvonen and Nupponen [87] studied female wing shape of this species, but we could not find other studies related to the biology of this species.

Most records were found in Daurian Forest Steppe, Selenge-Orkhon Forest Steppe, and Mongolian-Manchurian Grassland. For many ecoregions, rarefaction curves were not asymptotic, thus revealing that sampling there was incomplete. Two ecoregions have no geometrid moth records at all and were thus excluded from analysis, namely Khangai Mountains Conifer Forests and Sayan Intermontane Steppe. The less studied areas comprise higher altitude areas from central Mongolia, as well as border regions. Sampling in these ecoregions, many of them with high habitat heterogeneity, will certainly expand our checklist.

To assess beta diversity among these unevenly sampled groups we used an estimator for Soerenson similarity that includes unseen species in the calculation [70]. The results, on the one hand, reflect the high habitat heterogeneity of Mongolia, with is steep ecological north-south gradient and the diverse biomes of the country that promote high beta diversity (Table 1). On the other hand, it proved that ecoregions that include similar biomes had higher similarity of moth communities, a result corroborated by NMDS. The most similar ecoregions were Eastern Gobi Desert Steppe and Gobi Lakes Valley Desert Steppe that adjoin each other (β_s = 0.942).

In NMDS, ecoregions were grouped in two big groups. The first group included Alashan Plateau Semi-Desert, Eastern Gobi Desert Steppe, Gobi Lakes Valley Desert Steppe, Great Lakes Basin Desert Steppe and Altai Montane Forest and Forest Steppe, while in the second group there were Daurian Forest Steppe, Mongolian-Manchurian Grassland, Sayan Montane Coniferous Forests, Selenge-Orkhon Forest Steppe, and Trans-Baikal Coniferous Forests. The geographically nearest ecoregions were grouped together, and also the ecoregions included in the same group belonged to mostly same biome type (Table 1). The first group comprised mostly Deserts and Xeric Shrublands except Altai Montane Forest and Forest Steppe, while three ecoregions of the second group belonged to Temperate Grasslands, Savannas and Shrublands.

Environmental variables that shaped species distribution were nominated by forward selection in NMDS and included annual precipitation and maximum temperature of warmest quarter. Number of records was also selected as variable, but only temperature and precipitation were significant in NMDS, thus corroborating the general robustness of our analysis, which was less influenced by sample effort. The aforementioned groups of ecoregions in NMDS differ along the precipitation gradient and within groups in temperature, e.g., the montane forests regions of both groups have lower values of NMDS2.

In a study on Borneo, geometrid moths showed a similar relationship with precipitation and temperature [88]. Temperature has also been a major impact on geometrid species distribution in the Andes [89]. Moreover, habitat disturbance played a big role in shaping the geometrid moth ensemble in northern Borneo [90]. Similarly, grazing proved to be a factor influencing community pattern in Mongolian moths [4]. Temperature, rainfall and habitat disturbance are impacted by climate change and anthropgenic influence, so we expect future changes within the Mongolian geometrid communities. The species list we present here can be a tool helping to monitor these changes.

Finally, we have to admit that our study has a few weaknesses. We compiled records only from literature (we apologize if we missed any) due to limited time and funding. A total of 87 of the 388 species in our checklist are still missing an exact location. This information may be available in the museum collections pinned to the respective specimens. A detailed research in museums would have certainly brought more records and species. In addition, all our records were not systematically collected, which might affect the statistical analysis. The mere fact that data were sampled over a long period of time in different research projects, with different ways of sampling certainly impacts the value of a statistical analysis. For example, in our field study [4], we used UV light, but in other studies normal light bulbs were used, sometimes even moths have even been collected during day time. Together with the general problem of undersampling, these points hamper a more detailed analysis of the Mongolian geometrid communities at the present time.

Nevertheless, due to our study, future directions of research on Mongolian Geometridae have become more clear: geometrid moths are really under-studied in Mongolia. We found two unsampled and four extremely under-sampled ecoregions and for all ecoregions expected species numbers were higher than recorded ones. So, we expect to find many more amazing moth species in future collections in the respective regions.

5. Conclusions

In total, 1973 records of 388 species were recorded, but we also expect that many more species will be recorded in the future in more elaborated sampling designs, especially from locations of southern, eastern and western Mongolia. Despite the fact that our compiled data is not good enough to analyze the distribution and diversity pattern in full detail, our study could reveal the knowledge gaps and undersampled areas, provide a first estimate of the approximate species number in whole Mongolia (n = 663), visualize the currently recorded distribution and diversity pattern of geometrid moths of Mongolia and evaluate the main environmental factors that shape the communities.

Supplementary Materials: The following are available online at http://www.mdpi.com/1424-2818/12/5/186/s1, Table S1: Occurrence data of geometrid moths compiled from Mongolia.

Author Contributions: K.E., B.B. and M.P. designed research. K.E. performed research, analyzed data and wrote the paper with inputs from M.P. and B.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Checklist of geometrid moths in Mongolia. Note that we conducted all analysis at species level. Here subspecies are listed to show compiled data in more detail. The listed references include in most cases articles with location information.

