**Supporting Information**

**Disentangling how urbanisation influences moth diversity in grasslands**

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**Contents**

**Table S1** Moth species list……………………………………………….………………………………………………………..2

**Table S2** Full results of the path model on moth diversity…………………………………………..….………..5

**Table S3** Full results of the path model on moth diversity with two sites excluded………………..…..6

**Table S4** Full results of the path model on rarefied moth species richness…..….………………..………..7

**Table S5** Results of the post-hoc permutation test on NMDS axes scores…..….…………………………..8

**Figure S1** Correlation matrix…………………………………………..…………………………………………………..……..9

**Figure S2** Relations between moth species richness and diversity with abundance……………….10

**Figure S3** Species accumulation curves…………………………………………..………………………………………11

**Figure S4** Relations for specialist species richness and woody feeder species richness……..……12

**Figure S5** Path model on rarefied moth species richness…..….……………………..…………………………..13

**Supplementary material**

**Table S1.** Number of individuals of each moth species collected. Given are the number of individuals for sites in the city and surroundings (with the number of sites a species was found in parentheses). Nomenclature of species follows Steiner et al. (2014).

|  |  |  |
| --- | --- | --- |
| Species | City | Surroundings |
| *Abrostola triplasia* (Linnaeus, 1758) | - | 1 (1) |
| *Acontia lucida* (Hufnagel, 1766) | 1 (1) | - |
| *Acronicta megacephala* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Aedia funesta* (Esper, 1766) | 1 (1) | - |
| *Agrotis exclamationis* (Linnaeus, 1758) | 7 (6) | 8 (6) |
| *Agrotis puta* (Hübner, 1803) | 1 (1) | - |
| *Alcis repandata* (Linnaeus, 1758) | - | 2 (2) |
| *Amphipyra pyramidea* (Linnaeus, 1758) | 1 (1) | - |
| *Amphipyra tragopoginis* (Clerck, 1759) | 1 (1) | 1 (1) |
| *Anarta trifolii* (Hufnagel, 1766) | - | 3 (2) |
| *Apamea monoglypha* (Hufnagel, 1766) | 3 (3) | 5 (3) |
| *Apamea remissa* (Hübner, 1809) | - | 1 (1) |
| *Apamea scolopacina* (Esper, 1788) | - | 1 (1) |
| *Apoda limacodes* (Hufnagel, 1766) | - | 2 (2) |
| *Atolmis rubricollis* (Linnaeus, 1758) | 1 (1) | 3 (2) |
| *Autographa gamma* (Linnaeus, 1758) | 1 (1) | 1 (1) |
| *Axylia putris* (Linnaeus, 1761) | - | 9 (3) |
| *Biston betularia* (Linnaeus, 1758) | - | 1 (1) |
| *Cabera pusaria* (Linnaeus, 1758) | 1 (1) | 1 (1) |
| *Campaea margaritaria* (Linnaeus, 1761) | - | 3 (3) |
| *Caradrina clavipalpis* (Scopoli, 1763) | - | 1 (1) |
| *Caradrina morpheus* (Hufnagel, 1766) | - | 3 (3) |
| *Chiasmia clathrata* (Linnaeus, 1758) | 7 (3) | 16 (9) |
| *Chloantha hyperici* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Chloroclystis v-ata* (Haworth, 1809) | - | 1 (1) |
| *Cidaria fulvata* (Forster, 1771) | - | 1 (1) |
| *Colocasia coryli* (Linnaeus, 1758) | - | 1 (1) |
| *Cosmia affinis* (Linnaeus, 1767) | 1 (1) | - |
| *Cosmia trapezina* (Linnaeus, 1758) | 2 (1) | - |
| *Cossus cossus* (Linnaeus, 1793) | 1 (1) | - |
| *Crocallis elinguaria* (Linnaeus, 1758) | 1 (1) | 1 (1) |
| *Cybosia mesomella* (Linnaeus, 1758) | - | 1 (1) |
| *Cyclophora linearia* (Hübner, 1799) | - | 4 (3) |
| *Deilephila elpenor* (Linnaeus, 1758) | - | 1 (1) |
| *Deilephila porcellus* (Linnaeus, 1758) | - | 1 (1) |
| *Deltote bankiana* (Fabricius, 1775) | - | 2 (2) |
| *Deltote pygarga* (Hufnagel, 1766) | 1 (1) | 4 (4) |
| *Diachrysia chrysitis* (Linnaeus, 1758) / *D*. *stenochrysis* (Warren, 1913) | 2 (2) | - |
| *Drepana falcataria* (Linnaeus, 1758) | - | 1 (1) |
| *Drymonia obliterata* (Esper, 1785) | - | 2 (2) |
| *Drymonia querna* (Denis & Schiffermüller, 1775) | 5 (5) | 2 (2) |
| *Dypterygia scabriuscula* (Linnaeus, 1758) | 3 (3) | 2 (1) |
| *Dysstroma truncata* (Hufnagel, 1767) | - | 2 (1) |
| *Ecliptopera silaceata* (Denis & Schiffermüller, 1775) | - | 2 (2) |
| *Ectropis crepuscularia* (Denis & Schiffermüller, 1775) | 1 (1) | 3 (3) |
| *Eilema caniola* (Hübner, 1808) | 7 (5) | - |
| *Eilema complana* (Linnaeus, 1758) | 5 (2) | 5 (5) |
| *Eilema depressa* (Esper,1787) | - | 1 (1) |
| *Eilema lurideola* (Zincken, 1817) | 9 (5) | 72 (15) |
| *Eilema pygmaeola* (Doubleday, 1847) | - | 1 (1) |
| *Ennomos quercinaria* (Hufnagel, 1767) | - | 1 (1) |
| *Epione repandaria* (Hufnagel, 1767) | - | 1 (1) |
