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https://doi.org/10.5109/14047

出版情報：九州大学大学院農学研究院紀要. 54 (1), pp.123-132, 2009-02-27. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **54** (1), 123–132 (2009)

Phenetic Analysis of the Anisoptera (Insecta: Odonata) in Jeju Island, Korea, Based on Morphological Characters

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(*Received November 2, 2008 and accepted December 5, 2008*)

This study was conducted from April 2002 to September 2007 to investigate the relationships of 27 species of Anisoptera which were collected in wetlands of Jeju Island, using a phenetic analysis of external morphological characters. The generated phenogram revealed the presence of two superfamilies within Anisoptera, Aeshnoidea and Libelluloidea. Moreover, the three groups, Aeshinidae, Libellulidae and Corduliidae, were clearly branched. As a result, the phenogram was similar to that of the ordinary systematic classification. The Aeshnidae was divided into *Anax* and *Gynacantha*, and *Polycanthagyna* and *Aeschnophlebia*. Three species of *Anax* (e.g., *guttatus, parthenope* and *nigrofasciatus*) presented to have very similar external morphological characteristics. Particularly, *A. guttatus* has confused its name, e.g., someone treated it as a synonym with *A. parthenope* due to the presence of very similar morphological characters. However, major differences were observed in the upper edge of the frons and the anterior femur in these species. Therefore, we obtained a conclusion that is more valid to classify *A. guttatus* as an independent species rather than as a synonym. The Libellulidae consisted of three subgroups. When the relationship of the genus *Sympetrum* were considered, the key characteristics were determined to be the patterns of the first lateral suture, the second lateral suture and the humeral suture. The Corduliidae was divided into Macromiinae and Cordulinae. Particularly, *Somatochlora graeseri* and *S. clavata* were confirmed to be unregistered species in Jeju Island.

INTRODUCTION

Dragonflies belong to the order Odonata (Pterygota, Insecta, Arthropoda), which is divided into 3 suborders, 8 superfamilies, 29 families and 58 subfamilies. Overall, this order contained approximately 600 genera and 6000 named species (Jill, 2001). Linnaeus began the taxonomic study of the Odonata in 1758, when he placed one genus, the *Libellula*, in the Neuroptera, and recorded numerous. Subsequently, Fabricius (1783) separated the Odonata from the Neuroptera. Selys (1890) laid a foundation for the study of dragonflies by publishing many monographs between 1,840 and 1,898 (Yoon, 1988), which resulted in the division of the Odonata from Zygoptera and Anisoptera based on wing–shape, interocular characteristics, and the existence and absence of quadrangles and triangles on the wing membrane (Ishida *et al*., 1988). Domestic studies evaluating taxonomical systems of Odonata have been conducted since the 1900s, however, these studies have primarily focused on the introduction of unregistered species, the classifications of patterns, and distribution studies. Moreover, external morphological and ecological studies have been conducted, therefore, the identification of species and the classification system has not completely established.

Recently, several studies have been conducted on Korean Odonata. One report involved the chromosomal analysis of five species in the family Libelluidae, which was conducted using a cytotaxonomical method (Park *et al*., 1988). Another report was a relationship evaluation of *Sympetrum* that was based on morphological and physiochemistrical characters (Yoon, 1997). And a study was also conducted to evaluate the order based on the characters of the external genitalia (Lee, 2001). Finally, a study was a relationship of the Anisoptera that was based on mitochondrial 16S rRNA gene sequences (Kim *et al*., 2008).

Instead of adding the systemicity, the phenetic analysis found the relationship between classification groups based on the phenetic similarity by using phenetic characters. In addition, the character owned by an organism was treated as unweighted character for the quantification and objectification, and the information was used repeatedly for the efficient classification (Sneath and Sokal, 1962). Several studies have been conducted in other countries, such as a study conducted to evaluate Aeshnidae worldwide using 51 anatomical characters of imagoes and larvae. Another study was conducted on Libellulidae and Sympetrinae using wing venation (Ellenrieder, 2002; Pilgrim and Dohlen, 2007). Conversely, very few studies have been conducted in Korea, with the only known study being the arrangement of the lineage of Korean *Sympetrum* using classifiable characters such as anal appendages, graspable projections and accessory genitalia (Yoon, 1997).

Therefore, in this study, 27 species of Odonata in

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Jeju Island were initially investigated to organize a table of discernible characters based on external morphological characters. Then, a phenogram was generated using 35 selected characters to allow a phenetic analysis. Finally, the relationships of Odonata distributed in Jeju Island were evaluated by comparing the results to the phenetic analysis generated in this study with those of previous studies.

MATERIALS AND METHODS

Specimen collecting

Specimens collected at 78 wetlands in Jeju Island from April 2002 to October 2005 were investigated in this study (Fig. 1). Due to the characteristics of the taxon, the specimens were collected using an insect net (Diameter: 40 cm).

Classification and Identification

The identification were then conducted by comparing the external morphologies of the specimens according to references. Next, further evaluations were conducted using a gross and anatomical microscope (Dongwon OSM–1), with vernier calipers (Mitutoyo 530–101 N15) was used to determine the size of the specimen. The number of specimens of each species to be measured was limited to 10 individuals, however, when less than 10 individuals of a given species were available measurements were taken from all of the collected specimens. To reflect any variations within a species, individuals that differed greatly from each other in terms of size and color or that were collected at different times and from different places were also measured. Illustration was done using rapidograph pens (Rotring) on tracing paper after copy the outline of head, thorax, abdomen and leg.

The principal morphological characters used to distinguish species were as follows: the interocular distance, the direction of the triangle of the forewing and hindwing, the corpora incerta of the compound eye, the anal angle of the hindwing, the shape of the abdomen, and the form of the superior appendage, vein, and antenodal crossvein (Cho, 1958; Ishida *et al*., 1988; Lee, 2001).