Subfamily	Species	Author	Year	Reference
Archiearinae	*Archiearis notha*	Hübner	1802	[34]
Archiearinae	*Archiearis parthenias*	Linnaeus	1761	[34]
Archiearinae	*Archiearis parthenias sajana*	Prout	1912	[46]
Archiearinae	*Leucobrephos middendorfii*	Ménétriés	1858	[41]
Desmobathrinae	*Gypsochroa renitidata*	Hübner	1817	[57]
Ennominae	*Abraxas grossulariata*	Linnaeus	1758	[21,34,46,63,65]
Ennominae	*Abraxas grossulariata dsungarica*	Wehrli	1939	[38]
Ennominae	*Alcis deversata*	Staudinger	1892	[34,39,46,63,65]
Ennominae	*Alcis extinctaria*	Eversmann	1851	[23,34,36,39,65,91]
Ennominae	*Alcis jubata*	Thunberg	1788	[37]
Ennominae	*Alcis repandata*	Linnaeus	1758	[65]
Ennominae	*Alloharpina conjungens*	Alphéraky	1892	[33]
Ennominae	*Amraica superans*	Butler	1878	[33]
Ennominae	*Angerona prunaria*	Linnaeus	1758	[24,34,46,63,65]
Ennominae	*Angerona prunaria kentearia*	Staudinger	1892	[39]
Ennominae	*Angerona prunaria mongoligena*	Bryk	1949	[62]
Ennominae	*Apeira syringaria*	Linnaeus	1758	[63]
Ennominae	*Apocheima hispidaria*	Denis & Schiffermüller	1775	[34]
Ennominae	*Apocolotois almatensis*	Djakonov	1952	[39]
Ennominae	*Apocolotois smirnovi*	Romanoff	1885	[39]
Ennominae	*Arichanna barteli*	Prout	1915	[32,45]
Ennominae	*Arichanna melanaria*	Linnaeus	1758	[34,46,65,91]
Ennominae	*Arichanna melanaria decolorata*	Staudinger	1892	[45]
Ennominae	*Arichanna melanaria praeolivina*	Wehrli	1933	[39]
Ennominae	*Aspitates conspersaria*	Staudinger	1901	[23,45]
Ennominae	*Aspitates curvaria*	Eversmann	1852	[1,8,14]
Ennominae	*Aspitates forbesi*	Munroe	1963	[65]
Ennominae	*Aspitates gilvaria*	Denis & Schiffermüller	1775	[23,24,34,36,63,91]
Ennominae	*Aspitates gilvaria minimus*	Vojnits	1975	[39]
Ennominae	*Aspitates insignis*	Alphéraky	1883	[36,39]
Ennominae	*Aspitates kozhantchikovi*	Munroe	1963	[36,65]
Ennominae	*Aspitates mongolicus*	Vojnits	1975	[39,65]
Ennominae	*Aspitates mundataria*	Stoll	1782	[34,46,63,65]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Ennominae	*Aspitates mundataria uncinataria*	Vojnits	1975	[39]
Ennominae	*Aspitates obscurata*	Wehrli	1953	[33,34,39]
Ennominae	*Aspitates staudingeri*	Vojnits	1975	[39]
Ennominae	*Aspitates taylorae sibirica*	Djakonov	1955	[36,65]
Ennominae	*Aspitates tristrigaria*	Bremer & Grey	1853	[34,37]
Ennominae	*Astegania honesta*	Prout	1908	[34]
Ennominae	*Biston betularia*	Linnaeus	1758	[34,46,63,91]
Ennominae	*Biston betularia sibiricus*	Fuchs	1899	[37]
Ennominae	*Cabera exanthemata*	Scopoli	1763	[23,34,46,65]
Ennominae	*Cabera exanthemata hamica*	Wehrli	1939	[39]
Ennominae	*Cabera pusaria*	Linnaeus	1758	[34,39,63]
Ennominae	*Calcaritis pallida*	Hedemann	1881	[47]
Ennominae	*Chariaspilates formosaria*	Eversmann	1837	[37]
Ennominae	*Charissa agnitaria*	Staudinger	1897	[55]
Ennominae	*Charissa ambiguata*	Duponchel	1830	[34,36,46,65]
Ennominae	*Charissa ambiguata ophthalmicata*	Lederer	1853	[39]
Ennominae	*Charissa beljaevi*	Erlacher et al., 2017	2017	[55]
Ennominae	*Charissa bidentatus*	Shchetkin & Viidalepp	1980	[46]
Ennominae	*Charissa creperaria*	Erschoff	1877	[34,55,65]
Ennominae	*Charissa difficilis*	Alphéraky	1883	[21,24,34,39,65]
Ennominae	*Charissa gozmanyi*	Vojnits	1975	[14]
Ennominae	*Charissa macguffini*	Smiles	1979	[65]
Ennominae	*Charissa ochrofasciata*	Staudinger	1895	[21,30,34,36,39,55,65]
Ennominae	*Charissa remmi*	Viidalepp	1988	[56,63]
Ennominae	*Charissa sibiriata*	Guenée	1858	[21,24,30,34,36]
Ennominae	*Charissa subsplendidaria*	Wehrli	1922	[63,92]
Ennominae	*Charissa turfosaria*	Wehrli	1922	[30,34,39,45,62]
Ennominae	*Charissa vastaria*	Staudinger	1892	[30,34]
Ennominae	*Chiasmia aestimaria*	Hübner	1809	[65]
Ennominae	*Chiasmia aestimaria kuldschana*	Wehrli	1940	[39]
Ennominae	*Chiasmia clathrata*	Linnaeus	1758	[23,24,26,34,36,46,63,65,91]
Ennominae	*Chiasmia clathrata djakonovi*	Kardakoff	1928	[38,39]
Ennominae	*Chiasmia saburraria*	Eversmann	1851	[21,34,65]
Ennominae	*Chiasmia saburraria kenteata*	Staudinger	1892	[38]
