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A study of the spatio-temporal distribution changes of the Korean Hawk Moth (Lepidoptera: Sphingidae)

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Abstract

This study was conducted in an effort to identify the fluctuation of species according to space and time by collecting information on samples of Korean Sphingid moths housed in Korea. The number of Sphingidae moth species housed in Korea was found to be 53. As 48 species and 47 species were found in Gyeongsangnam-do and Gangwon-do, respectively, relatively diverse species were considered to be distributed in these areas. Comparatively, in Jeollabuk-do only 36 species were found, whereas in Chungcheongbuk-do and Jeju Island 39 species were found. The number of individual Sphingid moths surveyed in Korea was 21,414. With regard to the number of individuals per species, *Ampelophaga rubiginosa* was highest, at 2,483, followed by *Theretra japonica* (1,716), *Callambulyx tatarinovii* (1,457), *Acosmeryx naga* (1,340), *Rhagastis mongoliana* (1,191), *Marumba sperchius* (1,083), and *Dolbina tancrei* (1,072). By region, the largest number of individuals was surveyed in Gyeongsangnam-do (4,595), followed in order by Gangwon-do (3,648 individuals), Gyeonggi-do (3,011), Jeollanam-do (2,454), and Jeju Island (2,382). Over time, the highest numbers—in this case 9,498 individuals in 52 species—were identified after 2000. In the 1990s, there were 6,027 of 49 species identified; in 1980s, 4,332 individuals of 49 species were identified; and, in the 1970s, 937 individuals of 45 species were identified. It was confirmed that more species and individuals were identified as time passed. The appearance of Sphingid moths by month was found to be as relatively diverse, as they appeared from February to November. Overall, southern species, including *M. saishiuana*, *Cephonodes hylas*, *Acosmeryx castanea*, *T. nessus*, and *T. clotho*, which mainly inhabit Jeju Island and the southern part of Korea, have increased over time from the past to the present. Species inhabiting the middle or northern parts of the Korean Peninsula or the entire country of Korea, including *Sphingulus mus*, *Ambulyx schauffelbergeri*, and *Mimas christophi*, show decreases over time.

Key words: Sphingid moth, distribution change, environmental factor

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INTRODUCTION

Countries all over the world are making efforts to secure their biological sovereignty and preserve their biological resources in various ways, such as by joining the Convention on Biological Diversity or adhering to the Nagoya protocol. In order to preserve the variety of organisms, it is very important to identify mutual relationships between biological factors and non-biological factors (environmental factors), as these can have considerable effects on the extinction or survival of a species.

Lepidoptera, including Sphingidae, is one of the largest taxonomic groups of insects. As it has high species abundance, it shows sensitive responses to changes in environments which are a non-biological factor, while also reflecting the environmental conditions of any given region. Additionally, Lepidoptera has a relatively short life cycle. Thus, many generations appear in a short time. It produces a large issue at one time and has relatively diverse habitats. Well-known taxonomic groups of Lepidoptera have been preferred indicators of various environmental changes (Erhardt 1985, Erhardt and Thomas 1991, Daily and Ehrlich 1995, Hill et al. 1995, Hill and Hamer 1998). Butterflies and moths that are active in the daytime out of Lepidoptera have been used as biological indicators. However, butterflies are not easy to catch and often appear only rarely in forest environments. On the other hand, many taxonomic groups of moths in Lepidoptera, which are active at night, are easy to collect by using light traps. As there are numerous species, they provide strong and diverse power of discrimination for detecting a range of effects on the ecology of a region (Holloway 1977, 1985). Additionally, moths in Sphingidae are larger than other moths and are therefore easy to observe. Furthermore, they are well known taxonomically (Holloway 1977, 1985) and have been used as models of living things in various diversity studies (León-Cortés et al. 1998). Therefore, moths in Sphingidae, which are active in the daytime and at night and for which a range of species exist, are considered to be a very good taxonomical group as biological indicators responding to environmental changes.

More than 1,000 species of moths in Sphingidae have been reported around the world (Carter 1992), and it has been reported that 33 Sphinginae species and 25 Macroglossinae species (58 species in total) have inhabited or presently inhabit in Korea (Paek et al. 2010). Maintaining a database of bio-organisms over time is the only way to secure bio-diversity and to identify distributions and life patterns in the past and present related to various environmental changes, such as weather changes. Thus, in this study, fluctuations in different species according to space and time are identified by collecting information on samples of Korean Sphingid moths housed in Korea to provide basic materials with which to identify causes of species abundance and to determine the distributions of various insects, including Sphingid moths, according to environmental changes.

MATERIALS AND METHODS

Selection and collection of the research materials

To secure the basic materials used in this study, we contacted 15 national institutes, universities, and laboratories that were expected to have relatively abundant samples of Sphinginae moths. These institutions were selected out of domestic organizations which were known to house Sphingid moths. To obtain more accurate and reliable data, we have included at least one institute in each region. The number of selected institutions was 7 in Seoul and Gyeonggi-do, 1 in Gangwon-do, 3 in Chungcheong-do, 1 in Jeolla-do, 1 in Gyeongsang-do and 2 on Jeju Island (Table 1). We used sample information pertaining to a total of 53 species, or 21,414 individuals excluding samples that were less reliable in some way, such as missing or faulty information on the location grid or the year of the survey (Table 2).