The terms used for this study were quoted primarily from Cho (1969), and Ishida *et al*. (1998) was used as a guide to the classification systems. Finally, the Korean names of places were transliterated into English using the "Romanization System of Hangeul" (announced by the Ministry of Culture and Tourism July 7, 2007).

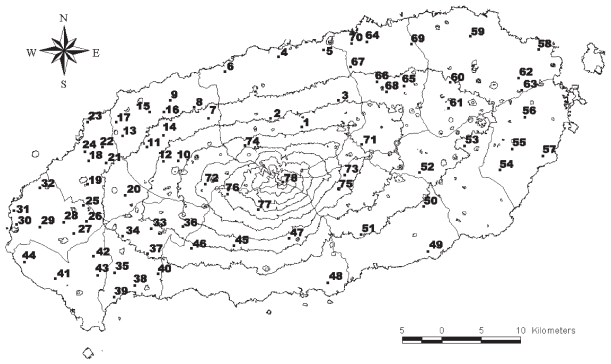

Fig. 1. Collecting sites of the Anisoptera used in this study (main collecting sites: ●) 1, Ara–dong; 2, Ora–dong; 3, Bonggae–dong; 4, Geonip–dong; 5, Samyang–dong; 6, Iho–dong; 7, Gwangnyeong–ri; 8, Goseong–ri; 9, Susan–ri; 10, Sogil–ri; 11, Eoeum–ri; 12, Jangjeon–ri; 13, Nabeup–ri; 14, Sangga–ri; 15, Haga–ri; 16, Yusuam–ri; 17, Gwakji–ri; 18, Myeongwol–ri; 19, Sangmyeong–ri; 20, Geumak–ri; 21, Sangdae–ri; 22, Sinheung–ri; 23, Suwon–ri; 24, Ongpo–ri; 25, Wollim–ri; 26, Jeoji–ri; 27, Cheongsu–ri; 28, Nakcheon–ri; 29, Josu–ri; 30, Yongsu–ri; 31, Yongdang–ri; 32, Panpo–ri; 33, Donggwang–ri; 34, Seogwang–ri; 35, Deoksu–ri; 36, Sangcheon–ri; 37, Sangchang–ri; 38, Hwasun–ri; 39, Sagye–ri; 40, Changcheon–ri; 41, Mureung–ri; 42, Boseong–ri; 43, Anseong–ri; 44, Sindo–ri; 45, Jungmun–dong; 46, Yerae–dong; 47, Seohong–dong; 48, Hyodon–dong; 49, Taeheung–ri; 50, Sinheung–ri; 51, Wimi–ri; 52, Gasi–ri; 53, Seongeup–ri; 54, Samdal–ri; 55, Nansan–ri; 56, Susan–ri; 57, Onpyeong–ri; 58, Hado–ri; 59, Hanwon–ri; 60, Deokcheon–ri; 61, Songdang–ri; 62, Sangdo–ri; 63, Jongdal–ri; 64, Hamdeok–ri; 65, Seonheul–ri; 66, Daeheul–ri; 67, Sinchon–ri; 68, Wasan–ri; 69, Dongbok–ri; 70, Jocheon–ri; 71, Gyorae–ri; 72, Eoseungsaeng catchment area; 73, Muljangol; 74, Gwaneumsa; 75, Seongpanak; 76, Eorimok; 77, Yeongsil; 78, Backrokdam.

Phenetic analysis

A total of 35 external morphological data were utilized in order to prepare the character state table and the character matrix (Tables 1 and 3). All of the observed characters were assigned values of 0, 1 or 2, and these values were then used to conduct the phenetic analysis (Table 1) using Statistical Package Social Science (SPSS) for IBM, version 11.5. In order to construct the phenogram, the characteristics of the species were equally weighted and treated unordered. At the time of phenetic analysis, the names of the species were substituted with the Operational Taxonomic Unit (OTU) code numbers in order to be suitable for computer processing. The raw data, which were organized in order to measure the similarity between the OTU were inputted to the Squared Euclidean Distance (Distance $(X \times Y) = \sum(Xi - Yi)^2$) to calculate the dissimilarity coefficient, and then categorized the ones with the lowest coefficient and connected them to the one with the higher coefficient in order to prepare the phenogram. By using the total 35 characters that include qualitative and quantitative characters, the cluster analysis was conducted for 27 species by average linkage between group (Sneath and Sokal, 1973).

RESULTS AND DISCUSSION

The 27 species of Anisoptera collected in Jeju Island were divided into 6 species of Aeshnidae, 4 species of Corduliidae, and 17 species of Libellulidae using 51 external morphological characters.

Thirteen of these external characters 1) Body length, 2) Abdomen length, 3) Hindwing length, 4) Compound eye color, 5) Patterns of frons, 6) Interocellar tubercle, 7) Labrum, 8) Mandible, 9) Labium, 10) Vein, 11) Costa, 12) Pterostigma and 13) Leg were organized

Table 1. The morphometric character states used in phenetic analysis of the Anisoptera