Ennominae	*Cleora cinctaria*	Denis & Schiffermüller	1775	[34,46,63]
Ennominae	*Colotois pennaria*	Linnaeus	1760	[46]
Ennominae	*Deileptenia ribeata*	Clerck	1759	[63]
Ennominae	*Digrammia rippertaria*	Duponchel	1830	[34]
Ennominae	*Ectropis crepuscularia*	Denis & Schiffermüller	1775	[34,46]
Ennominae	*Eilicrinia orias*	Wehrli	1933	[45]
Ennominae	*Elophos banghaasi*	Wehrli	1922	[30,34,45]
Ennominae	*Ematurga atomaria*	Linnaeus	1758	[23,24,34,36,46,65]
Ennominae	*Ematurga atomaria krassnojarscensis*	Fuchs	1899	[39]
Ennominae	*Ennomos autumnaria*	Werneburg	1859	[46]
Ennominae	*Epione repandaria*	Hufnagel	1767	[34]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Ennominae	*Epione vespertaria*	Linnaeus	1767	[34,39]
Ennominae	*Epirranthis diversata*	Denis & Schiffermüller	1775	[63]
Ennominae	*Erannis jacobsoni*	Djakonov	1926	[34,46,65]
Ennominae	*Gnophopsodos ravistriolaria*	Wehrli	1922	[36]
Ennominae	*Gnophopsodos ravistriolaria ravistriolaria*	Wehrli	1922	[55]
Ennominae	*Gnophopsodos stemmataria*	Eversmann	1848	[39]
Ennominae	*Gnophopsodos tholeraria*	Püngeler	1901	[50]
Ennominae	*Gnophos bipartitus*	Vojnits	1975	[39]
Ennominae	*Gnophos rubefactaria*	Püngeler	1902	[37]
Ennominae	*Heliomata glarearia*	Denis & Schiffermüller	1775	[46]
Ennominae	*Hypomecis punctinalis*	Scopoli	1763	[46]
Ennominae	*Hypomecis roboraria*	Denis & Schiffermüller	1775	[23,34,39,63]
Ennominae	*Hypoxystis pluviaria*	Fabricius	1787	[34,46,63]
Ennominae	*Isturgia altaica*	Vojnits	1978	[43]
Ennominae	*Isturgia arenacearia*	Denis & Schiffermüller	1775	[63,91]
Ennominae	*Isturgia arenacearia mongolica*	Vojnits	1974	[38]
Ennominae	*Isturgia falsaria*	Alphéraky	1892	[34]
Ennominae	*Isturgia halituaria*	Guenée	1858	[48]
Ennominae	*Isturgia kaszabi*	Vojnits	1974	[38]
Ennominae	*Isturgia murinaria*	Denis & Schiffermüller	1775	[34,36]
Ennominae	*Isturgia murinaria uralica*	Wehrli	1937	[63]
Ennominae	*Jankowskia bituminaria*	Lederer	1853	[65]
Ennominae	*Jankowskia bituminaria raddensis*	Wehrli	1941	[93]
Ennominae	*Lomaspilis marginata*	Linnaeus	1758	[23,34,46,65]
Ennominae	*Lomaspilis opis amurensis*	Hedemann	1881	[38]
Ennominae	*Lomographa buraetica*	Staudinger	1892	[34]
Ennominae	*Lomographa temerata*	Denis & Schiffermüller	1775	[46]
Ennominae	*Lycia hirtaria*	Clerck	1759	[63]
Ennominae	*Lycia lapponaria*	Boisduval	1840	[37]
Ennominae	*Macaria alternata*	Denis & Schiffermüller	1775	[34,46,91]
Ennominae	*Macaria artesiaria*	Denis & Schiffermüller	1775	[34,38]
Ennominae	*Macaria brunneata*	Thunberg	1784	[36,38,91]
Ennominae	*Macaria circumflexaria*	Eversmann	1848	[38,46,63,91]
Ennominae	*Macaria costimaculata*	Graeser	1888	[34]
Ennominae	*Macaria latefasciata*	Staudinger	1896	[21,34]
Ennominae	*Macaria liturata*	Clerck	1759	[65]
Ennominae	*Macaria liturata pressaria*	Christoph	1893	[37]
Ennominae	*Macaria loricaria*	Eversmann	1837	[36]
Ennominae	*Macaria notata*	Linnaeus	1758	[34,63]
Ennominae	*Macaria notata kirina*	Wehrli	1940	[38]
Ennominae	*Macaria serenaria*	Staudinger	1896	[21,34]
Ennominae	*Macaria signaria*	Hübner	1809	[38,46]
Ennominae	*Macaria wauaria*	Linnaeus	1758	[34,36]
Ennominae	*Megalycinia strictaria*	Lederer	1853	[21,34,39,46,63]
Ennominae	*Megametopon piperatum*	Alphéraky	1892	[34,39,65]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Ennominae	*Narraga fasciolaria*	Hufnagel	1767	[34,63]
Ennominae	*Odontopera bidentata*	Clerck	1759	[21,35,40,47,66]
Ennominae	*Odontopera bidentata exsul*	Tchetrerikov	1905	[36,39]
Ennominae	*Odontopera bidentata rava*	Vojnits	1975	[39,65]
Ennominae	*Ourapteryx persica*	Ménétriés	1832	[34]
Ennominae	*Ourapteryx sambucaria*	Linnaeus	1758	[63,65]
Ennominae	*Perconia strigillaria*	Hübner	1787	[46,63]
Ennominae	*Petrophora kaszabi*	Vojnits	1978	[43]
Ennominae	*Phaselia narynaria*	Oberthür	1913	[49]
Ennominae	*Phaselia serrularia*	Eversmann	1847	[65]
Ennominae	*Phthonandria emaria*	Bremer	1864	[39]