RESULTS

Species distribution by region

There were 53 Sphingidae moth species housed in Korea. As 48 species and 47 species were found in Gyeongsangnam-do and Gangwon-do, respectively, it was considered that relatively diverse species were distributed in these areas. Comparatively, in Jeollabuk-do, only 36 species were found, and 39 species were found in Chungcheongbuk-do as well as in Jeju Island (Table 3). The number of individual Sphingid moths surveyed in Korea was found to be 21,414. With regard to the number of individuals per species, *Ampelophaga rubiginosa* was highest, at 2,483, followed by *Theretra japonica* (1,716), *Callambulyx tatarinovii* (1,457), *Acosmeryx naga* (1,340), *Rhagastis mongoliana* (1,191), *Marumba sperchius* (1,083), and *Dolbina tancrei* (1,072). The species which showed the fewest individuals were *Sphinx caliginea* and *Hyles gallii*, with as 1 and 2, respectively. By region, where the highest number

Table 1. The list of institutions investigated in this study

Area	Name of Institution	Address
Seoul & Gyeonggi-do	Natural History Museum, Kyunghee University	26, Kyungheedae-ro, Dongdaemun-gu, Seoul
	Division of Life Sciences, Korea University	145, Anam-ro, Seongbuk-gu, Seoul
	Natural History Museum, Ewha Womans University	52, Ewhayeodae-gil, Seodaemun-gu, Seoul
	National Academy of Agricultural Science	126, Suin-ro, Gwonseon-gu, Suwon-si, Gyeonggi-do
	National Institute of Biological Resources	42, Hwangyeong-ro, Seo-gu, Incheon
	Korea National Arboretum	415, Gwangneungsumogwon-ro, Soheul-eup, Pocheon-si, Gyeonggi-do
	Division of Life Sciences, Incheon National University	119, Academy-ro, Yeonsu-gu, Incheon
Gangwon-do	Department of Applied Biology, Kangwon National University	1, Gangwondaehak-gil, Chuncheon-si, Gangwon-do
Chungcheong-do	National Science Museum	481, Daedeok-daero, Yuseong-gu, Daejeon
	Division of Life Science, Daejeon University	62, Daehak-ro, Dong-gu, Daejeon
	Natural History Museum of Hannam University	70, Hannam-ro, Daedeok-gu, Daejeon
Jeolla-do	Department of Environmental Education, Mokpo National University	1666, Yeongsan-ro, Cheonggye-myeon, Muan-gun, Jeollanam-do
Gyeongsang-do	Department of Biology, Gyeongsang National University	501, Jinju-daero, Jinju-si, Gyeongsangnam-do
Jeju Island	Jeju Folklore & Natural Museum Jeju Special Self-Governing Province	40, Samseong-ro, Jeju-si, Jeju Island
	Jeju Regional Office, Animal and Plant Quarantine Agency	59, Cheongsa-ro, Jeju-si, Jeju Island

Table 2. Number of data samples used in the study

Species	No. of individual	Species	No. of individual
Agrius convolvuli	454	*Smerinthus caecus*	121
Acherontia styx medusa	222	*Smerinthus planus*	352
Meganoton scribae	235	*Laothoe amurensis sinica*	118
Psilogramma increta	267	*Phillosphingia dissimilis*	650
Sphinx ligustri amurensis	174	*Hemaris fuciformis*	4
Sphinx morio arestus	302	*Hemaris affinis*	351
Sphinx caliginea	1	*Hemaris radians*	32
Dolbina tancrei	1,072	*Hemaris staudingeri ottonis*	23
Dolbina exacta	586	*Cephonodes hylas*	31
Kentochrysalia consimilis	889	*Sphecodina caudata*	13
Kentochrysalia sieversi	275	*Ampelophaga rubiginosa*	2,483
Sphingulus mus	30	*Acosmeryx naga*	1,340
Ambulyx sericeipennis tobii	179	*Acosmeryx castanea*	270
Ambulyx schauffelbergeri	73	*Neogurelca himachala sangaica*	53
Ambulyx ochracea	321	*Macroglossum stellatarum*	200
Ambulyx japonica	711	*Macroglossum bombylans*	164
Clanis bilineata	674	*Macroglossum pyrrhosticum*	213
Clanis undulosa jankowskii	251	*Macroglossum saga*	163
Marumba gaschkewitschii	784	*Hyles gallii*	2
Marumba saishiuana	331	*Deilephila askoldensis*	57
Marumba maackii	82	*Deilephila elpenor*	750
Marumba jankowskii	182	*Theretra nessus*	38
Marumba sperchius	1,083	*Theretra clotho*	17
Langia zenzeroides nawai	58	*Theretra japonica*	1,716
Parum colligata	307	*Theretra oldenlandiae*	55
Mimas christophi	7	*Rhagastis mongoliana*	1,191
Callambulyx tatarinovii	1,457	**Total**	**21,414**

Table 3. Number of species by province area

Province	GW	GG	GN	GB	JN	JB	CN	CB	JJ	Total
No. of Species	47	45	48	44	44	36	44	39	39	53

GW, Gangwon-do; GG, Gyeonggi-do; GN, Gyeongsangnam-do; GB, Gyeongsangbuk-do; JN, Jeollanam-do; JB, Jeollabuk-do; CN, Chungcheongnam-do; CB, Chungcheongbuk-do; JJ, Jeju Island.

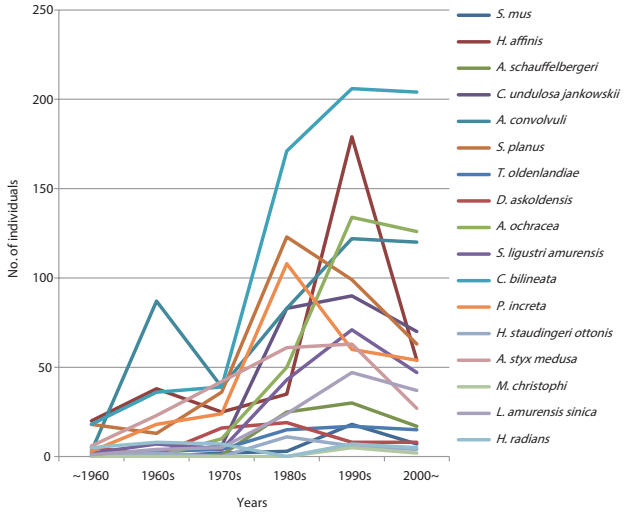

Fig. 1. Appearances of decreasing species over time.