No.	Characters
1	Compound eye: (0) contact; (1) apart
2	Triangle direction of forewing and hindwing: (0) different; (1) the same
3	Corpora incerta of compound eye: (0) curved; (1) smooth
4	Lobe on abdomen's second node: (0) absent; (1) present
5	Metallic luster on thorax: (0) absent; (1) present
6	Anal angle of hindwing: (0) projected; (1) round
7	Abdomen length: (0) over 40 mm; (1) under 40 mm
8	Hindwing length: (0) over 40 mm; (1) under 40 mm
9	Abdomen's third node: (0) not; (1) slender
10	Shape of abdomen's first, second, and third nodes: (0) not; (1) club–shaped
11	Superior appendage, compared with inferior appendage: (0) not; (1) longer
12	Back side of superior appendage: (0) bending; (1) straight
13	Pterostigma: (0) not; (1) black
14	Yellow line on front head: (0) none; (1) 1; (2) 2
15	Two black spot patterns on frons: (0) absent; (1) present
16	A band on the brim of the upper frons: (0) absent; (1) straight; (2) T–shaped
17	A pattern on the whole abdomen: (0) absent; (1) present
18	Membranule: (0) small; (1) big
19	Brindle on wing: (0) absent; (1) present
20	Basal part of hindwing: (0) not; (1) transparent
21	Macrotrichium on prothorax anal margin: (0) dense; (1) thin
22	White powder on abdomen: (0) absent; (1) present
23	The end of the wing: (0) not; (1) colored
24	Lobe on the abdomen's tenth node: (0) absent; (1) present
25	Abdomen: (0) not; (1) wide and flat
26	Wide yellow band on the abdomen's second, third, and fourth nodes: (0) absent; (1) present
27	Both sides of the abdomen's node: (0) not; (1) saw–toothed
28	Two yellow bands on the medithorax: (0) absent; (1) present
29	Vein: (0) not; (1) black
30	Costa: (0) not; (1) black
31	Leg: (0) not; (1) black
32	Cercus: (0) black; (1) brown; (2) white
33	Cercus length: (0) long; (1) short
34	Brace vein: (0) absent; (1) present
35	Antenodal crossvein: (0) not; (1) in line

as shown in Table 2. In addition, a table of discernible characters was constructed by organizing the external morphological characters that represented each taxon clearly, such as the form of appendage, the first lateral suture, the second lateral suture, the humeral suture, the patterns of the abdomen, and the existence of a lobe (Table 2).

Phenetic analysis to reveal the relationships of the 27 species of Anisoptera in Jeju Island was used to reconstruct a phenogram based on the most useful 35 characters were selected at the level of species (Table 1), and were then incorporated into a data matrix to allow them to be coded (Table 3).

Within 27 species of Anisoptera, the lowest dissimilarity index was found between *Anax parthenope* and *A. guttatus*, *Somatochlora clavata* and *S. graeseri, Sympetrum eroticum* and *S. kunckeli, S. infuscatum* and *S. risi*, and *S. striolatum* and *S. darwinianum*, which indicated that these species were more closely related to themselves than to other species in Anisoptera (Table 4). However, the highest dissimilarity index was found between *Aeschnophlebia anisoptera* and *Epophthalmia elegans*, which indicated that these species were not closely related (Table 4).

The phenogram was similar to the results of the ordinary systematic classification. The generated phenogram revealed the presence of two superfamilies within Anisoptera, Aeshnoidea and Libelluloidea (Fig. 2). Moreover, the three independent groups, Aeshnidae (Fig. 2, Ⅰ), Libellulidae (Fig. 2, Ⅱ) and Corduliidae (Fig. 2, Ⅲ), were also clearly branched. These results were similar to other findings, such as the classification systems for Japanese Odonata, which differentiates species based on the existence of a lobe at the 2nd abdominal segment (Ishida *et al*., 1988), the classification system for Korean Odonata, which differentiates species external genitalia (Lee, 2001), a previous study that differentiated species based on the characters of eggs, genitalia, and flight musculature and larva (Pfau, 2005), and the relationships study that differentiated species grounded on mitochondrial 16S rRNA gene sequences (Kim *et al*., 2008). However, several different conclusions were reported. For example, Odonata was found to be composed of two families, Libellulidae and Aeshnidae. In addition, Corduliidae was classified into one subgroup of Libellulidae (Cho, 1958; Gloyd, 1959). In the first domestic external morphological study, Korean Odonata was classified according to the inner margin and anterior margin of the triangle of the forewing (Cho, 1958), as well as by the characters of veins in the wings in another previous study (Gloyd, 1959). Moreover, in yet another study, Trameidae was inde-

Table 2. The morphometric character states used in phenetic analysis of the Anisoptera