Ennominae	*Plagodis dolabraria*	Linnaeus	1767	[34]
Ennominae	*Plagodis pulveraria*	Linnaeus	1758	[21,34,65]
Ennominae	*Plagodis pulveraria singularis*	Vojnits	1975	[39]
Ennominae	*Pleogynopteryx bituminaria*	Lederer	1853	[21,34,39]
Ennominae	*Pseudopanthera macularia*	Linnaeus	1758	[34]
Ennominae	*Pseudopanthera macularia cryptica*	Beljaev	1997	[94]
Ennominae	*Selenia dentaria*	Fabricius	1775	[39]
Ennominae	*Selenia dentaria alpestris*	Wehrli	1940	[37]
Ennominae	*Selenia ononica*	Kostjuk	1991	[37]
Ennominae	*Selenia sordidaria*	Leech	1897	[39]
Ennominae	*Selenia tetralunaria*	Hufnagel	1767	[34,36,46,63]
Ennominae	*Siona lineata*	Scopoli	1763	[23,26,34,36,39,46,63,65]
Ennominae	*Spartopteryx kindermannaria*	Staudinger	1871	[36,39,46]
Ennominae	*Xandrames dholaria*	Moore	1868	[33]
Ennominae	*Yezognophos vittaria*	Thunberg	1792	[65]
Geometrinae	*Chlorissa viridata*	Linnaeus	1758	[34]
Geometrinae	*Dyschloropsis impararia*	Guenée	1858	[21,24,34,40,41,65]
Geometrinae	*Geometra papilionaria*	Linnaeus	1758	[40,46,63]
Geometrinae	*Geometra papilionaria herbacearia*	Ménétriés	1859	[41,65]
Geometrinae	*Hemistola chrysoprasaria*	Esper	1794	[46,63]
Geometrinae	*Hemistola chrysoprasaria lissas*	Prout	1912	[40]
Geometrinae	*Hemistola zimmermanni*	Hedemann	1879	[34,40,41]
Geometrinae	*Hemithea aestivaria*	Hübner	1799	[46]
Geometrinae	*Jodis lactearia*	Linnaeus	1758	[37]
Geometrinae	*Microloxia herbaria*	Hübner	1813	[34,65]
Geometrinae	*Microloxia herbaria advolata*	Eversmann	1837	[41]
Geometrinae	*Thalera chlorosaria*	Graeser	1890	[34,40,41,91]
Geometrinae	*Thalera fimbrialis*	Scopoli	1763	[63]
Geometrinae	*Thetidia atyche*	Prout	1935	[40,41]
Geometrinae	*Thetidia chlorophyllaria*	Hedemann	1879	[37]
Geometrinae	*Thetidia correspondens*	Alpheraky	1883	[49]
Geometrinae	*Thetidia volgaria*	Guenée	1858	[21,34,40,46,65]
Geometrinae	*Thetidia volgaria mongolica*	Staudinger	1897	[41]
Larentiinae	*Acasis appensata*	Eversmann	1842	[46,65]
Larentiinae	*Anticlea badiata*	Denis & Schiffermüller	1775	[34,63]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Larentiinae	*Anticlea derivata*	Denis & Schiffermüller	1775	[24,34,46,63]
Larentiinae	*Aplocera plagiata roddi*	Vasilenko	1995	[59]
Larentiinae	*Baptria tibiale*	Esper	1804	[34,42]
Larentiinae	*Camptogramma bilineata*	Linnaeus	1758	[46]
Larentiinae	*Carsia sororiata*	Hübner	1813	[23,34,36]
Larentiinae	*Catarhoe cuculata*	Hufnagel	1767	[37,46,59,63]
Larentiinae	*Catarhoe rubidata*	Denis & Schiffermüller	1775	[46]
Larentiinae	*Chloroclysta miata*	Linnaeus	1758	[36]
Larentiinae	*Cidaria distinctata*	Staudinger	1892	[37]
Larentiinae	*Cidaria fulvata*	Forster	1771	[34,44,63,65]
Larentiinae	*Coenocalpe lapidata*	Hübner	1809	[21,23,34,36,46,65]
Larentiinae	*Coenotephria korschunovi*	Viidalepp	1976	[34]
Larentiinae	*Colostygia aptata*	Hübner	1813	[34,65]
Larentiinae	*Cosmorhoe ocellata*	Linnaeus	1758	[37]
Larentiinae	*Dysstroma citrata*	Linnaeus	1761	[34,46,63,65]
Larentiinae	*Dysstroma citrata septentrionalis*	Heydemann	1929	[36]
Larentiinae	*Dysstroma citratum kamtshadalarium*	Beljaev & Vasilenko	2002	[48]
Larentiinae	*Dysstroma infuscata*	Tengström	1869	[65]
Larentiinae	*Dysstroma latefasciata*	Blöcker	1908	[34,44,65]
Larentiinae	*Dysstroma pseudimmanata*	Heydemann	1929	[31,34,44]
Larentiinae	*Dysstroma truncata*	Hufnagel	1767	[23,31,34,44,65,91]
Larentiinae	*Dysstroma truncata transbaicalensis*	Heydemann	1929	[36]
Larentiinae	*Ecliptopera capitata*	Herrich-Schäffer	1839	[63]
Larentiinae	*Ecliptopera dimita*	Prout	1938	[37]
Larentiinae	*Ecliptopera umbrosaria*	Motschulsky	1861	[34]
Larentiinae	*Ecliptoptera oblongata*	Guenée	1858	[44]
Larentiinae	*Electrophaes chimakaleparia*	Oberthür	1893	[44]
Larentiinae	*Electrophaes corylata*	Thunberg	1792	[46,65]
Larentiinae	*Entephria caesiata*	Denis & Schiffermüller	1775	[34,36,44]
Larentiinae	*Entephria kuznetzovi*	Viidalepp	1976	[34,45]
Larentiinae	*Entephria tzygankovi*	Wehrli	1929	[36]
