SAVE ALL SPECIES – MOTHS LIGHT A WAY?

BY
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Abstract -- What would it take to save all species from extinction? A new initiative, *Save all species*, plans to answer this question and provide the tools we need to do so by 2050. Here we consider the merits and problems associated with inventorying moths to help decide which terrestrial areas to protect. We compare the scientifically-described moth fauna of the British Isles which, with 2,441 species, is taxonomically complete, with 11,806 described species from North America north of Mexico, the fauna of which is not fully described. As a percentage of the described moth fauna, there are fewer "*macro"* moths (Geometroidea, Drepanoidea, Noctuoidea, Bombycoidea, Lasiocampidae) in the British Isles (34.9%) than those known for the United States and Canada (46.1%). We present data on 1,254 species for an intensively-studied site in Clarke County, Georgia and consider whether species in the British Isles are generally smaller than ones in Georgia. We recommend using a protocol that photographs all specimens attracted to lights, as an efficient means to inventory most moth species, including small ones that are often undersampled. Much work still needs to be done on sampling methodology and across-site comparisons of moths and their host plant communities, before we might use moth inventories as an efficient means to compare floral diversity across areas.

Introduction -- Inspired by the recent book, *Half-Earth --- Our Planet's Fight for Life*, in which E.O. Wilson (2016) calls for half the planet to be devoted to preserving nature, Discover Life has started *Save all species* (see discoverlife.org/saveallspecies). This initiative is developing a 30-year plan. Its goal is to ensure that by 2050, the world has the scientific knowledge, environmental policies, protected areas, trained resource managers, technology, funding, and public support to protect them. Because the task of inventorying the world's biodiversity is huge and would take centuries at the current rate of study, the initiative plans to inventory only a dozen representative taxa that will enable us to speed the selection of enough potential parks and protected areas to save all species, including rare and locally-restricted endemics. Candidate taxa include amphibians, ants, bees, birds, bivalves, corals, fish, macro fungi, moths, and vascular plants. Here we consider moths.

Moths are an almost ideal candidate taxon for a global inventory because of several attributes. Most species are attracted to lights, and hence, are easily sampled by non-experts. They are safe. Unlike rabid bats, venomous snakes, and stinging insects, they pose no health risk. Moths are an exceedingly species-rich group, for which the diversity at a terrestrial site will typically exceed any other taxon except for beetles. Because moth larvae are restricted in their diet to specific host taxa, differences in the assemblages of resident moth species could reflect differences across sites in plants and other hosts. If that's true, we may be able to use moth inventories as efficient proxies to compare surrounding plant communities.

Inventorying moths presents challenges, notably, sampling smaller species, describing thousands of species new to science, and identifying specimens accurately. Our experience is that we can identify 99% of moths from digital images to species, species-groups, which contain species of similar appearance, or morphospecies, in the case of undescribed species. Thus, digital photography now empowers non-experts to inventory and monitor sites with verifiable data on their sightings. Online identification tools and human experts can then help in specimen identification via the Internet.

This is the fifth article in the SLN that concerns Discover Life's *Mothing* project, which since 2010 has taken over 625,000 photographs to inventory 3,000 species at 25 sites in North America and Costa Rica (see discoverlife.org/moth). Pickering (2015) gives an overview of the project and invites SLS members to join. Pickering (2016) considers factors that affect seasonal flight activity. Pickering and Staples (2016) describe how to inventory moths efficiently by sampling around new moons. And Pickering et al. (2016) compare moth diversity and taxonomy between Africa and North America north of Mexico. Here we extend our analysis to include data from the British Isles and focus on differences across samples in the percentage of "*macro"* moths (Geometroidea, Drepanoidea, Noctuoidea, Bombycoidea, Lasiocampidae) to "*other"* moths (notably the species-rich Pyraloidea, Tortricidae, Gelechioidea, and Gracillarioidea). [Note that this definition of *macro* moths differs from the one used in Britain, which also includes Cossoidea and some other large moths.]