Abbreviation	Species	Characters												
		Body length* (m)	Abdomen length* (m)	Hindwing length* (m)	Compound eye	Frons	Interocellar tubercle	Labrum	Mandible	Labium	Vein	Costa	Pterostigma	Leg
A.par	*Anax parthenope*	74.0±2.72	52.0±1.62	51.6±1.34	yellowish green	straight band	dark brown	greenish yellow	yellow	yellow	black	yellow	brown	below tibia black
		Remark: There is no pattern on the thorax. The top of the 2nd and the 3rd abdominal segments are light blue and the bottom is white silver. The 4th abdominal segment and below are colored light brown and have a square shape at the sideline of the body. The length of the superior appendage is same as the 9th and the 10th abdominal segments. The inferior appendage is very short.												
A.nig	*Anax nigrofasciatus*	74.8±1.48	54.7±1.49	46.9±0.88	dark blue	T–shaped band	black	green	yellow green	yellow	black	yellow	brown	black
		Remark: There are black stripes on the humeral suture and the second lateral suture. The 4th abdominal segment and below are black and have light blue spots on the side.												
A.gut	*Anax guttatus*	81.5±1.08	60.0±1.49	54.2±0.92 yellowish green	without band	dark brown	greenish yellow	yellow	yellow	black	yellow	brown	below	femur 1/2 black
		Remark: There is a black stripe between the 1st abdominal segment and the 2nd abdominal segment. The 4th abdominal segment and below have brown spots on the side.												
G.jap	*Gynacantha japonica*	67.6±2.61	51.4±2.07	46.0±2.54	dark brown	T–shaped band	green	yello green	yellow green	yellow	black	black	black	black
		Remark: An indigo blue lobe is developed on the 2nd abdominal segment. The 3rd abdominal segment is very narrow when compared with the 1st and the 2nd abdominal segments. Every segment has light yellow spots on top, showing symmetrical patterns except for the 9th and 10th abdominal segments. The superior appendage is slender and longer than that of Aeshnidae species. Long circuses are observed.												
P.mel	*Polycanthagyna melanictera*	77.2±3.35	59.4±3.05	52.4±2.30	dark brown	black	dark brown	black	yellow	yellow	black	black	black	black
		Remark: There are very heavy and dark black stripes on the humeral suture and the second lateral suture. The 4th abdominal segment and below are colored dark brown, and have T–shaped yellow patterns on the side. The basal parts of the wings are reddish yellow.												
A.ani	*Aeschnophlebia anisoptera*	80.5±3.54	55.5±2.12	52.5±3.54	edge bluishgreen on brown ground	T–shaped band	black	greenish yellow	greenish yellow	yellow	black	yellow	black	black
		Remark: There are dark black stripes on the anteclypeus, postclypeus and edge. The stripes of the second lateral suture separate as they approach the basal part of the wings, eventually forming a Y–shape. The top of the abdomen is entirely black, and the bottom is light green. The basal part is yellow.												
S.gra	*Somatochlora graeseri*	55.8±1.30	41.2±0.84	40.4±0.55	brilliant bluish green	edge yellow on brilliant bluish green	bluish green	black	black	yellow	black	black	black	black
		Remark: The thorax, which is colored golden green, has no patterns but has many yellow trichomes. The 1st, 2nd, and 3rd abdominal segments are club shaped. The 2nd abdominal segment has yellow circle spots. The 3rd abdominal segment has yellow triangle patterns. From the 5th abdominal segment, the width gets until the 8th abdominal segment, after which the width becomes narrow.												
S.cla	*Somatochlora clavata*	59.3±2.08	47.0±3.61	42.7±2.08	brilliant bluish green	brilliant bluish green	black	yellow	black	yellow	black	black	black	black
		Remark: There are yellow spots on the epimeron2 and epimerion3. The 2nd abdominal segment has yellow and triangle shaped patterns. A yellow band is shown between the 2nd and the 3rd abdominal segments. The shape of the superior appendage is curved downward, but its end is sharply protruded.												
E.ele	*Epophthalmia elegans*	70.2±1.30	47.8±0.84	50.0±2.55	green	edge yellow pattern on brilliant bluish green	brilliant bluish green	yellow	yellow	yellow	black	black	black	black
		Remark: There are two yellow stripes on the forehead. The thorax is blue with two yellow stripes and shows dense growth of hairs. The abdomen's color is dark brown and has yellow patterns on every segment except the 6th and the 9th abdominal segments. There is a lobe on top of the 10th abdominal segment. The end of the superior appendage shows a sudden cut and it is almost the same length as the inferior appendage.												
M.amp	*Macromia amphigena*	52.5±3.54	50.5±0.71	41.5±0.71	green	brilliant bluish green	black	brown	black	brown	black	yellow	black	black
		Remark: The anteclypeus has T–shaped and black striped patterns. There is one yellow stripe on the thorax that is connected to the upper part. The yellow marks on the 3rd abdominal segment are "L" shaped. The yellow marks on the 7th abdominal segment are wider than those of other segments. The length of the superior appendage is same as that of the inferior appendage. The bottom of the hindwings are light yellow.												

* Each values indicate the M±SD

Table 2. Continued

Abbreviation	Species	Characters												
		Body length* (m)	Abdomen length* (m)	Hindwing length* (m)	Compound eye	Frons	Interocellar tubercle	Labrum	Mandible	Labium	Vein	Costa	Pterostigma	Leg
L.pac	*Lyriothemis pachygastra*	35.9±1.60	22.0±0.94	25.1±1.60	brown	brilliant bluish green	brilliant bluish green	yellow	brown	yellow	black	black	black and light yellow	below trochanter black
		Remark: The thorax is basically yellow and has clear black stripes on the humeral suture and the second lateral suture. There is a black stripe that is connected imperfectly on the first lateral suture. The abdomen is shot and flat as a whole. It has three black stripes with a yellow background on the center and edge. The superior appendage is black and the inferior appendage is brown.												
O.alb	*Orthetrum albistylum*	52.4±1.07	34.9±0.88	40.4±0.52	bluish green	isabella	black	isabella	yellow	isabella	black	black	black	below femur 1/2 black
		Remark: There are black stripes on the humeral suture, the first lateral suture, and the second lateral suture. The abdominal segment (1 – 3) is club shaped. The 7th abdominal segment and below are black, and the superior appendage is white.												
O.mel	*Orthetrum melania*	52.4±3.50	33.9±1.85	41.6±1.17	bluish green	black	black	black	black	black	black	yellow	black	black
		Remark: The male's thorax is white green. The female's thorax has two black stripes on a yellow background. There is a fan shaped lobe below the female's 9th abdominal segment. The superior appendage and inferior appendage are almost the same length and are both black.												
C.ser	*Crocothemis servilia*	47.2±2.94	29.9±1.91	33.3±2.31	red	red	reddish brown	red	red	red	black	yellow	yellow	red
		Remark: The thorax has no pattern. There are black stripes that are connected to each segment on the top and center of the abdomen. The edges of the abdominal segments show sawteeth shapes. The superior appendage and inferior appendage are almost the same length. The basal part of the wing is red. The marks on the hindwing are very large.												
D.pha	*Deielia phaon*	42.4±2.22	29.0±1.15	32.1±1.66	brown	black	black	brown	black	yellow	reddish brown	black	reddish brown	black
		Remark: The male's anteclypeus has a black band. The thorax of the male is grayish blue. The thorax of the female is yellow with four black stripes on it. There are lateral stripes that are tangled together between the first lateral suture and the second lateral suture. The color of the abdomen is basically grayish blue except for the parts between the 8th and the 10th abdominal segments, which are black.												
S.str	*Sympetrum striolatum*	40.4±1.14	30.0±2.92	28.4±1.52	reddish brown	yellow	reddish brown	yellow	yellow	yellow	black	yellow	brown	tibia inner and the rest of segment black
		Remark: The frons has no pattern. There are thin and black stripes on the humeral suture and the second lateral suture. The first lateral suture has black stripes that begin at the bottom and continue 1/3 of the way up, and it is connected to the second lateral suture. The color of the abdomen is red for males and reddish yellow for females. The color from the 1st abdominal segment to the 5th abdominal segment is white silver. Females have black dot stripes from the 4th to the 10th abdominal segment on the center of the side. There are black triangle patterns below the 8th and the 9th abdominal segments.												
S.dar	*Sympetrum darwinianum*	42.2±1.81	29.0±1.15	30.8±0.92	reddish brown	yellow	reddish brown	yellow	yellow	yellow	dark brown	dark brown	brown	below the trochanter black
		Remark: The thorax is yellow on the ground with slender and black stripes on the humeral suture and the second lateral suture. The first lateral suture has heavy and black stripes from the bottom that extend halfway up. It is extended to the second lateral suture, but not connected to each other, which is different from *Sympetrum striolatum*. The male's abdomen has no pattern. The 10th abdominal segment has black spots on the top and the bottom. The superior appendage is reddish yellow. The inferior appendage is very short.												
S.ero	*Sympetrum eroticum*	38.0±0.82	24.5±1.27	29.7±0.48	reddish brown	two black spot	reddish brown	yellow	yellow	yellow	black	dark brown	reddish brown	below femur black
		Remark: The humeral suture shows an X–shape made by heavy and black stripes that are divided from the top and the bottom. The second lateral suture is slender and long. The first lateral suture shows black stripes on the bottom third. The male's abdomen is red and has no patterns. The female has black stripes from the 4th to the 10th abdominal segment on the center of the side. The superior appendage is long, curved upward and popped out. There are two types of wings for females, one with no pattern and one with a black pattern.												
S.uni	*Sympetrum uniforme*	42.0±1.87	27.2±1.79	34.6±2.07	reddish brown	gamboge	gamboge	gamboge	gamboge	gamboge	gamboge	yellow	reddish brown	gamboges
		Remark: The entire body is reddish yellow. There are no patterns on the thorax or the abdomen. Both the superior and inferior appendages are brown. The basal part and the end of the wings are yellow.												