Larentiinae	*Epirrhoe alternata*	Müller	1764	[23,34,36]
Larentiinae	*Epirrhoe hastulata*	Hübner	1790	[34,36,44,46]
Larentiinae	*Epirrhoe hastulata reducta*	Djakonov	1929	[48]
Larentiinae	*Epirrhoe pupillata*	Thunberg	1788	[23,34,36,44,46,63,65,91]
Larentiinae	*Epirrhoe tristata*	Linnaeus	1758	[23,34,46]
Larentiinae	*Epirrita autumnata*	Borkhausen	1794	[21,34,34]
Larentiinae	*Epirrita autumnata smetanini*	Beljaev & Vasilenko	2002	[48]
Larentiinae	*Epirrita autumnata tunkunata*	Bang-Haas	1910	[36]
Larentiinae	*Esakiopteryx volitans*	Butler	1878	[44]
Larentiinae	*Eulithis mellinata*	Fabricius	1787	[34]
Larentiinae	*Eulithis populata*	Linnaeus	1758	[36,44,63,91]
Larentiinae	*Eulithis prunata*	Linnaeus	1758	[34,44,46]
Larentiinae	*Eulithis pyraliata*	Denis & Schiffermüller	1775	[23,34,44,46,63,65]
Larentiinae	*Eulithis pyropata*	Hübner	1809	[91]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Larentiinae	*Eulithis testata*	Linnaeus	1761	[23,34,44,46,63]
Larentiinae	*Euphyia coangulata*	Prout	1914	[21,23,24,34,36,44,65]
Larentiinae	*Euphyia intersecta*	Staudinger	1882	[21,23,34]
Larentiinae	*Euphyia unangulata*	Haworth	1809	[34,46,63,65]
Larentiinae	*Eupithecia selinata*	Herrich-Schäffer	1861	[34]
Larentiinae	*Eupithecia absinthiata*	Clerck	1759	[95]
Larentiinae	*Eupithecia actaeata*	Walderdorff	1869	[52]
Larentiinae	*Eupithecia addictata*	Dietze	1908	[37]
Larentiinae	*Eupithecia aggregata*	Guenée	1858	[37]
Larentiinae	*Eupithecia amplexata*	Christoph	1881	[34,65]
Larentiinae	*Eupithecia anikini*	Mironov & Galsworthy	2014	[52]
Larentiinae	*Eupithecia aporia*	Vojnits	1975	[41,45]
Larentiinae	*Eupithecia assimilata*	Doubleday	1856	[52]
Larentiinae	*Eupithecia bastelbergeri*	Dietze	1910	[52]
Larentiinae	*Eupithecia biornata*	Christoph	1867	[34,65]
Larentiinae	*Eupithecia bohatschi*	Staudinger	1897	[25,34,65]
Larentiinae	*Eupithecia carpophilata*	Staudinger	1897	[34,65]
Larentiinae	*Eupithecia catharinae*	Vojnits	1969	[65]
Larentiinae	*Eupithecia centaureata*	Denis & Schiffermüller	1775	[34,63,65]
Larentiinae	*Eupithecia chingana*	Wehrli	1926	[45]
Larentiinae	*Eupithecia corroborata*	Dietze	1908	[36]
Larentiinae	*Eupithecia denotata*	Hübner	1813	[34]
Larentiinae	*Eupithecia despectaria*	Lederer	1853	[34,37]
Larentiinae	*Eupithecia dissertata*	Püngeler	1905	[34,36,65]
Larentiinae	*Eupithecia djakonovi*	Shchetkin	1956	[37]
Larentiinae	*Eupithecia dolosa*	Vojnits	1977	[45]
Larentiinae	*Eupithecia ericeata*	Rambur	1833	[52,65]
Larentiinae	*Eupithecia extensaria*	Freyer	1844	[36,65]
Larentiinae	*Eupithecia fennoscandica*	Knaben	1949	[36,96]
Larentiinae	*Eupithecia fuscicostata*	Christoph	1887	[65]
Larentiinae	*Eupithecia graciliata*	Dietze	1906	[34]
Larentiinae	*Eupithecia hannemanni*	Vojnits & De Laever	1973	[65]
Larentiinae	*Eupithecia holti*	Viidalepp	1973	[34,65,97]
Larentiinae	*Eupithecia illaborata*	Dietze	1904	[52]
Larentiinae	*Eupithecia impolita*	Vojnits	1980	[52]
Larentiinae	*Eupithecia inculta*	Vojnits	1975	[65]
Larentiinae	*Eupithecia indigata*	Hübner	1813	[63]
Larentiinae	*Eupithecia innotata*	Hufnagel	1767	[21,34,65]
Larentiinae	*Eupithecia intricata*	Zetterstedt	1839	[34]
Larentiinae	*Eupithecia inveterata*	Vojnits	1987	[65]
Larentiinae	*Eupithecia irriguata*	Hübner	1813	[65]
Larentiinae	*Eupithecia kozlovi*	Viidalepp	1973	[34,97]
Larentiinae	*Eupithecia kuldschaensis*	Staudinger	1892	[34,65]
Larentiinae	*Eupithecia laboriosa*	Vojnits	1977	[65]
Larentiinae	*Eupithecia lariciata*	Freyer	1841	[34,36,65]
Larentiinae	*Eupithecia leptogrammata*	Staudinger	1882	[65]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Larentiinae	*Eupithecia linariata*	Denis & Schiffermüller	1775	[65]
Larentiinae	*Eupithecia mima*	Mironov	1989	[65]
Larentiinae	*Eupithecia minusculata*	Alphéraky	1883	[34,65]
Larentiinae	*Eupithecia mongolica*	Vojnits	1974	[65]
Larentiinae	*Eupithecia morosa*	Vojnits	1976	[65]
Larentiinae	*Eupithecia munguata*	Mironov & Galsworthy	2014	[52]