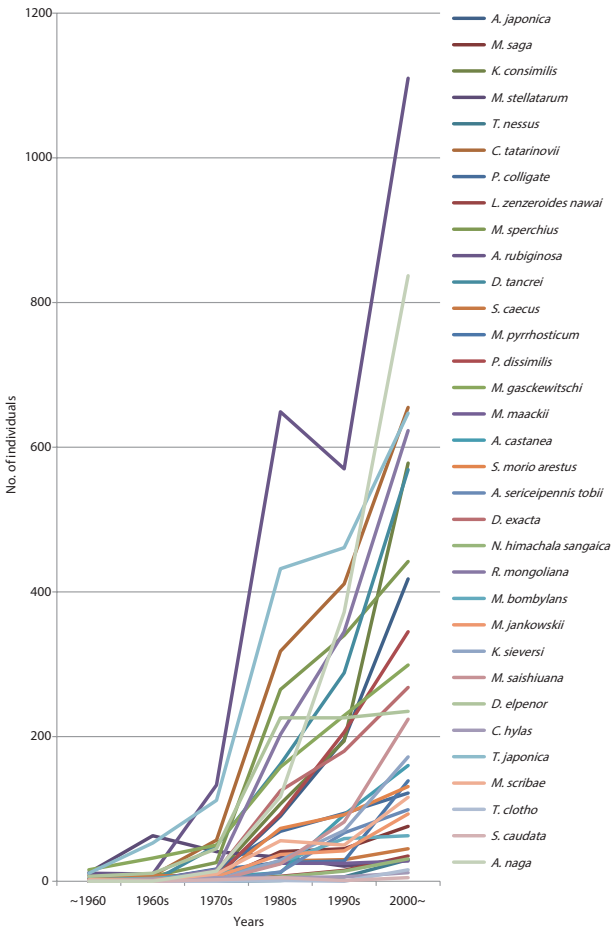

Fig. 2. Appearances of increasing species over time.

of individuals found was in Gyeongsangnam-do (4,595), followed by Gangwon-do (3,648 individuals), Gyeonggi-do (3,011), Jeollanam-do (2,454), and Jeju Island (2,382) (Table 4).

Species distribution by time

If we see the distribution of Sphingid moths identified up to now, the most number such as 9,498 individuals of 52 species were identified after 2000. In 1990s, 6,027 of 49 species, in 1980s 4,332 individuals of 49 species, and, in 1970s, 937 individuals of 45 species were identified. It was confirmed that more species and individuals were identified as time went by (Table 5). Species and individuals of Sphingidae identified in Korea by region and by time do not exactly mean the current distribution or biomass of Sphingidae, as they were not surveyed and identified quantitatively in survey place or time. When checking the progress of appearance by year, 17 species including *Agrius convolvuli* had increased in the past and then decreased as time went by (Fig. 1 and Table 6). 33 species including *Meganoton scribae* have continuously increased up to present (Fig. 2 and Table 6). *Sphinx caliginea*, *H. gallii*, and *Hemaris fuciformis* were excluded from this report, as it was difficult to judge the progress of their appearance due to their small numbers of identified samples. All southern species, including *M. saishiuana*, *Cephonodes hylas*, *A. castanea*, *T. nessus*, and *T. clotho*, which inhabit southern areas including Jeju Island, show a tendency to increase in terms of their numbers of individuals over time. Species inhabiting middle or northern parts of the Korean Peninsula or those spread throughout the country, including *Sphingulus mus*, *Ambulyx schauffelbergeri*, and *Mimas christophi*, show lower numbers over time (Appendix 1).

Species distribution by season

The appearance of Sphingid moths by month was found to be relatively diverse, as they appear from February to November. By using appearance as the starting point, species which begin to appear in May numbered 26 in total, accounting for approximately half of all species. It was also found that 15 species started to appear in April, while only 3 started to appear in June. With regard to the ending point of their appearance, the number of species lasting until August was highest, at 23, with 17 for September and 5 for October. For the peak of appearance of Sphingid moths, 21 species showed the highest frequency of appearance in July, followed by 10 species in June, 8 in August, and 6 in May. For Sphinginae, most species apart from *Langia zenzeroides nawai* mainly ap-