Along with other parts of Europe, the biota of the British Isles is amongst the best studied in the world. Its Lepidoptera are scientifically described and there is a wealth of data documenting the distribution, phenology, food plants, and abundance of most species, in part because of considerable contributions from amateur naturalists. Highlights from these include an online checklist to 2,441 moths and 83 butterflies by Agassiz et al. (2015) and Butterfly Conservation's *Moths Count* (www.mothscount.org) which runs a national moth recording scheme to collect data on over 900 of the larger species. Through partnerships, including with the Garden Moth Schema (www.gardenmoths.org.uk), which now monitors approximately 200 species with weekly trapping through the flight season at 350 sites, *Moths Count* has assembled over 20 million current and historical sightings since its launch in 2007. With Rothamsted Research (www.rothamsted.ac.uk), which has coordinated a national network of light-traps at a total of over 430 sites since 1968, they produced *The State of Britain's Larger Moths* (Butterfly Conservation and Rothamsted Research, 2013), that documents the decline in many common and widespread species, the possible causes of which include habitat loss and are reviewed by Fox (2013). In addition, the British Isles has a slew of websites rich in information on their Lepidoptera. These include UK moths (www.uk moths.org.uk), UK Butterflies (www.ukbutterflies.co.uk), UK Lepidoptera (www.ukleps.co.uk), Moths Ireland (www.mothsireland.com), and regional websites, such as for Berkshire (sites.google.com/site/berks moths), Devon (devonmoths.org.uk), Essex (www.essexfieldclub.org.uk), Gloucestershire (www.gloucestershire-butterflies.org.uk), Hampshire (http://www.hantsmoths.org.uk), Huntingdonshire (http://www.hmbg.org), Lancashire (www.lancashire moths.co.uk), Norfolk (www.norfolkmoths.co.uk), Northamptonshire (www.northamptonshirewildlife.co.uk), Northumberland (www.northumberland moths.org.uk), and Suffolk (www.suffolkmoth group.org.uk), and speciality websites, such as sites on leaf mines (www.ukflymines.co.uk) and genitalia (mothballs?) (mothdissection.co.uk).

Here we compare the moth faunas of the British Isles and North America north of Mexico. Our goal is to examine how best to inventory moths *per se*, as a methodology, rather than to understand fundamental biological differences across the faunas presented. Thus, we leave a discussion of Bergmann's rule and its converse, which concern the size of specimens as a function of latitude (Chown and Gaston, 2010; Kivela et. al, 2011), to a future paper in which we will include measurements of wing lengths.

Our primary concern is to contend with the taxonomic and sampling biases that favor the better documentation of larger species over smaller ones. We do this by including a comparison of higher taxa within regional checklists for Gloucestershire and Northumberland within England, for Georgia and North Carolina within the United States, and for Discover Life's intensively-studied Blue Heron site in Clarke County, Georgia.

Methods & Results

British Isles

Table 1 summarizes the moth fauna by higher taxa for the British Isles (in pink) and North America north of Mexico (in green). It follows the phylogeny listed at discoverlife.org/moth/highertaxa.txt which is based on the Lepidoptera of the Tree of Life web project (tolweb.org), as per pickering et al. (2016). It gives the total