Larentiinae	*Eupithecia necessaria*	Vojnits	1977	[41,45]
Larentiinae	*Eupithecia nephelata*	Staudinger	1897	[21,23,34,65]
Larentiinae	*Eupithecia nobilitata*	Staudinger	1882	[36,65]
Larentiinae	*Eupithecia olgae*	Mironov	1986	[52]
Larentiinae	*Eupithecia opisthographata*	Dietze	1906	[34]
Larentiinae	*Eupithecia perfuscata*	Vojnits	1975	[65]
Larentiinae	*Eupithecia pernotata*	Guenée	1858	[48]
Larentiinae	*Eupithecia pimpinellata*	Hübner	1813	[34,65]
Larentiinae	*Eupithecia propria*	Vojnits	1977	[65]
Larentiinae	*Eupithecia pusillata*	Denis & Schiffermüller	1775	[52]
Larentiinae	*Eupithecia pygmaeata*	Hübner	1799	[65]
Larentiinae	*Eupithecia recens*	Dietze	1904	[34,36]
Larentiinae	*Eupithecia relaxata*	Dietze	1904	[65]
Larentiinae	*Eupithecia repentina*	Vojnits & De Laever	1978	[52]
Larentiinae	*Eupithecia rubellata*	Dietze	1904	[41,45]
Larentiinae	*Eupithecia saisanaria*	Staudinger	1882	[52]
Larentiinae	*Eupithecia satyrata*	Hübner	1813	[36]
Larentiinae	*Eupithecia selinata*	Herrich-Schäffer	1861	[95]
Larentiinae	*Eupithecia simpliciata*	Haworth	1809	[52]
Larentiinae	*Eupithecia sinuosaria*	Eversmann	1848	[23,34,36]
Larentiinae	*Eupithecia subbrunneata*	Dietze	1904	[52]
Larentiinae	*Eupithecia subexiguata*	Vojnits	1974	[65]
Larentiinae	*Eupithecia subfuscata*	Haworth	1809	[34]
Larentiinae	*Eupithecia suboxydata*	Staudinger	1897	[65,98]
Larentiinae	*Eupithecia subtacincta*	Hampson	1895	[37]
Larentiinae	*Eupithecia subumbrata*	Denis & Schiffermüller	1775	[23,34,65]
Larentiinae	*Eupithecia succenturiata*	Linnaeus	1758	[95]
Larentiinae	*Eupithecia sutiliata*	Christoph	1877	[65]
Larentiinae	*Eupithecia thalictrata*	Püngeler	1902	[52]
Larentiinae	*Eupithecia undata*	Freyer	1840	[65]
Larentiinae	*Eupithecia veratraria*	Herrich-Schäffer	1848	[95]
Larentiinae	*Eupithecia vicina*	Mironov	1989	[65]
Larentiinae	*Eupithecia virgaureata*	Doubleday	1861	[21,23,34,65]
Larentiinae	*Eupithecia vulgata*	Haworth	1809	[21,23,34]
Larentiinae	*Eupithecia vulgata lepsaria*	Staudinger	1882	[37]
Larentiinae	*Eupithecis unedonata*	Mabille	1868	[33]
Larentiinae	*Eustroma reticulatum obsoleta*	Djakonov	1929	[48]
Larentiinae	*Gagitodes sagittata*	Fabricius	1787	[44,46,63]
Larentiinae	*Gagitodes sagittata albiflua*	Prout	1939	[48]
Larentiinae	*Horisme aemulata*	Hübner	1813	[23,34,46,65]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Larentiinae	*Horisme aquata*	Hübner	1813	[23,34,36,46,65,91]
Larentiinae	*Horisme falcata*	Bang-Haas	1907	[25,27,34,36,63,65]
Larentiinae	*Horisme incurvaria*	Erschoff	1877	[34,36,65]
Larentiinae	*Horisme lucillata*	Guenée	1858	[23,34]
Larentiinae	*Horisme parcata*	Püngeler	1909	[65]
Larentiinae	*Horisme scotosiata*	Guenée	1858	[21,23,34,63,65]
Larentiinae	*Horisme tersata*	Denis & Schiffermüller	1775	[34,65]
Larentiinae	*Horisme tersata tetricata*	Guenée	1858	[37]
Larentiinae	*Horisme vitalbata*	Denis & Schiffermüller	1775	[21,23,34,36,46,65]
Larentiinae	*Hydrelia flammeolaria*	Hufnagel	1767	[44,46]
Larentiinae	*Hydria cervinalis*	Scopoli	1763	[34]
Larentiinae	*Hydria undulata*	Linnaeus	1758	[34,65]
Larentiinae	*Hydriomena furcata*	Thunberg	1784	[21,23,34,36,44]
Larentiinae	*Hydriomena impluviata*	Denis & Schiffermüller	1775	[21,34,36]
Larentiinae	*Hydriomena impluviata djakonovi*	Beljaev & Vasilenko	2002	[48]
Larentiinae	*Hydriomena ruberata*	Freyer	1831	[65]
Larentiinae	*Juxtephria consentaria*	Freyer	1846	[36,44,65]
Larentiinae	*Kyrtolitha obstinata*	Staudinger	1892	[34]
Larentiinae	*Laciniodes denigrata abiens*	Prout	1938	[33]
Larentiinae	*Lampropteryx albigirata*	Kollar	1848	[65]
Larentiinae	*Lampropteryx jameza*	Butler	1898	[37]
Larentiinae	*Lampropteryx minna*	Butler	1881	[44,45,65]
Larentiinae	*Lampropteryx suffumata*	Denis & Schiffermüller	1775	[63]
Larentiinae	*Leptostegna tenerata*	Christoph	1881	[99]
Larentiinae	*Lithostege coassata mongolica*	Vojnits	1978	[42]
Larentiinae	*Lithostege coassata ochraceata*	Staudinger	1897	[42,65]