Table 4. Number of individuals of each species by province area

Species	Province area									Total
	GW	GG	GN	GB	JN	JB	CN	CB	JJ	
Agrius convolvuli	27	164	125	13	62	9	31	5	18	454
Acherontia styx medusa	4	20	127	19	18	15	15	2	2	222
Meganoton scribae	83	24	47	31	27	9	5	8	1	235
Psilogramma increta	17	79	78	12	29	5	20	4	23	267
Sphinx ligustri amurensis	39	64	18	6	1	15	26	5	0	174
Sphinx morio arestus	93	63	70	17	19	10	27	2	1	302
Sphinx caliginea	1	0	0	0	0	0	0	0	0	1
Dolbina tancrei	126	120	278	124	121	34	97	27	145	1,072
Dolbina exacta	168	72	80	68	81	24	52	17	24	586
Kentochrysalia consimilis	307	119	70	100	199	31	34	21	8	889
Kentochrysalia sieversi	142	58	4	31	13	2	3	22	0	275
Sphingulus mus	9	0	2	14	4	0	0	0	1	30
Ambulyx sericeipennis tobii	47	13	55	14	23	8	13	4	2	179
Ambulyx schauffelbergeri	2	68	1	0	0	0	1	1	0	73
Ambulyx ochracea	97	40	57	25	23	12	24	8	35	321
Ambulyx japonica	81	131	113	46	54	27	20	17	222	711
Clanis bilineata	33	124	217	48	51	41	84	16	60	674
Clanis undulosa jankowskii	27	36	92	16	19	6	48	7	0	251
Marumba gaschkewitschii	107	181	125	57	58	22	88	19	127	784
Marumba saishiuana	0	0	91	5	99	23	0	1	112	331
Marumba maackii	43	11	0	18	2	0	2	0	6	82
Marumba jankowskii	43	7	7	27	70	6	3	5	14	182
Marumba sperchius	88	106	282	93	163	43	135	55	118	1,083
Langia zenzeroides nawai	12	14	13	0	7	1	4	3	4	58
Parum colligata	13	29	111	20	65	17	28	12	12	307
Mimas christophi	5	0	0	0	0	0	0	0	2	7
Callambulyx tatarinovii	306	153	323	157	148	69	161	46	94	1,457
Smerinthus caecus	86	5	4	10	2	0	4	1	9	121
Smerinthus planus	52	124	73	35	15	11	35	4	3	352
Laothoe amurensis sinica	73	24	5	8	0	0	4	0	4	118
Phillosphingia dissimilis	110	52	142	53	127	38	50	15	63	650
Hemaris fuciformis	1	2	1	0	0	0	0	0	0	4
Hemaris affinis	42	128	8	9	12	5	127	20	0	351
Hemaris radians	5	19	4	2	0	0	1	1	0	32
Hemaris staudingeri ottonis	5	11	4	0	3	0	0	0	0	23
Cephonodes hylas	0	0	9	1	0	0	2	0	19	31
Sphecodima caudata	1	7	1	2	1	0	1	0	0	13
Ampelophaga rubiginosa	471	217	504	232	249	96	361	141	212	2,483
Acosmeryx naga	408	126	198	148	164	63	54	29	150	1,340
Ascomeryx catanea	20	6	75	3	62	1	1	1	101	270
Neogurelca himachala sangaica	0	0	16	3	4	0	1	0	29	53
Macroglossum stellaparum	21	109	23	3	8	3	13	3	17	200
Macroglossum bombylans	4	40	52	7	11	10	4	2	34	164
Macroglossum pyrrhosticta	1	5	38	4	26	3	2	1	133	213
Macroglossum saga	4	2	42	12	17	1	38	2	45	163
Hyles gallii	0	1	1	0	0	0	0	0	0	2
Deilephila askoldensis	6	21	1	14	0	1	6	4	4	57
Deilephila elpenor	136	117	240	34	35	29	119	33	7	750
Theretra nessus	0	0	15	0	11	0	0	0	12	38
Theretra clotho	0	0	0	0	17	0	0	0	0	17
Theretra japonica	90	176	442	89	198	50	272	48	351	1,716
Theretra oldenlandiae	16	4	3	3	5	0	1	0	23	55
Rhagastis mongoliana	176	119	308	77	131	52	149	44	135	1,191
Total	**3,648**	**3,011**	**4,595**	**1,710**	**2,454**	**792**	**2,166**	**656**	**2,382**	**21,414**

GW, Gangwon-do; GG, Gyeonggi-do; GN, Gyeongsangnam-do; GB, Gyeongsangbuk-do; JN, Jeollanam-do; JB, Jeollabuk-do; CN, Chungcheongnam-do; CB, Chungcheongbuk-do; JJ, Jeju Island.

Table 5. Number of species and individuals over time

	~1960	1960s	1970s	1980s	1990s	2000~	Total
No. of species	27	30	45	49	49	52	53
No. of individuals	166	454	937	4,332	6,027	9,498	21,414

Table 6. Species which increase and decrease over time

Increasing species (33)	Decreasing species (17)
Meganoton scribae	*Agrius convolvuli*
Sphinx morio arestus	*Acherontia styx medusa*
Dolbina tancrei	*Psilogramma increta*
Dolbina exacta	*Sphinx ligustri amurensis*
Kentochrysalia consimilis	*Sphingulus mus*
Kentochrysalia sieversi	*Ambulyx schauffelbergeri*
Ambulyx sericeipennis tobii	*Ambulyx ochracea*
Ambulyx japonica	*Clanis bilineata*
Marumba gaschkewitschii	*Clanis undulosa jankowskii*
Marumba saishiuana	*Mimas christophi*
Marumba maackii	*Smerinthus planus*
Marumba jankowskii	*Laothoe amurensis sinica*
Marumba sperchius	*Hemaris affinis*
Langia zenzeroides nawai	*Hemaris radians*
Parum colligata	*Hemaris staudingeri ottonis*
Callambulyx tatarinovii	*Deilephila askoldensis*
Smerinthus caecus	*Theretra oldenlandi*ae
Phillosphingia dissimilis	
Cephonodes hylas	
Sphecodina caudata	
Ampelophaga rubiginosa	
Acosmeryx naga	
Acosmeryx castanea	
Neogurelca himachala sangaica	
Macroglossum stellatarum	
Macroglossum bombylans	
Macroglossum pyrrhosticum	
Macroglossum saga	
Deilephila elpenor	
Theretra nessus	
Theretra clotho	
Theretra japonica	
Rhagastis mongoliana	

Table 7. Appearances of samples by month

Increased species (33)	Month*		
	Start point	End point	Peak point
Meganoton scribae	5	9	7
Sphinx morio arestus	4	10	5
Dolbina tancrei	5	8	7
Dolbina exacta	5	8	8
Kentochrysalia consimilis	4	8	5
Kentochrysalia sieversi	5	8	7
Ambulyx sericeipennis tobii	4	9	6
Ambulyx japonica	4	8	6
Marumba gaschkewitschii	5	9	7
Marumba saishiuana	5	8	7
Marumba maackii	5	8	6
Marumba jankowskii	5	8	6
Marumba sperchius	5	8	7
Langia zenzeroides nawai	3	8	4
Parum colligata	6	9	7
Callambulyx tatarinovii	5	8	7
Smerinthus caecus	3	9	6
Phillosphingia dissimilis	5	8	6
Cephonodes hylas	6	10	8
Sphecodina caudata	4	8	5, 7
Ampelophaga rubiginosa	5	8	7
Acosmeryx naga	4	8	6
Acosmeryx castanea	4	8	7
Neogurelca himachala sangaica	4	11	9
Macroglossum stellatarum	2	11	10
Macroglossum bombylans	5	11	9
Macroglossum pyrrhosticum	5	11	10
Macroglossum saga	4	10	6
Deilephila elpenor	3	9	7
Theretra nessus	6	9	8
Theretra clotho	6	8	6
Theretra japonica	5	10	7
Rhagastis mongoliana	5	8	7
Decreased species (17)	**Month***		
	Start point	**End point**	**Peak point**
Agrius convolvuli	5	10	9
Acherontia styx medusa	5	9	8
Psilogramma increta	5	9	8
Sphinx ligustri amurensis	4	9	5
Sphingulus mus	5	8	7
Ambulyx schauffelbergeri	4	8	7
Ambulyx ochracea	4	9	6
Clanis bilineata	5	9	7
Clanis undulosa jankowskii	5	9	7
Mimas christophi	6	8	8
Smerinthus planus	4	8	7
Laothoe amurensis sinica	4	9	8
Hemaris affinis	4	9	5
Hemaris radians	5	9	5
Hemaris staudingeri ottonis	5	8	7
Deilephila askoldensis	5	8	7
Theretra oldenlandiae	5	9	8