* Each values indicate the M±SD

Table 2. Continued

Abbreviation	Species	Characters												
		Body length* (m)	Abdomen length* (m)	Hindwing length* (m)	Compound eye	Frons	Interocellar tubercle	Labrum	Mandible	Labium	Vein	Costa	Pterostigma	Leg
S.kun	*Sympetrum kunckeli*	34.7±0.95	22.4±0.84	24.4±0.84	reddish brown	light bluish green	reddish brown	yellow	yellow	yellow	black	black	dark brown	below femur black
		Remark: The front of the head shows white in blue. There are three black stripes scattered irregularly between the humeral suture and the second lateral suture. Females have black stripes from the 4th to the 10th abdominal segment on the center of the side. The superior appendage is long and bends upward at a right angle.												
S.inf	*Sympetrum infuscatum*	46.2±1.10	32.6±0.55	35.6±0.55	reddish brown	two black spot	brown	brown	brown	brown	dark brown	reddish brown	reddish brown	black
		Remark: The humeral suture and the first lateral suture have heavy and black stripes, and the second lateral suture is slender and long. The black stripe on the first lateral suture is connected to the end of the thorax. The abdomen is colored reddish brown on the top and black on the bottom. There are black vertical stripes between the 4th Both the forewing and hindwing have a reddish brown color at the ends of the wings.												
S.ris	*Sympetrum risi*	45.0±4.08	29.0±2.58	33.3±2.06	reddish brown	gamboge	brown	brown	brown	brown	dark brown	dark brown	dark brown	black
		Remark: The humeral suture and the first lateral suture are heavy and have black stripes on them. The first lateral suture is not completely connected to the top, which is different from *Sympetrum infuscatum*. The male's abdomen is red without any patterns. There are black stripes below the 9th and 10th abdominal segment. Females have heavy and black stripes on every segment's border line in the middle of the side. The superior appendage is red. Both the forewing and hindwing have a reddish brown color.												
S.spe	*Sympetrum speciosum*	42.9±2.18	26.4±1.26	33.3±0.95	reddish brown	red	red	dark brown	dark brown	dark brown	black	reddish brown	dark brown	black
		Remark: There are heavy and black stripes on the humeral suture and the second lateral suture. There are two black stripes under the thorax, one that connects the humeral suture to the second lateral suture, and one that connects it to the second lateral suture. Males have black spots below the 10th abdominal segment. The length of the superior appendage and inferior appendage is almost same. Both the forewing and the hindwing show reddish yellow broadly on the basal parts of the wings.												
P.zon	*Pseudothemis zonata*	42.7±2.36	28.7±1.70	37.2±0.92	reddish brown	milky	black	black	brown	yellow	black	black	black	black
		Remark: The thorax is basically black and has episternum3, which has thin yellow stripes, and epimeron3, which has triangle–shaped yellow stripes. The abdomen is basically black and has shown white or yellow colors on the 3rd and 4th abdominal segments. The basal parts of the wings are black–brown. There are black–brown patterns on the ends of wings and the lower parts of the hindwings.												
R.ful	*Rhyothemis fuliginosa*	38.8±1.50	25.0±1.41	35.3±0.96	reddish brown	dark blue	dark blue	black	black	black	brown	brown	brown	black
		Remark: The parts of the thorax and abdomen are black as a whole and have no pattern. The superior appendage is slender and long. Two thirds of the forewing and the entire hindwing are metallic blue in males. Some individuals have blue patterns on the end of the forewing, and show a clear empty space on the hindwing and pterostigma. The hindwing is very large and well developed when compared with the forewing.												
P.fla	*Pantala flavessens*	47.5±1.58	30.5±1.27	40.5±0.53	reddish brown	gamboge	yellow	gamboge	yellow	yellow	yellowish brown	light yellow	yellowish brown	below femur 1/2 black
		Remark: The head is large when compared with the body. There are black stripes on the humeral suture and the second lateral suture, but they are not connected to the bottom. The abdomen is basically reddish yellow and has black stripes on the center of the top. There are triangle black patterns from the 8th to the 10th abdominal segments. Females are white silver on the bottom between 1st and 4th abdominal segments. The superior appendage is slender, long and black. The inferior appendage is brown. The hindwing is more developed than the forewing.												
T.vir	*Tramea virginia*	50.8±0.84	34.6±0.55	43.6±0.55	reddish brown	red	reddish brown	black	yellow	black	black	reddish yellow	black	black
		Remark: The thorax is basically red brown and shows black stripes that are not connected to the humeral suture, the first lateral suture, or the second lateral suture. The abdomen is red and has black triangle marks between the top of the 8th and 10th abdominal segment. Every segment of the abdomen shows black stripes. The superior appendage is long and slender. The basal part of the forewing is reddish yellow. The basal part of the hindwing is large and shows reddish brown patterns.												