Larentiinae	*Lithostege mesoleucata*	Püngeler	1899	[34,42]
Larentiinae	*Lithostege pallescens*	Staudinger	1897	[21,34]
Larentiinae	*Lobophora halterata*	Hufnagel	1767	[44,46]
Larentiinae	*Martania taeniata*	Stephens	1831	[44]
Larentiinae	*Mesoleuca albicillata*	Linnaeus	1758	[34,37,44,46]
Larentiinae	*Mesotype verberata*	Scopoli	1763	[44]
Larentiinae	*Nebula lamata*	Staudinger	1897	[21,34]
Larentiinae	*Nebula mongoliata*	Staudinger	1897	[21,34,44,65]
Larentiinae	*Odezia atrata*	Linnaeus	1758	[23,34]
Larentiinae	*Orthonama obstipata*	Fabricius	1794	[34]
Larentiinae	*Pelurga comitata*	Linnaeus	1758	[34,44,63,65]
Larentiinae	*Pelurga taczanowskiaria*	Oberthür	1880	[63,91]
Larentiinae	*Perizoma alchemillata*	Linnaeus	1758	[34,36,44]
Larentiinae	*Perizoma bifaciata*	Haworth	1809	[65]
Larentiinae	*Perizoma blandiata*	Denis & Schiffermüller	1775	[23,34]
Larentiinae	*Perizoma hydrata*	Treitschke	1829	[36,44,65]
Larentiinae	*Perizoma minorata*	Treitschke	1828	[46]
Larentiinae	*Phibalapteryx virgata*	Hufnagel	1767	[34,36,42,91]
Larentiinae	*Photoscotosia palaearctica*	Staudinger	1882	[23,34]
Larentiinae	*Plemyria rubiginata*	Denis & Schiffermüller	1775	[34,44,65]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Larentiinae	*Plesioscotosia pulchrata*	Alphéraky	1883	[23,34]
Larentiinae	*Povilasia kashghara*	Moore	1878	[51]
Larentiinae	*Pseudentephria remmi*	Viidalepp	1976	[35]
Larentiinae	*Pseudobaptria corydalaria*	Graeser	1889	[34]
Larentiinae	*Rheumaptera hastata*	Linnaeus	1758	[34,36,44,46,65]
Larentiinae	*Rheumaptera subhastata*	Nolcken	1870	[36]
Larentiinae	*Rheumaptera subhastata commixta*	Matsumura	1925	[48]
Larentiinae	*Schistostege nubilaria*	Hübner	1799	[23,34,36,42,65]
Larentiinae	*Scotopteryx chenopodiata*	Linnaeus	1758	[23,34,46,63,65]
Larentiinae	*Scotopteryx chenopodiata sibirica*	Bang-Haas	1907	[42]
Larentiinae	*Scotopteryx golovushkini*	Kostjuk	1991	[65]
Larentiinae	*Scotopteryx sinensis*	Alphéraky	1883	[23,34]
Larentiinae	*Scotopteryx transbaicalica*	Djakonov	1955	[28,34,36]
Larentiinae	*Spargania luctuata*	Denis & Schiffermüller	1775	[23,34,44,63,65]
Larentiinae	*Stamnodes danilovi*	Erschoff	1877	[21,23,34,36,42,65]
Larentiinae	*Stamnodes danilovi djakonovi*	Alphéraky	1916	[33]
Larentiinae	*Stamnodes pauperaria*	Eversmann	1848	[65]
Larentiinae	*Thera obeliscata*	Hübner	1787	[34,91]
Larentiinae	*Thera variata*	Denis & Schiffermüller	1775	[23,34]
Larentiinae	*Trichopterigia consobrinaria*	Leech	1891	[44]
Larentiinae	*Trichopteryx carpinata*	Borkhausen	1794	[65]
Larentiinae	*Xanthorhoe abrasaria*	Herrich-Schäffer	1855	[36,44,65]
Larentiinae	*Xanthorhoe deflorata*	Erschoff	1877	[23,34,44,65]
Larentiinae	*Xanthorhoe montanata*	Denis & Schiffermüller	1775	[34,36,46]
Larentiinae	*Xanthorhoe quadrifasiata tannuensis*	Prout	1924	[45,63]
Larentiinae	*Xanthorhoe sajanaria*	Prout	1914	[36,44]
Larentiinae	*Xanthorhoe sajanaria djakonovi*	Vasilenko	1995	[100]
Larentiinae	*Xanthorhoe spadicearia*	Denis & Schiffermüller	1775	[44,46]
Larentiinae	*Xanthorhoe stupida aridela*	Prout	1937	[37]
Larentiinae	*Zola terranea*	Butler	1879	[34]
Sterrhinae	*Cleta jacutica (Axel Hausmann: probably only one Cleta species occurring in Mongolia)*	Viidalepp	1976	[36]
Sterrhinae	*Cleta perpusillaria*	Eversmann	1847	[65]
Sterrhinae	*Cyclophora albipunctata*	Hufnagel	1767	[46]
Sterrhinae	*Cyclophora pendularia*	Clerck	1759	[46]
Sterrhinae	*Glossotrophia rufotinctata*	Prout	1913	[49]
Sterrhinae	*Holarctias rufinaria*	Staudinger	1861	[58]
Sterrhinae	*Idaea aureolaria*	Denis & Schiffermüller	1775	[23,34,46]
Sterrhinae	*Idaea biselata extincta*	Staudinger	1897	[101]
Sterrhinae	*Idaea muricata*	Hufnagel	1967	[34]
Sterrhinae	*Idaea muricata minor*	Sterneck	1727	[40]
Sterrhinae	*Idaea nitidata*	Herrich-Schäffer	1861	[37]
Sterrhinae	*Idaea nudaria*	Christoph	1881	[37]
Sterrhinae	*Idaea pallidata*	Denis & Schiffermüller	1775	[34,40]
Sterrhinae	*Idaea rufaria*	Hübner	1799	[65]