Table 1	British Isles	%	Gloucestershire	%	Northumberland	%	Glouc. & Northum.	%	North America	%	Georgia	%	North Carolina	%	Georgia & NC	%	Blue Heron	%
Total	**2,441**		**1,590**		**1,297**		**1,131**		**11,806**		**2,783**		**2,755**		**2,266**		**1,254**	
MACRO MOTHS	853	**34.9**	584	**36.7**	522	**40.2**	469	**41.5**	5,448	**46.1**	1,417	**50.9**	1,399	**50.8**	1,239	**54.7**	577	**46.0**
Geometroidea	307	12.6	235	14.8	203	15.7	188	16.6	1,448	12.3	317	11.4	325	11.8	279	12.3	132	10.5
Noctuoidea	498	20.4	309	19.4	285	22.0	249	22.0	3,718	31.5	1,001	36.0	987	35.8	876	38.7	403	32.1
Arctiinae	32	1.3	20	1.3	12	0.9	12	1.1	298	2.5	72	2.6	76	2.8	62	2.7	27	2.2
Bombycoidea	20	0.8	17	1.1	15	1.2	13	1.1	225	1.9	83	3.0	71	2.6	70	3.1	30	2.4
Saturniidae	1	0.0	1	0.1	1	0.1	1	0.1	87	0.7	23	0.8	20	0.7	20	0.9	11	0.9
Sphingidae	18	0.7	16	1.0	14	1.1	12	1.1	133	1.1	57	2.0	49	1.8	48	2.1	17	1.4
Lasiocampidae	12	0.5	8	0.5	6	0.5	6	0.5	36	0.3	9	0.3	9	0.3	8	0.4	7	0.6
OTHER MOTHS	1,588	**65.1**	1,006	**63.3**	775	**59.8**	662	**58.5**	6,358	**53.9**	1,366	**49.1**	1,356	**49.2**	1,027	**45.3**	677	**54.0**
Pyraloidea	199	8.2	113	7.1	96	7.4	84	7.4	1,538	13.0	425	15.3	408	14.8	335	14.8	214	17.1
Tortricidae	383	15.7	264	16.6	216	16.7	184	16.3	1,319	11.2	295	10.6	360	13.1	227	10.0	178	14.2
Zygaenoidea	12	0.5	5	0.3	2	0.2	2	0.2	101	0.9	42	1.5	33	1.2	33	1.5	27	2.2
Pterophoridae	46	1.9	23	1.4	16	1.2	13	1.1	161	1.4	34	1.2	28	1.0	23	1.0	8	0.6
Sesioidea	16	0.7	10	0.6	2	0.2	2	0.2	130	1.1	47	1.7	42	1.5	40	1.8	4	0.3
Cossoidea	3	0.1	2	0.1	1	0.1	1	0.1	48	0.4	6	0.2	6	0.2	6	0.3	5	0.4
Gelechioidea	468	19.2	254	16.0	184	14.2	147	13.0	1,808	15.3	306	11.0	239	8.7	201	8.9	130	10.4
Yponomeutoidea	102	4.2	73	4.6	70	5.4	59	5.2	241	2.0	29	1.0	31	1.1	21	0.9	12	1.0
Gracillarioidea	111	4.5	87	5.5	69	5.3	63	5.6	413	3.5	50	1.8	82	3.0	39	1.7	26	2.1
Tineoidea	70	2.9	35	2.2	23	1.8	16	1.4	218	1.8	75	2.7	65	2.4	60	2.6	55	4.4
Nepticulidae	100	4.1	75	4.7	52	4.0	47	4.2	96	0.8	15	0.5	19	0.7	12	0.5	3	0.2

Table 1. British and North American moth species tabulated by higher taxa.

numbers for each location at the top in bold and the percentage of this total for each taxon to the right. It puts in bold the percentage for the subtotals of *macro* and *other* moths. Thus, there are 2,441 species for the British Isles of which 34.9% are *macro* moths. We extracted these species from Agassiz et al. (2015) and tabulated them, excluding 83 butterflies. Except for some accidentals and other exceptions, this checklist includes all the Lepidoptera in the British Isles.

North America north of Mexico

Table 1 presents a total of 11,806 moths for North America, of which 46.1% are *macro* moths. These species are in Discover Life's identification guide and checklist of North America north of Mexico (Pickering, 2010). This list excludes the names of unpublished morphospecies and for which Discover Life's database did not include an occurrence record on the continent north of Mexico. Pickering (2015) and Pickering et al. (2016) give details on how we assembled these names and attempt to keep them current.

Taxonomic descriptions by year

Figure 1 graphs the species in these two columns as a function of the year when taxonomists described them, starting with Linnaeus in 1758. It presents the accumulative number of *macro* and *other* moths for the British Isles (labelled UK) and the curves for Geometroidea, Noctuoidea, Bombycoidea, and *other* moths for North America (labelled NA). By 1860, the British fauna was effectively described. In contrast, species in North America are still being described. Pickering et al. (2016) presents curves for additional North American higher taxa, comparing them to accumulative curves for African regions.