* Each values indicate the M±SD

pendently classified under Libelluloidea along with Libellulidae and Cordulinae (Yoon, 1988). Based on these conflicting findings, a clear taxonomical review of these organisms should be conducted.

In this study, Group I, which belongs to Aeshnidae, was divided into *Anax, Gynacantha, Polycanthagyna* and *Aeschnophlebia* (Fig. 2, I). These results were similar to other previous study. Analysis of the anatomical characters of 58 imagoes and larvae formed a group between *Anax* and *Gynacantha* (Ellenrieder, 2002). Specifically, *Aeschnophlebia anisoptera* has been grouped into *Aeschnophlebia* in Jeju Island since it was initially reported by Kobayashi in 1941 (Jung, 2007). Therefore, a thorough analysis of the ecological charac-

Table 3. The morphometric data matrix for phenetic analysis. Species abbreviations are given in Table 2

Species	Character Number																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
A.par	0	1	1	1	0	1	0	0	0	1	1	1	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0
A.nig	0	1	1	1	0	1	0	0	0	1	1	1	0	0	0	2	1	1	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	1	0
A.gut	0	1	1	1	0	1	0	0	0	1	1	1	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0
G.jap	0	1	1	1	0	0	0	0	1	0	1	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	1	0
P.mel	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	1	0	1	1	1	1	0
A.ani	0	1	1	1	0	0	0	0	0	0	1	0	1	0	0	2	1	1	0	0	1	0	1	0	0	0	0	0	1	0	1	1	1	1	0
S.cla	1	0	0	0	1	1	0	0	0	1	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
S.gra	1	0	0	0	1	1	0	0	0	1	1	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
E.ele	1	0	0	0	1	1	0	0	0	1	0	1	1	2	0	0	1	1	0	1	0	0	0	1	0	0	0	1	1	0	1	0	1	0	1
M.amp	1	0	0	0	1	1	0	0	0	1	0	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	1
L.pac	1	0	1	1	0	1	1	1	0	0	1	0	1	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	1
O.alb	1	0	1	1	0	1	1	0	0	1	1	1	1	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	1	0	1	2	1	0	1
O.mel	1	0	1	1	0	1	1	0	0	1	1	0	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	1	0	1	1	1	0	1
C.ser	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	1	0	0	1	1	0	1
D.pha	1	0	1	1	0	1	1	1	0	1	0	0	1	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	1	1	1	0	1	0	1
S.str	1	0	1	1	0	1	1	1	0	1	1	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1
S.dar	1	0	1	1	0	1	1	1	0	1	1	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
S.ero	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	1	0	0	1	1	0	1
S.kun	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1
S.inf	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1	0	1
S.ris	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	1
S.uni	1	0	1	1	0	1	1	1	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
S.spe	1	0	1	1	0	1	1	1	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1
P.zon	1	0	1	1	0	1	1	1	0	1	1	0	1	0	0	0	1	1	0	0	1	0	1	0	0	1	0	0	1	0	1	0	0	0	1
R.ful	1	0	1	1	0	1	1	1	0	1	1	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	1	1	0	1	0	1
P.fla	1	0	1	1	0	1	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1
T.vir	1	0	1	1	0	1	1	0	0	1	1	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	1

Table 4. Dissimilarity matrix in the combined data set of Anisoptera species. The umbers below in the diagonal are divergence values corrected for multiple substitutions using SPSS for IBM, version 11.5. Species abbreviations are given in Table 2