Table A1. *Cont.*

Subfamily	Species	Author	Year	Reference
Sterrhinae	*Idaea rusticata*	Denis & Schiffermüller	1775	[40,63]
Sterrhinae	*Idaea serpentata*	Hufnagel	1767	[23,34,36,41,63]
Sterrhinae	*Idaea straminata*	Borkhausen	1794	[34,91]
Sterrhinae	*Idaea straminata sibirica*	Djakonov	1926	[40]
Sterrhinae	*Ochodontia adustaria*	Fischer de Waldheim	1840	[23,34,65]
Sterrhinae	*Rhodometra sacraria*	Linnaeus	1767	[34]
Sterrhinae	*Rhodostrophia jacularia*	Hübner	1813	[21,23,34,36,40,41,63,65]
Sterrhinae	*Rhodostrophia tyugui*	Vasilenko	1998	[64]
Sterrhinae	*Rhodostrophia ustyuzhanini*	Vasilenko	2006	[49]
Sterrhinae	*Rhodostrophia vibicaria*	Clerck	1759	[34,46,63]
Sterrhinae	*Scopula aequifasciata*	Christoph	1881	[47]
Sterrhinae	*Scopula albiceraria*	Herrich-Schäffer	1847	[21,25,34,65]
Sterrhinae	*Scopula albiceraria vitellinaria*	Eversmann	1851	[40,41]
Sterrhinae	*Scopula beckeraria*	Lederer	1853	[34,40,41,63,65]
Sterrhinae	*Scopula beckeraria amataria*	Wehrli	1927	[36,40,65]
Sterrhinae	*Scopula cajanderi*	Herz	1903	[41,46]
Sterrhinae	*Scopula caricaria*	Reutti	1853	[46]
Sterrhinae	*Scopula contramutata*	Prout	1920	[34]
Sterrhinae	*Scopula cumulata*	Alpheraky	1883	[65]
Sterrhinae	*Scopula decorata*	Denis & Schiffermüller	1775	[21,23,34,41,63,65]
Sterrhinae	*Scopula decorata przewalskii*	Viidalepp	1975	[36,40,65]
Sterrhinae	*Scopula dignata*	Guenée	1858	[34]
Sterrhinae	*Scopula floslactata*	Haworth	1809	[37]
Sterrhinae	*Scopula frigidaria*	Möschler	1860	[47]
Sterrhinae	*Scopula immorata*	Linnaeus	1758	[23,34,36,40,46,63,65]
Sterrhinae	*Scopula immutata contramutata*	Prout	1913	[58]
Sterrhinae	*Scopula impersonata*	Walker	1861	[34]
Sterrhinae	*Scopula impersonata macescens*	Butler	1879	[40,41]
Sterrhinae	*Scopula incanata*	Linnaeus	1758	[34,41,65]
Sterrhinae	*Scopula latelineata*	Graeser	1892	[49]
Sterrhinae	*Scopula marginepunctata*	Goeze	1781	[23,34,63]
Sterrhinae	*Scopula nigropunctata*	Hufnagel	1767	[34]
Sterrhinae	*Scopula nigropunctata subcandidata*	Walker	1863	[37]
Sterrhinae	*Scopula ornata*	Scopoli	1763	[34,41,46]
Sterrhinae	*Scopula permutata*	Staudinger	1897	[34,39,65]
Sterrhinae	*Scopula rubiginata*	Hufnagel	1767	[34,40,41,63,65,91]
Sterrhinae	*Scopula ternata*	Schrank	1802	[25,34,36,46]
Sterrhinae	*Scopula tessellaria*	Boisduval	1840	[65]
Sterrhinae	*Scopula umbelaria*	Hübner	1813	[34,46,63]
Sterrhinae	*Scopula umbelaria graeseri*	Prout	1935	[41,65]
Sterrhinae	*Scopula virgulata*	Denis & Schiffermüller	1775	[23,34,40,41,46,63,65,91]
Sterrhinae	*Scopula virgulata substrigaria*	Staudinger	1900	[36]
Sterrhinae	*Timandra griseata*	Petersen	1902	[46]
Sterrhinae	*Timandra paralias*	Prout	1935	[34,40]
Sterrhinae	*Timandra recompta*	Prout	1930	[40,63]

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