*The numbers correspond to the order of months from January (1) to December (12).

peared from spring to summer. On the other hand, many species in Macroglossinae, including *Marcroglossum stellatarum*, widely appeared regardless of the season, except for mid-winter. Although there were no major differences in terms of their appearance by month between species which show an increase and those which show a decrease, species in Macroglossinae appeared earlier and disappeared later than other decreasing species in the same family (Table 7 and Appendix 2).

DISCUSSION

When analyzing major habitats and distributions by year and month using the information on Sphingidae samples housed in Korea, the southern species *M. saishiuana*, *C. hylas*, *A. castanea*, *T. nessus*, and *T. clotho*, which mainly inhabit Jeju Island and the southern part of Korea, have increased over time. These species are distributed throughout Southeast Asia and in the southern part of China. Both of these areas have tropical climates with high temperatures and high humidity levels which last a long time (Kim et al. 1982, Park et al. 1999, Shin 2001). These species as well have been increasing in Korea in recent years. This indicates that the habitats of these species are gradually expanding. It was reported that Jeju Island and the southern part of Korea had at this point a subtropical climate (Kwon et al 2007, Kim 2008, National Institute of Meteorological Research 2009). This climate change affects temperatures and rainfall amounts, which have major impacts on changes in bio-distributions. Species inhabiting the middle or northern parts of the Korean Peninsula or all of Korea, including *S. mus*, *A. schauffelbergeri*, and *M. christophi*, decreased over time. Most of them also inhabit the Russian Far East and Siberia, Northern China, and Northern Japan (Kim et al. 1982, Park et al. 1999, Shin 2001). The aforementioned species seem to prefer drier and cooler areas to the areas of Korea. In Korea, they inhabit forests and mountainous areas at high altitudes rather than the sea shores and plains at lower altitudes. Thus, it is likely that they have a topical distribution in areas which have undergone moderate climate changes. Generally, the number of individuals of Sphingidae, inhabiting southern areas, increased, while those inhabiting mainly middle or northern areas or topically in mountainous areas throughout Korea decreased in number. Additionally, it was found that species distributed widely across the nation increased, whereas species relatively few in numbers of individuals and with relatively topical distributions relative to species with wide distributions were found to be decreasing in number. It was considered that more accurate reasons for these increases and decreases should be identified through various research methods in the future.

With regard to the monthly appearance of species which mainly inhabit Jeju Island and the southern part of Korea and show recent increases in the numbers of individuals, *M. saishiuana* appeared from May to August, the same period reported by Shin (2001), and this is similar to that reported by Park et al. (1999) (May to July). It was considered that this species appeared once annually in spring and summer. It mainly appears in June and July, which are hotter and more humid than May, showing the highest frequency of appearance in July. *Cephonodes hylas* appears from June to October, which is somewhat earlier than "July to September" as reported by Park et al. (1999) and "July to November" as reported by Shin (2001). This species seems to appear twice a year from early summer to late autumn. It was considered that it made its second appearance in August, when it showed the highest frequency of appearance. *Ascomeryx castanea* appears from April to August, which is different from "June to August" as reported by Park et al. (1999). It appears that some individuals of this species appear in spring, and the greatest number of individuals appears in July, after which the number of individuals gradually decreases in August. *Theretra nessus* appears from June to September, which is slightly earlier than "July to September" as reported by Park et al. (1999) and Shin (2001). Additionally, it showed the highest frequency of appearance in the hottest month, August. *Theretra clotho* appears from June to August, but it was found to appear in August by Park et al. (1999). In our survey, it showed the highest frequency of appearance in June rather than in August. In fact, it showed the lowest appearance frequency in August.

With regard to monthly appearances of the species inhabiting the middle or northern parts of the Korean Peninsula or topically all areas of Korea, *S. mus* appears from May to August, but this is slightly earlier than "June to July" and "June to August" as reported by Park et al. (1999) and Shin (2001), respectively. Additionally, it appears to show the highest appearance frequency in June, in midsummer. *Ambulyx schauffelbergeri* was found to appear from April to August, but Park et al. (1999) reported that it appeared from June to August. It was noted that very few individuals appeared in spring, individuals increased in number over time, the greatest number of individuals appeared in July, and the number of indi-

viduals gradually decreased in August. *Mimas christophi* appears from June to August, which is slightly later than "May to August" as reported by Park et al. (1999). Although it is difficult to determine the exact time of appearance because the surveyed individuals are very few in number, it is highly probable that they appear in May. The highest appearance frequency occurs in August, the hottest month.

On the other hand, species active until relatively late in the year, such as species with very early appearance times, including *L. zenzeroides nawai*, or species active in the daytime, such as Macroglossinae, can be used in phenological studies by examining their starting and ending appearance times. Furthermore, more detailed research should be conducted considering changes in various environmental elements, such as climate (temperature and rainfall), vegetation (the distribution of food plants), and the destruction of wildlife habitats.

ACKNOWLEDGMENTS

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LITERATURE CITED

Carter D. 1992. Butterflies and Moths. Dorling Kindersley, London.

Daily GC, Ehrlich PR. 1995. Preservation of biodiversity in small rain-forest patches: rapid evaluations using butterfly trapping. Biodivers Conserv 4: 35-55.

Erhardt A. 1985. Diurnal lepidoptera: sensitive indicators of cultivated and abandoned grassland. J Appl Ecol 22: 849-861.