| *Epirrhoe alternata* (Müller, 1764) | 6 (4) | 2 (2) |
| *Eublemma minutata* (Fabricius, 1794) | 1 (1) | - |
| *Euchoeca nebulata* (Scopoli, 1763) | - | 7 (3) |
| *Eupithecia centaureata* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Eupithecia haworthiata* Doubleday, 1856 | - | 2 (1) |
| *Eupithecia inturbata* (Hübner, 1817) | 3 (2) | - |
| *Euxoa nigrofusca/tritici/eruta* complex | 5 (1) | 2 (2) |
| *Gandaritis pyraliata* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Gluphisia crenata* (Esper, 1785) | - | 1 (1) |
| *Habrosyne pyritoides* (Hufnagel, 1766) | - | 1 (1) |
| *Hadena perplexa* (Denis & Schiffermüller, 1775) | 1 (1) | - |
| *Herminia tarsipennalis* (Treitschke, 1835) | 1 (1) | - |
| *Hoplodrina blanda* (Denis & Schiffermüller, 1775) | - | 2 (1) |
| *Hoplodrina octogenaria* (Goeze, 1781) | 4 (3) | 14 (10) |
| *Hypena proboscidalis* (Linnaeus, 1758) | 1 (1) | - |
| *Hypomecis punctinalis* (Scopoli, 1763) | - | 3 (3) |
| *Hypomecis roboraria* (Denis & Schiffermüller, 1775) | - | 5 (3) |
| *Idaea aversata* (Linnaeus, 1758) | 5 (5) | 8 (6) |
| *Idaea biselata* (Hufnagel, 1767) | - | 1 (1) |
| *Idaea dimidiata* (Hufnagel, 1767) | 3 (3) | 2 (2) |
| *Idaea humiliata* (Hufnagel, 1767) | 3 (1) | 3 (1) |
| *Idaea ochrata* (Scopoli, 1763) | 7 (3) | - |
| *Idaea rusticata* (Denis & Schiffermüller, 1775) | 4 (3) | - |
| *Lacanobia oleracea* (Linnaeus, 1758) | 1 (1) | 2 (2) |
| *Laothoe populi* (Linnaeus, 1758) | 1 (1) | 1 (1) |
| *Laspeyria flexula* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Ligdia adustata* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Lithosia quadra* (Linnaeus, 1758) | - | 6 (2) |
| *Lomaspilis marginata* (Linnaeus, 1758) | - | 3 (3) |
| *Lomographa temerata* (Denis & Schiffermüller, 1775) | - | 1 (1) |
| *Macaria alternata* (Denis & Schiffermüller, 1775) | - | 4 (2) |
| *Malacosoma neustria* (Linnaeus, 1758) | - | 1 (1) |
| *Mamestra brassicae* (Linnaeus, 1758) | - | 1 (1) |
| *Mesapamea secalella* Remm, 1983 | - | 1 (1) |
| *Mesapamea secalis* (Linnaeus, 1758) | - | 1 (1) |
| *Mesoligia furuncula* (Denis & Schiffermüller, 1775) | 1 (1) | 2 (2) |
| *Mimas tiliae* (Linnaeus, 1758) | - | 1 (1) |
| *Mythimna impura* (Hübner, 1808) | - | 9 (5) |
| *Mythimna pallens* (Linnaeus, 1758) | - | 4 (3) |
| *Mythimna pudorina* (Denis & Schiffermüller, 1775) | - | 11 (5) |
| *Noctua comes* Hübner, 1813 | 1 (1) | 1 (1) |
| *Noctua fimbriata* (Schreber, 1759) | 1 (1) | 3 (3) |
| *Noctua janthe/janthina/tertia* complex | 3 (3) | 4 (3) |
| *Noctua pronuba* (Linnaeus, 1758) | 1 (1) | 3 (3) |
| *Ochropleura plecta* (Linnaeus, 1761) | - | 2 (1) |
| *Oligia latruncula* (Denis & Schiffermüller, 1775) | 3 (2) | 1 (1) |
| *Oligia strigilis* (Linnaeus, 1758) | - | 3 (3) |
| *Oligia versicolor* (Borkhausen, 1792) | - | 1 (1) |
| *Paracolax tristalis* (Fabricius, 1794) | 2 (2) | 3 (3) |
| *Pasiphila rectangulata* (Linnaeus, 1758) | - | 1 (1) |
| *Peribatodes rhomboidaria* (Denis & Schiffermüller, 1775) | 3 (2) | 3 (2) |
| *Phalera bucephala* (Linnaeus, 1758) | 1 (1) | 10 (7) |
| *Philereme transversata* (Hufnagel, 1767) | - | 1 (1) |
| *Photedes extrema* (Hübner, 1809) | - | 4 (2) |
| *Photedes fluxa* (Hübner, 1809) | - | 1 (1) |
| *Phragmatobia fuliginosa* (Linnaeus, 1758) | 1 (1) | 11 (8) |
| *Polyphaenis sericata* (Esper, 1787) | 5 (4) | - |
| *Pseudoips prasinana* (Linnaeus, 1758) | 1 (1) | 1 (1) |
| *Scopula nigropunctata* (Hufnagel, 1767) | - | 1 (1) |
| *Scopula rubiginata* (Hufnagel, 1767) | 1 (1) | - |
| *Selenia dentaria* (Fabricius, 1775) | 1 (1) | - |
| *Sideridis reticulata* (Goeze, 1781) | 1 (1) | - |
| *Smerinthus ocellata* (Linnaeus, 1758) | 1 (1) | 1 (1) |
| *Spatalia argentina* (Denis & Schiffermüller, 1775) | - | 2 (2) |
| *Sphinx ligustri* Linnaeus, 1758 | 1 (1) | - |
| *Sphinx pinastri* Linnaeus, 1758 | - | 2 (1) |
| *Thalera fimbrialis* (Scopoli, 1763) | - | 3 (1) |
| *Thumatha senex* (Hübner, 1808) | - | 1 (1) |
| *Timandra comae* Schmidt, 1931 | 1 (1) | 3 (3) |
| *Trachea atriplicis* (Linnaeus, 1758) | - | 2 (2) |
| *Watsonalla binaria* (Hufnagel, 1767) | - | 1 (1) |
| *Watsonalla cultraria* (Fabricius, 1775) | - | 1 (1) |
| *Xanthorhoe ferrugata* (Clerck, 1759) | - | 1 (1) |
| *Xestia c-nigrum* (Linnaeus, 1758) | 4 (3) | 14 (8) |
| *Xestia triangulum* (Hufnagel, 1766) | 2 (2) | 8 (6) |