OTU	Squared Euclidean Distance																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1. A.par	–																										
2. A.nig	2.000	–																									
3. A.gut	1.000	5.000	–																								
4. G.jap	6.000	6.000	7.000	–																							
5. P.mel	9.000	11.000	8.000	7.000	–																						
6. A.ani	9.000	7.000	12.000	7.000	6.000	–																					
7. S.cla	14.000	16.000	13.000	16.000	13.000	17.000	–																				
8. S.gra	13.000	15.000	12.000	15.000	14.000	18.000	1.000	–																			
9. E.ele	20.000	22.000	19.000	22.000	19.000	25.000	10.000	9.000	–																		
10. M.amp	17.000	19.000	16.000	19.000	16.000	20.000	5.000	6.000	3.000	–																	
11. L.pac	14.000	18.000	13.000	16.000	11.000	15.000	10.000	11.000	18.000	13.000	–																
12. O.alb	12.000	14.000	11.000	14.000	13.000	17.000	12.000	11.000	16.000	13.000	12.000	–															
13. O.mel	14.000	16.000	13.000	16.000	11.000	13.000	8.000	9.000	16.000	11.000	8.000	4.000	–														
14. C.ser	15.000	19.000	14.000	19.000	14.000	18.000	15.000	16.000	21.000	16.000	5.000	13.000	11.000	–													
15. D.pha	17.000	19.000	16.000	19.000	14.000	18.000	11.000	12.000	17.000	12.000	7.000	11.000	7.000	10.000	–												
16. S.str	9.000	13.000	8.000	15.000	14.000	18.000	11.000	10.000	15.000	12.000	7.000	5.000	7.000	8.000	10.000	–											
17. S.dar	10.000	14.000	9.000	16.000	15.000	19.000	12.000	11.000	16.000	13.000	8.000	6.000	8.000	9.000	11.000	1.000	–										
18. S.ero	12.000	16.000	11.000	18.000	15.000	17.000	12.000	11.000	18.000	15.000	8.000	8.000	6.000	9.000	11.000	3.000	4.000	–									
19. S.kun	11.000	15.000	10.000	17.000	14.000	18.000	11.000	10.000	17.000	14.000	7.000	7.000	7.000	8.000	10.000	2.000	3.000	1.000	–								
20. S.inf	14.000	16.000	13.000	18.000	15.000	17.000	12.000	11.000	18.000	15.000	10.000	8.000	6.000	11.000	11.000	5.000	4.000	2.000	3.000	–							
21. S.ris	15.000	17.000	14.000	19.000	14.000	16.000	11.000	12.000	19.000	14.000	9.000	9.000	5.000	10.000	10.000	6.000	5.000	3.000	4.000	1.000	–						
22. S.uni	12.000	16.000	11.000	18.000	15.000	19.000	12.000	13.000	18.000	13.000	8.000	8.000	8.000	7.000	11.000	3.000	2.000	6.000	5.000	6.000	5.000	–					
23. S.spe	12.000	14.000	11.000	16.000	11.000	15.000	8.000	9.000	16.000	11.000	6.000	6.000	4.000	7.000	7.000	3.000	4.000	4.000	3.000	4.000	3.000	4.000	–				
24. P.zon	14.000	16.000	13.000	16.000	13.000	15.000	8.000	9.000	18.000	13.000	6.000	12.000	6.000	11.000	7.000	9.000	10.000	8.000	9.000	8.000	7.000	10.000	6.000	–			
25. R.ful	17.000	19.000	16.000	21.000	16.000	18.000	13.000	14.000	21.000	16.000	9.000	15.000	9.000	10.000	6.000	10.000	9.000	9.000	10.000	7.000	6.000	7.000	7.000	7.000	–		
26. P.fla	9.000	13.000	8.000	15.000	12.000	16.000	9.000	10.000	19.000	14.000	7.000	9.000	7.000	8.000	10.000	6.000	5.000	7.000	6.000	7.000	6.000	5.000	5.000	7.000	8.000	–	
27. T.vir	11.000	13.000	10.000	15.000	12.000	16.000	7.000	8.000	17.000	12.000	7.000	11.000	7.000	10.000	6.000	8.000	9.000	9.000	8.000	9.000	8.000	9.000	5.000	5.000	6.000	4.000	–

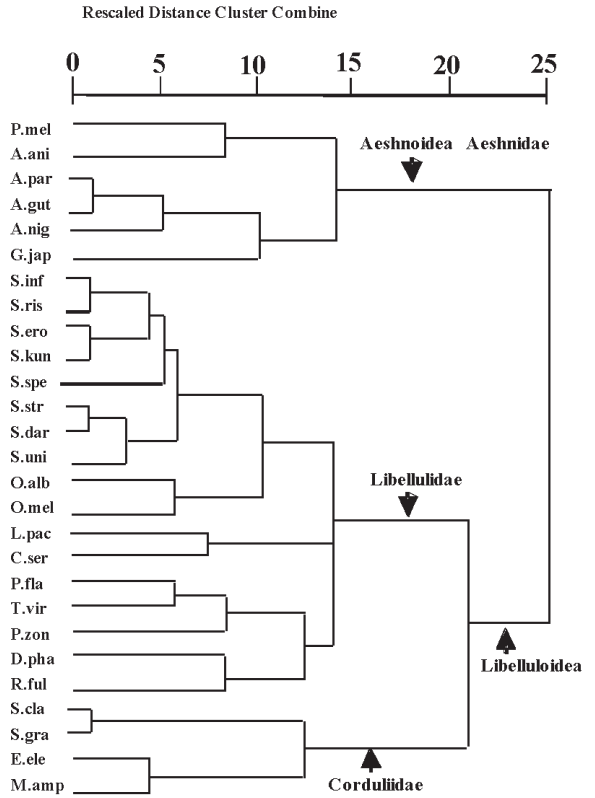

Fig. 2. Phenogram of the 27 species of Anisoptera based on the Squared Euclidean Distance using 35 characters (Average linkage between groups). Dotted lines phenogram indicated 70% similarity and solid line below phenogram indicated major grouping. Species abbreviations are given in Table 2.

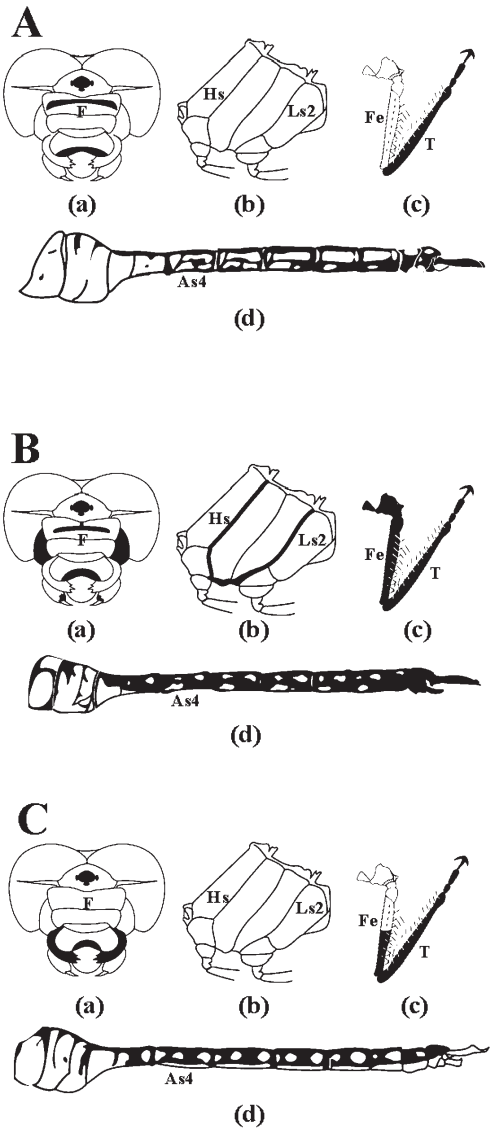

Fig. 3. Schematic drawings of the body morphology of the genus *Anax*. A, *A. parthenope*; B, *A. nigrofasciatus*; C, *A. guttatus*. (a) Head in frontal view, (b) Thorax in lateral view, (c) Leg in lateral view, (d) Abdomen in lateral view. F: Frons, Hs: Humeral suture, Ls2: 2 Lateral suture, Fe: Femur, T: Tibia, As4: 4 Abdominal segment.

ters of this species should be conducted.