Erhardt A, Thomas JA. 1991. Lepidoptera as indicators of change in the semi-natural grasslands of lowland and upland Europe. In: The Conservation of Insects and Their Habitats (Collins NM, Thomas JA, eds). Academic Press, London, pp 213-236.

Hill JK, Hamer KC. 1998. Using species-abundance models as indicators of habitat disturbance in tropical forests. J Appl Ecol 35: 458-460.

Hill JK, Hamer KC, Lace LA, Banham WMT. 1995. Effects of selective logging on tropical forest butterflies on Buru, Indonesia. J Appl Ecol 32: 754-760.

Holloway JD. 1977. The Lepidoptera of Norfolk Island: Their Biogeography and Ecology. Junk Publisher, The Hague.

Holloway JD. 1985. Moths as indicator organisms for categorising rain forest and monitoring changes and regenerating processes. In: Tropical Rain-Forest, The Leeds Symposium (Chadwick AC, Sutton SL, eds). Philosophical and Literary Society, Leeds, pp 235-242.

Kim CW, Nam SH, Lee SM. 1982. Illustrated Flora and Fauna of Korea, Vol. 26, Insect (VIII). Ministry of Education, Seoul. (in Korean)

Kim SH. 2008. Influence of the trend of subtropical climate on the characteristics of precipitation change in Korea. MS Thesis. Inje University, Soeul, Korea. (in Korean)

Kwon YA, Kwon WT, Boo KO, Choi YE. 2007. Future projections on subtropical climate regions over South Korea using SRES A1B data. J Korean Geogr Soc 42: 355-367. (in Korean)

León-Cortés JL, Soberón-Mainero J, Llorente-Bousquets J. 1998. Assessing completeness of Mexican sphinx moths inventories through species accumulation functions. Divers Distrib 4: 37-44.

National Institute of Meteorological Research. 2009. The study on the regional characteristics of climate change in Jeju Island. Korea Meteorological Administration. (in Korean)

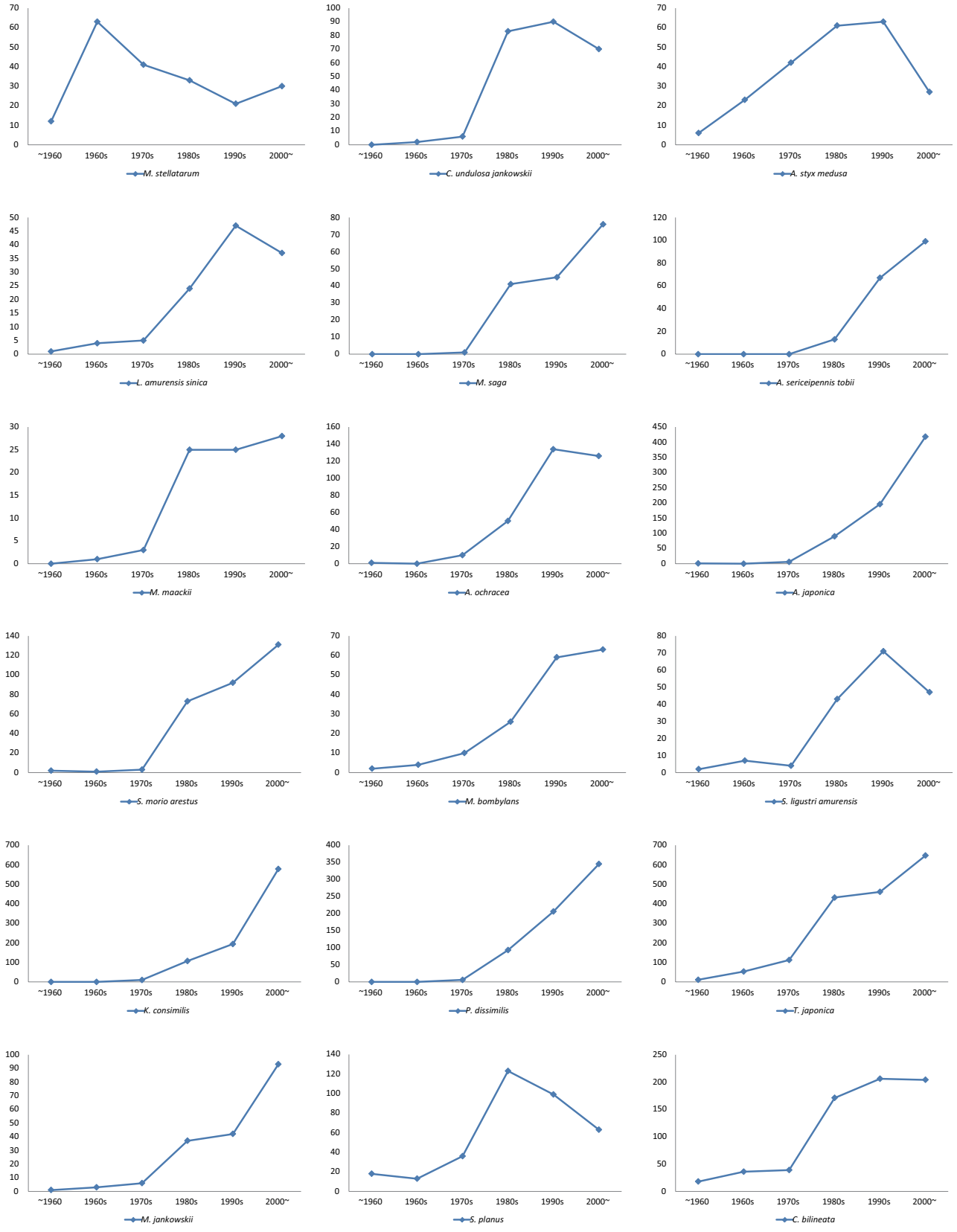
Paek MK, Hwang JM, Jung KS, Kim TW, Kim MC, Lee YJ, Cho YB, Park SW, Lee HS, Ku DS, Jeong JC, Kim KG, Choi DS, Shin EH, Hwang JH, Lee JS, Kim SS, Bae YS. 2010. Checklist of Korean Insects. Nature & Ecology, Soeul. (in Korean)