**Table S2.** Full results of the path model (Fisher’s C=2.057, p=0.914) with moth diversity as terminal endogenous variable (Figure 3). Estimates give standardized path coefficients ± SE. Significant paths are shown in bold. Marginal (R²m, fixed effects) and conditional (R²c, fixed and random effects) variances are also given.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Response | Predictor | Estimate ± SE | Critical value | p-value |
| *Causal path* |  |  |  |  |
| Moth diversity | ~ Urbanisation | -0.298 ± 0.173 | 2.463 | 0.126 |
| Moth diversity | ~ Mowing intensity | -0.021 ± 0.100 | 0.042 | 0.838 |
| Moth diversity | ~ Sky brightness | -0.005 ± 0.150 | 0.001 | 0.978 |
| Moth diversity | ~ Habitat area | -0.072 ± 0.101 | 0.479 | 0.494 |
| **Moth diversity** | **~ Moth abundance** | **0.670 ± 0.009** | **29.835** | **<0.001** |
| Moth abundance | ~ Urbanisation | -0.218 ± 0.166 | -1.309 | 0.191 |
| **Moth abundance** | **~ Mowing intensity** | **-0.278 ± 0.099** | **-2.812** | **0.005** |
| Moth abundance | ~ Sky brightness | -0.044 ± 0.146 | -0.301 | 0.764 |
| **Moth abundance** | **~ Habitat area** | **0.256 ± 0.086** | **2.982** | **0.003** |
| **Mowing intensity** | **~ Urbanisation** | **0.562 ± 0.134** | **13.113** | **0.005** |
| **Sky brightness** | **~ Urbanisation** | **0.774 ± 0.110** | **41.250** | **<0.001** |
| **Habitat area** | **~ Urbanisation** | **-0.453 ± 0.149** | **6.960** | **0.023** |
|  |  |  |  |  |
| *Explained variance* |  |  |  |  |
| Moth diversity | R²m = 0.703 | R²c = 0.751 |  |  |
| Moth abundance | R²m = 0.527 | R²c = 0.699 |  |  |
| Mowing intensity | R²m = 0.310 | R²c = 0.310 |  |  |
| Sky brightness | R²m = 0.620 | R²c = 0.723 |  |  |
| Habitat area | R²m = 0.201 | R²c = 0.219 |  |  |