It is unclear whether the moth fauna of the British Isles has generally smaller moths than North America, as the respective values of 34.9% to 46.1% *macro* moths in Table 1 might suggest, or whether the value of 46.1% for North America is inflated because of a tendency by taxonomists to describe large species before small ones, as Figure 1 might suggest.

Gloucestershire versus Northumberland

To show the potential bias in inventorying *macro* versus *other* moths, which are generally smaller, we tabulated the moths of Gloucestershire (1,590 species, 36.7% *macro* moths) and Northumberland (1,297 species, 40.2%). These species are those in Agassiz et al. (2015) and listed on the respective county websites given above. Both of these counties have a higher percentage of *macro* moths in their checklists than the 34.9% value for the entire British Isles. Furthermore, we tabulated the species listed for both counties and present them in the column labelled 'Glouc. & Northumb.', which has a total of 1,311 overlapping species, of which an even higher percentage (41.5%) are *macro* moths. We could interpret these results as indicative of the counties over sampling *macro* species relative to smaller *other* moths. Alternatively, smaller moths may have more restricted distributions than *macros* and are simply not sampled because they are not at sampling sites.

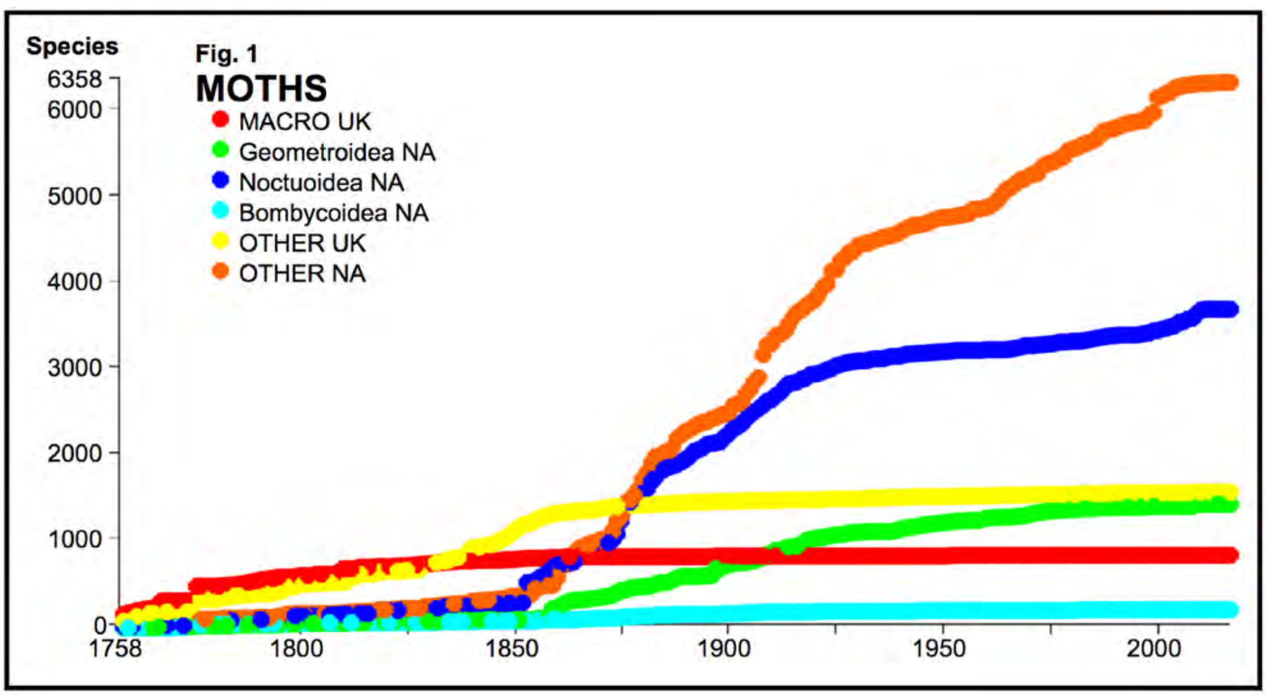

Fig. 1. Accumulation of species by year of scientific description for moths of the British Isles (UK) and North America north of Mexico (NA). MACRO are species in Geometroidea, Drepanoidea, Noctuoidea, Bombycoidea and Lasiocampidae. OTHER are those in all other Lepidoptera taxa excluding butterflies.