Park KT, Kim SS, Tshistjakov YA, Kwon YD. 1999. Illustrated Catalogue of Moths in Korea(I) (Sphingidae, Bombicoidea, Notodontidae). Korea Research Institute of Bioscience and Biotechnology and Center for Insect Systematics, Seoul. (in Korean)

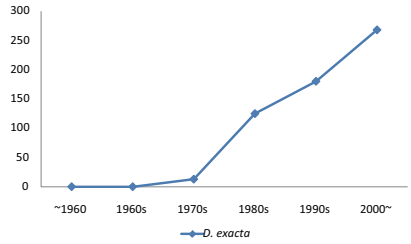
Shin YH. 2001. Coloured Illustrations of the Moths of Korea. Academybook Publishing Co., Ltd., Seoul. (in Korean)

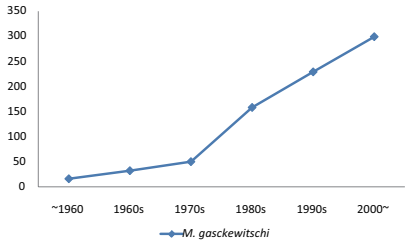
Appendix 1. Appearances of each species over time.

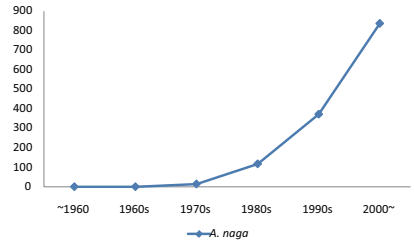
Appendix 1. Continued.

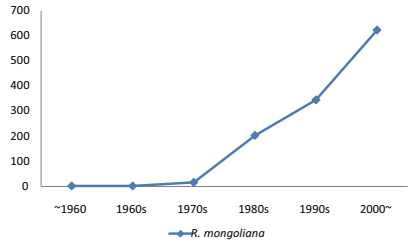


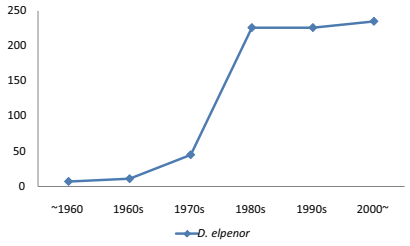
Appendix 1. Continued.