**Table S3.** Full results of the path model (Fisher’s C=2.551, p=0.863) with moth diversity as terminal endogenous variable in which the two sites where the trap was placed on the ground have been excluded. Estimates give standardized path coefficients ± SE. Significant paths are shown in bold. Marginal (R²m, fixed effects) and conditional (R²c, fixed and random effects) variances are also given. Results are qualitatively and quantitatively very similar to the model (Table S2; Figure 3) with the full data, indicating that a bias by those two sites is unlikely.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Response | Predictor | Estimate ± SE | Critical value | p-value |
| *Causal path* |  |  |  |  |
| Moth diversity | ~ Urbanisation | -0.297 ± 0.179 | 2.420 | 0.130 |
| Moth diversity | ~ Mowing intensity | -0.019 ± 0.104 | 0.033 | 0.856 |
| Moth diversity | ~ Sky brightness | 0.001 ± 0.155 | 0.001 | 0.994 |
| Moth diversity | ~ Habitat area | -0.077 ± 0.116 | 0.542 | 0.468 |
| **Moth diversity** | **~ Moth abundance** | **0.670 ± 0.010** | **27.291** | **<0.001** |
| Moth abundance | ~ Urbanisation | -0.221 ± 0.168 | -1.315 | 0.189 |
| **Moth abundance** | **~ Mowing intensity** | **-0.277 ± 0.100** | **-2.760** | **0.006** |
| Moth abundance | ~ Sky brightness | -0.046 ± 0.148 | -0.308 | 0.758 |
| **Moth abundance** | **~ Habitat area** | **0.287 ± 0.096** | **2.992** | **0.003** |
| **Mowing intensity** | **~ Urbanisation** | **0.546 ± 0.140** | **11.285** | **0.546** |
| **Sky brightness** | **~ Urbanisation** | **0.765 ± 0.115** | **36.552** | **<0.001** |
| **Habitat area** | **~ Urbanisation** | **-0.405 ± 0.142** | **4.994** | **0.048** |
|  |  |  |  |  |
| *Explained variance* |  |  |  |  |
| Moth diversity | R²m = 0.692 | R²c = 0.751 |  |  |
| Moth abundance | R²m = 0.562 | R²c = 0.692 |  |  |
| Mowing intensity | R²m = 0.293 | R²c = 0.293 |  |  |
| Sky brightness | R²m = 0.601 | R²c = 0.715 |  |  |
| Habitat area | R²m = 0.161 | R²c = 0.175 |  |  |