U.S. states

Using Discover Life's state checklists, which are compiled from numerous sources, including Moth Photographers' Group (mothphotographersgroup.ms state.edu), we tabulated the number of described species and percentage *macro* moths for 23 selected states with the following results: Alabama (1,432, 47.7%), Arizona (855, 55.0%), California (4,217, 50.3%), Colorado (1,722, 70.0%), Florida (2,809, 45.1%), Georgia (2,783, 50.9%), Illinois (2,032, 43.0%), Louisiana (1,474, 67.9%), Maryland (2,286, 50.3%), Massachusetts (1,714, 61%), Michigan (2,021, 56.5%), Mississippi (1,256, 37.8%), New York (1,468, 61.4%), North Carolina (2,755, 50.8%), Ohio (2,468, 46.8%), Oregon (1,097, 76.1%), Pennsylvania (2,122, 52,2%), South Carolina (1,962, 52.4%), Tennessee (2,300, 50.3%), Texas (2,799, 57.9%), Virginia (918, 58.7%), Washington (1,392, 63.6%) and Wisconsin (1,543, 67.6%). Only three of these states, Florida, Illinois and Mississippi, have a lower percentage of *macros* than the value of 46.1% for North America as a whole. Again, these data suggest that either macro moths are more likely to be included in a checklist, that smaller moths are more regional, or possibly both. As a caution we note that these checklists are incomplete. Alabama is grossly undersampled, for example. Its current checklist has about half the species of neighboring Georgia.

Georgia versus North Carolina

To compare two U.S. states in a similar way as for the two English counties, Table 1 shows the checklists for Georgia and North Carolina by higher taxa. It also presents the 2,266 species (54.7% *macro* moths) that are recorded from both Georgia and North Carolina (labelled 'Georgia & NC'). These results are similar to the English ones. For whatever reason, there are a higher percentage of *macro* moths in these state checklists and more so in the species that are reported as in both.

We note that the British Isles (315,160 sq. km) are a bit more than twice the size of Georgia (153,910 sq. km) and North Carolina (139,390 sq. km). Gloucestershire (3,149 sq. km) is 10 times, and Northumberland (5,014 sq. km) 16 times the area of Clarke County (313 sq. km), the smallest county in Georgia. We forego bragging here about how moth diversity and favorable climate may be linked.

Blue Heron

The final column in Table 1, labelled 'Blue Heron', lists the higher taxa of 1,254 moth species (46% *macro* moths) that we photographed at Discover Life's intensively-studied site in Clarke County, Georgia (latitude 33.8882°N, longitude 83.2973°W), during nightly sampling over five years, 2011-2015. Pickering (2015, 2016) and Pickering and Staples (2016) provide details on the site and our methodology. The Blue Heron values in Table 1 include 91 morphospecies, one *macro* moth, an undescribed *Papaipema* (Noctuidae, *sp_new_species_3*) and 90 *other* morphospecies as follows: Acrolophidae (4), Blastobasidae (4), Bucculatricidae (1), Coleophoridae (1), Cosmopterigidae (2), Crambidae (2), Gelechiidae (21), Gracillariidae (6), Lyonetiidae (1), Micropterigidae (1), Nepticulidae (2), Oecophoridae (1), Opostegidae (1), Pyralidae (9), Symmocidae (2), Tineidae (7), Tischeriidae (1), Tortricidae (24). These morphospecies are ones that we cannot identify to a described species and may be new to science. For databasing and analysis we name each morphospecies with a binomial that includes the string '*sp_*'. Detailed information on all species with specimen photographs, abundance, and seasonal phenology is online. For the Blue Heron species in Table 1 see www.discoverlife.org/moth/data/table 2_33.9_-83.3.html.