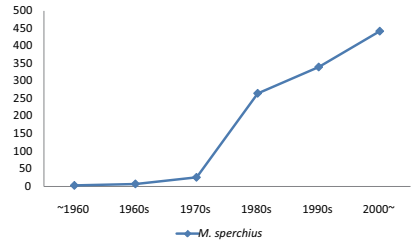


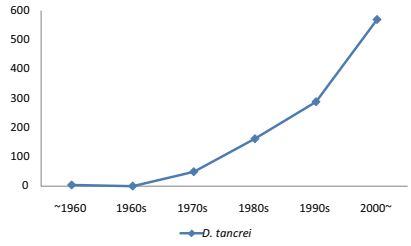


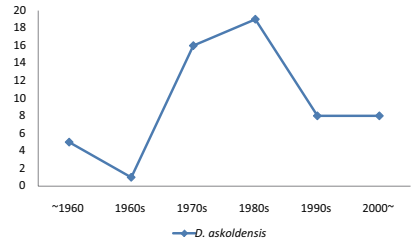


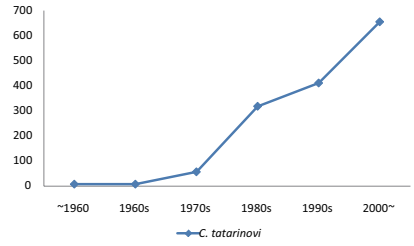


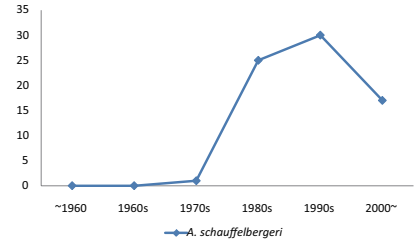


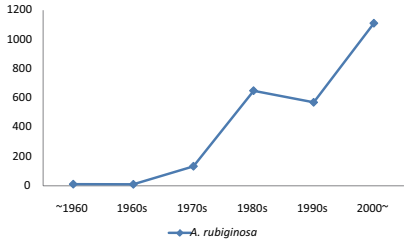




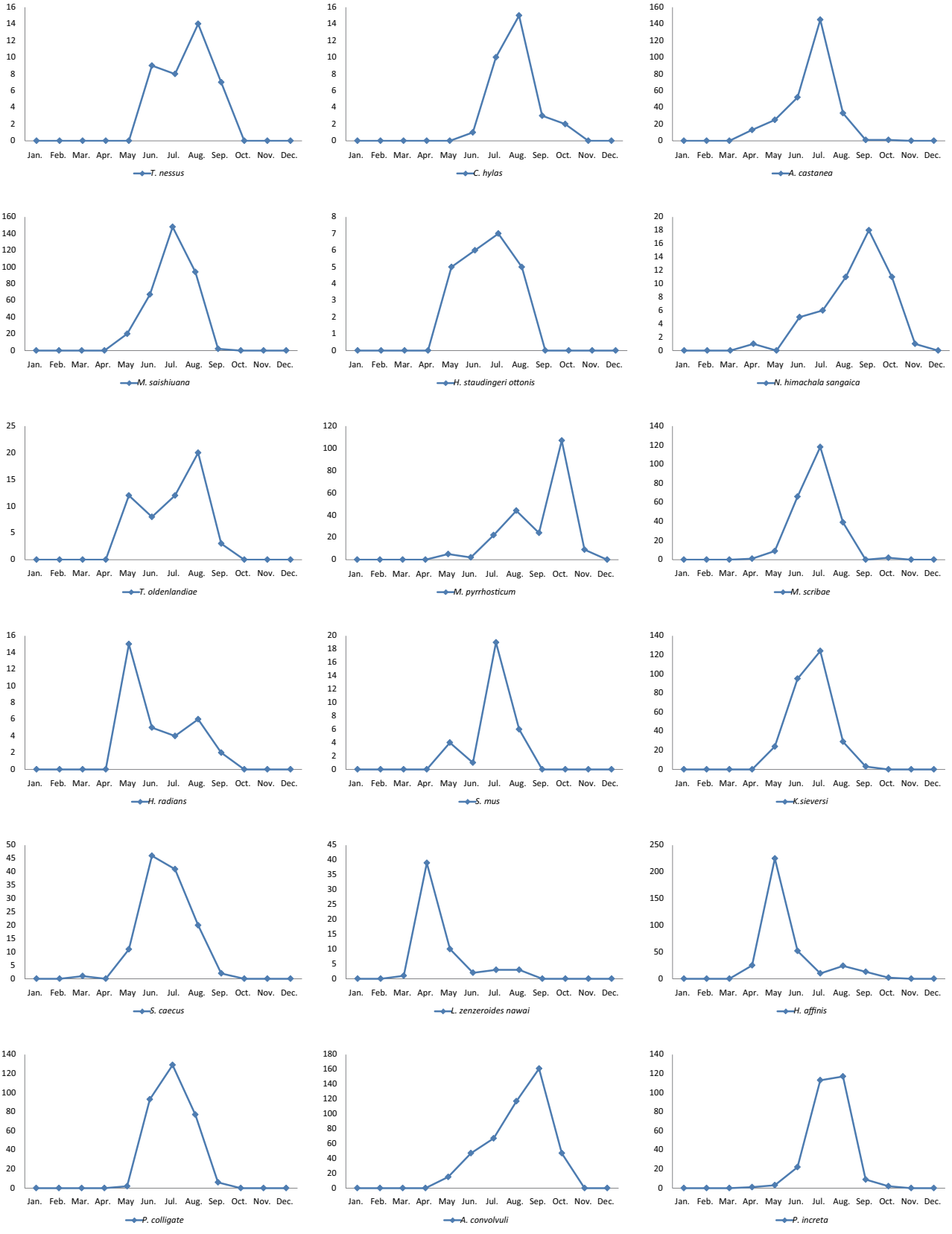








Appendix 2. Appearance aspect of each species by month.



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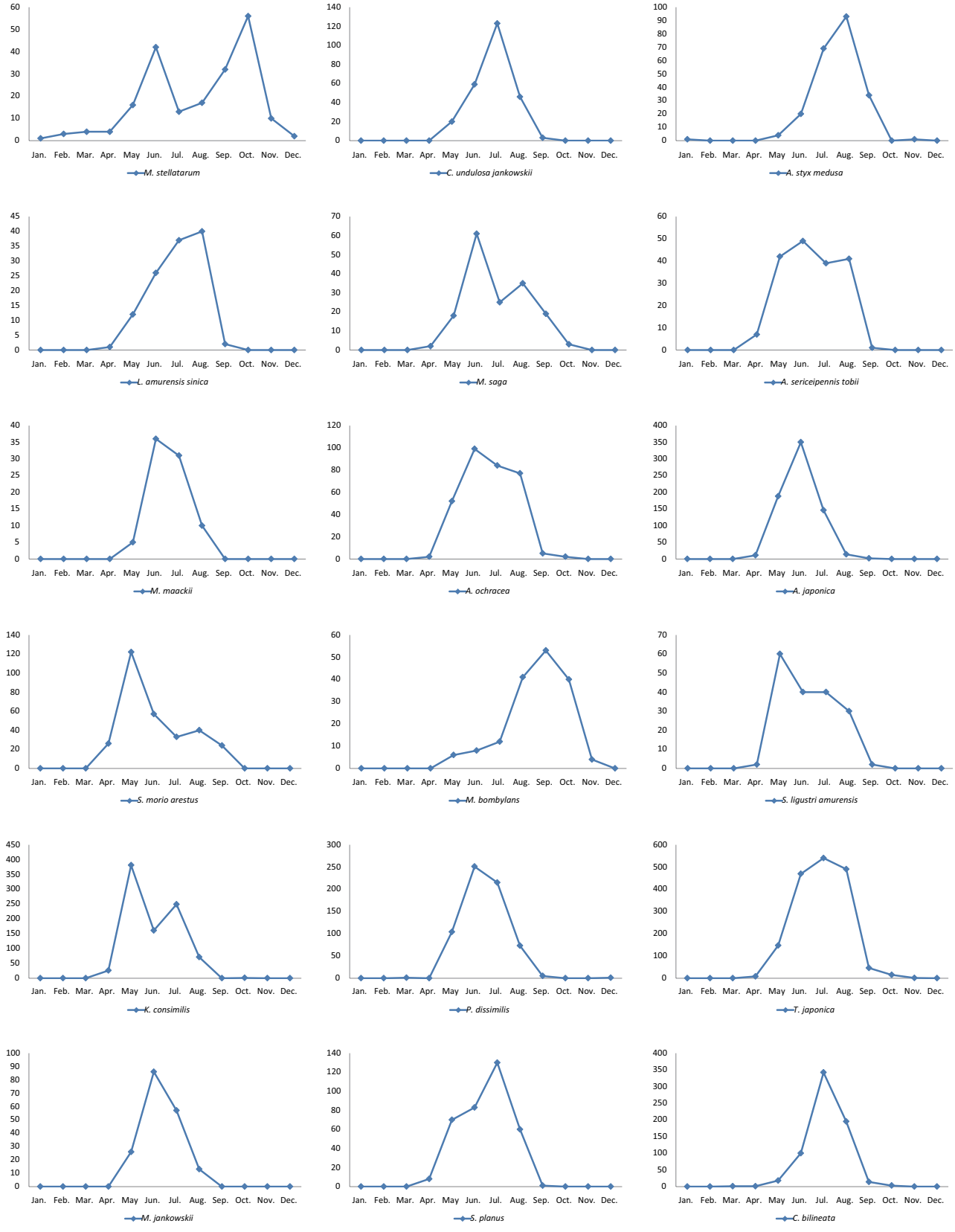

Appendix 2. Continued.