**Table S4.** Full results of the path model (Fisher’s C=2.057, p=0.914) with rarefied moth species richness as terminal endogenous variable (Figure S5). Estimates give standardized path coefficients ± SE. Significant paths are shown in bold. Marginal (R²m, fixed effects) and conditional (R²c, fixed and random effects) variances are also given.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Response | Predictor | Estimate ± SE | Critical value | p-value |
| *Causal path* |  |  |  |  |
| Rarefied moth richness | ~ Urbanisation | -0.373 ± 0.283 | 1.2679 | 0.274 |
| Rarefied moth richness | ~ Mowing intensity | -0.088 ± 0.177 | 0.238 | 0.629 |
| Rarefied moth richness | ~ Sky brightness | -0.012 ± 0.245 | 0.238 | 0.629 |
| Rarefied moth richness | ~ Habitat area | 0.142 ± 0.164 | 0.647 | 0.427 |
| **Mowing intensity** | **~ Urbanisation** | **0.562 ± 0.134** | **13.113** | **0.005** |
| **Sky brightness** | **~ Urbanisation** | **0.774 ± 0.110** | **41.250** | **<0.001** |
| **Habitat area** | **~ Urbanisation** | **-0.453 ± 0.149** | **6.960** | **0.023** |
|  |  |  |  |  |
| *Explained variance* |  |  |  |  |
| Rarefied moth richness | R²m = 0.245 | R²c = 0.245 |  |  |
| Mowing intensity | R²m = 0.310 | R²c = 0.310 |  |  |
| Sky brightness | R²m = 0.620 | R²c = 0.723 |  |  |
| Habitat area | R²m = 0.201 | R²c = 0.219 |  |  |

**Table S5.** Results of the post-hoc permutation test (n=10,000 permutations) relating the scores of the first two NMDS axes to environmental variables (ordered by decreasing R²). Significant (at p<0.05) variables are in bold.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | NMDS1 | NMDS2 | p-value | R² |
| **Urbanisation** | **-0.985** | **-0.174** | **0.002** | **0.274** |
| **Sky brightness** | **-0.970** | **-0.245** | **0.003** | **0.264** |
| Julian day | -0.999 | -0.022 | 0.052 | 0.147 |
| Plant species richness | 0.502 | -0.865 | 0.371 | 0.051 |
| Habitat area | 0.863 | 0.505 | 0.494 | 0.037 |
| Mowing intensity | -0.941 | 0.338 | 0.660 | 0.023 |
| Habitat isolation | -0.026 | -0.999 | 0.700 | 0.020 |