Since inception in 2010, Discover Life's team has taken 216,000 photographs at the Blue Heron site and identified 162,400 of its Lepidoptera into 1,293 species, species-groups, and morphospecies. Table 1 only tabulates those photographed for 2011-2015. Our sampling for 2010 and identification for 2016 are incomplete. The Blue Heron site provides the most complete moth dataset for North America of which we are aware. Because we attempted to photograph all moths, both *macro* and *other*, every night over the five years, and have identified over 99% of the specimens to species, there is reduced bias in favor of *macro* moths compared with most studies that use light-traps.

If we assume that there is no bias in favor of sampling *macro* versus *other* species in the Blue Heron data, then we can assert that the size of moth species at the site are larger on average than those in the fauna of the British Isles, based on the respective 46.0% to 34.9% *macro* moth values. Such an assertion would be the converse of Bergmann's rule. However, because the data from Blue Heron are only based on specimens attracted to lights and not on reared material and other collecting methods used in the description of the British fauna, we caution about using the data in that way. Clearly, it would be far better to use the same methods to compare across faunas.

Temporal bias favors sampling *macro* moths

A further complication that may favor the sampling of *macro* moths concerns flight activity based on size. At the Blue Heron site, we found that *macro* moths were present more nights than *other* species. Of all 1,254 species recorded in 2011-2015, 46.0% are *macro* moths. This percentage increases to 46.4% when we exclude the 171 species recorded on a single night and to 48.3% when we also exclude the 95 species recorded on only two nights. When we exclude species present for under 9 nights, it is 51.1%; under 17, 54.1%; under 33, 57.3%, and under 65, 62.8%. The percentage is 80.0% when only the five species sampled on the most nights remain, a crambid, *Microcrambus elegans*, and four geometrids. Multiple factors may explain this trend in the data, including the possibilities that (1) smaller species may be more likely to be vagrants that are rarely sampled, (2) smaller species may have shorter seasonal flight periods, (3) smaller species may be more thermally challenged and not fly on colder nights, and (4) smaller moths may not respond to lights as much or from as far as larger species.

Discussion

One of our goals is to understand the many factors that influence the sampling of moth species at lights. How do the different methods that we use affect our understanding of moth diversity, abundance, and phenology over time and across distance? Clearly, as suggested by the percentage of *macro* to *other* moths in the data presented, size is a key factor that we should consider. Much current information on the occurrence of smaller species is biased for a number of reasons. Relative to *macro* moths, smaller species are under-described by taxonomists, they are under-sampled by most research protocols, and they are harder to identify, in part, because the tools and expertise to do so is lagging behind what is available for *macro* moths. As a consequence, they are underrepresented in databases and checklists.

The biology and natural history of smaller moths may be such that their flight activity is more restricted in both time and space. If smaller species are more restricted to particular host plants, or if they fly shorter distances to lights, then they may better reflect local host plant communities than *macro* moths. They may be the species that we need to study to better document and understand local differences in biodiversity. Hopefully, with the help of better resources, such as the *Field Guide to Micro Moths of Great Britain and Ireland* (Sterling and Parsons, 2012), naturalists will be inspired to work more with them and answer the questions posed.

For the purposes of *Save all species,* Discover Life plans to expand its *Mothing* project and improve how we inventory moths around the world. At the last SLS meeting in October and since, we have recruited five individuals to help us. This paper was inspired by Julie Doherty, who works at the Avon Wildlife Trust in England. She will help us integrate our efforts with British naturalists and their research and conservation projects. Vijay Barve and Joe Martinez at the University of Florida will help us with Indian and Mexican moths, respectively. Ron Parry has contributed photographs of 330 species from sites in New Mexico and Texas. And, Frank DiStephano has uploaded 7,700 images of moths in Pennsylvania and Costa Rica. We invite others to join us too.

Conclusions

To keep it fun, we end with a poem.

On moth lights

Ask away,
a way?
Let's
answer
a way
or
away
before
we say
aweigh.

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