**Figure S1.** Correlations (Spearman’s ρ) among all environmental and response variables.



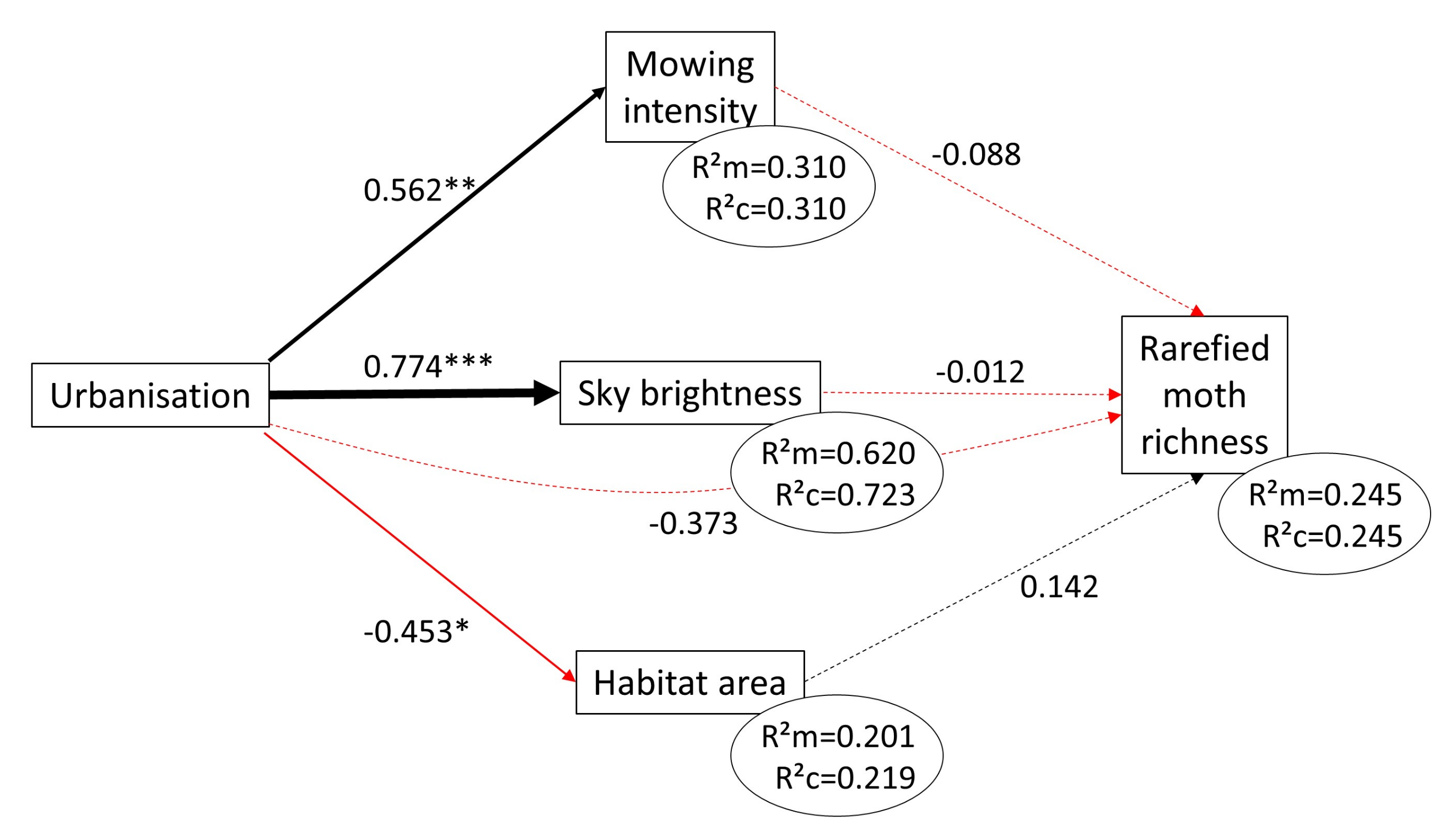
**Figure S2.** The a) species richness and b) diversity (e^H) of moths was strongly related to their abundance (Spearman’s ρ=0.947 and 0.889, respectively). Note that all axes are on a log-scale.



**Figure S3.** Sample-based species accumulation curves (based on n=10,000 permutations, shaded polygons indicate 95% CI) for all sites and separated for city and surrounding. The expected number of species (jackknife 1 estimator, all sites: 187, city: 91, surrounding: 160) is each indicated by horizontal lines. Total sampling efficiency was comparable each (all sites: 68%, city: 64%, surrounding: 66%).



**Figure S4**. Specialist species richness decreased a) with higher urbanisation while b) woody feeder species richness increased with larger habitat area. Regression lines (95% CI as shaded polygons) indicate the predictions of averaged (generalized) linear mixed-effects models. Full statistical parameters are available in Table 2. Note that the x-axis in b) and all y-axes are on a log-scale.



**Figure S5.** Path model (Fisher’s C=2.057, p=0.914) illustrating that urbanisation did not directly influence rarefied moth species richness once the simultaneous relationships with environmental variables related to urbanisation was considered. Numbers next to arrows give the standardized path coefficients (\*\*\*p<0.001, \*\*p<0.010, \*p<0.050). Arrow width scales with the strength of association, black arrows indicate positive relationships, red arrows negative relationships, with non-significant relationships indicated by dashed arrows. Values below endogenous variables are the explained marginal (R²m, fixed effects) and conditional (R²c, fixed and random effects) variances. Full statistical parameters are given in Table S3.