Among the three species of *Anax* collected in Jeju Island, the species with similar external morphological characteristics were compared as below. *Anax guttatus* has been classified as a synonym of *A. parthenope* (Asahina, 1989; Lee, 1996), as an independent species (Steinmann, 1997; Kim, 1998). Moreover, *A. guttatus* is generally confused with *A. parthenope* due to the presence of similar morphological characters. However, the results of this study showed that the thoraces of *A. parthenope* and *A. guttatus* were greenish and had no black line on the humeral suture or the second lateral suture (Fig. 3, A and C). Moreover, the light brown tetragonal patterns on the black or yellowish brown background appeared to be connected to each other node by node below the 4th abdominal segment in *A. parthenope* (Fig. 3, A). Conversely, the sky–blue or yellowish brown dots were observed to form a line in both *A. nigrofasciatus* and *A. guttatus* (Fig. 3, B and C). Based on these external morphological characters, *A. guttatus* shared morphological characters with *A. parthenope* and *A. nigrofasciatus*, therefore, it could be recognized as a synonym with *A. parthenope*. However, major differences were observed in the upper edge of the frons in these species. Specifically, the black and straight band in the upper edge of the frons was observed in *A. parthenope* (Fig. 3, A), whereas a black and T–shaped band was observed in *A. nigrofasciatus* (Fig. 3, B) and no striped band was observed in *A. guttatus* (Fig. 3, C). In addition to these observations, a black color was observed below the anterior tibia in *A. parthenope* (Fig. 3, A), whereas black was observed in the bottom half of the anterior femur in *A. guttatus* (Fig. 3, C) and in the whole leg in *A. nigrofasciatus* (Fig. 3, B). Therefore, it is more valid to classify *A. guttatus* as an independent species rather than a synonym of *A. parthenope*, even though it shares some morphological characters with *A. parthenope* and *A. nigrofasciatus*. Moreover, the previous study, which was conducted in terms of ecological characters, reported that *A. guttatus* always competed against *A. parthenope* in the same dwellings, and that its copulation and oviposition were different from those of *A. parthenope* even though they shared similar ecology (Kim, 1998). It has also been reported that, while *A.*

parthenope preferred bright and wild ponds and reservoirs, *A. nigrofasciatus* favored dark and narrow places (Ishida *et al*., 1988). Therefore, if these ecological characters are considered, it is expected that they will be useful characters for further studies.

Group Ⅱ, which belongs to Libellulidae, consisted of three subgroups, Subgroup Ⅰ, which included *Lyriothemis* and *Crocothemis*; Subgroup Ⅱ, which consisted of *Pantala, Tramea, Pseudothemis, Deielia* and *Rhyothemis*; and Subgroup Ⅲ, which consisted of *Orthetrum* and *Sympetrum*; Interestingly, it was composed of eight species belonging to *Sympetrum: S. striolatum, S. darwinianum, S. eroticum, S. kunckeli, S. infuscatum, S. risi, S. uniforme*, and *S. speciosum* (Fig. 2, Ⅱ). The similar classification of *Sympetrum* as a subgroup was also reported in a previous study. For example, in the previous study on Sympetrinae, *Sympetrum* consisted of a group by the relationship of systematics by means of morphology (Pilgrim and Dohlen, 2007). Also, in the previous study on Anisoptera taken on the basis of mitochondrial 16S rRNA sequences (Kim *et al*., 2008). One study, which confirmed the group analysis by constructing a phenogram of Korean *Sympetrum* based on 26 morphological characters, reported that *Sympetrum* was comprised of four groups: *S. darwinianum* and *S. depressiculum*, *S. eroticum* and *S. kunckeli, S. risi and S. infuscatum*, and *S. uniforme* and *S. striolatum* (Yoon, 1997). Although the results of that report were similar to the results of this study, *S. darwinianum* was found to be more closely related to *S. striolatum* than *S. depressiculum* in this study. This may have occurred as a result of *S. depressiculum* not being distributed in Jeju island, which prevented actual specimens collected from Jeju island from being investigated in this study.

When comparing the external morphological characters of the eight species in *Sympetrum*, the presence of two black dots on the frons, the pattern on the superior appendage, and the pattern on the side of the abdomen were similar in *S. eroticum* and *S. kunckeli*. However, the thin and long second lateral suture and the first lateral suture that was observed in *S. eroticum* (Fig. 4, C). Conversely, three black lines were scattered irregularly between the humeral suture and the second lateral suture in *S. kunckeli* (Fig. 4, H).

Both *S. infuscatum* and *S. risi* had brown apexes of the anterior and posterior wings, however, there were differences between these species. For example, the black line in the first lateral suture reached to the end of the thorax (Fig. 4, A) and the vertical stripes appeared in each segment from the 4th to the 10th abdominal segment in male *S. infuscatum*. Conversely, in *S. risi*, the first lateral suture was not completely connected to the back and the male abdomen had a red background and no patterns (Fig. 4, D).

Both *S. striolatum* and *S. darwinianum* had no patterns on either the frons or the apexes of the wings. However, the first lateral suture, which appeared as a thick black line, reached halfway across the thorax from the abdomen in *S. darwinianum* (Fig. 4, E).

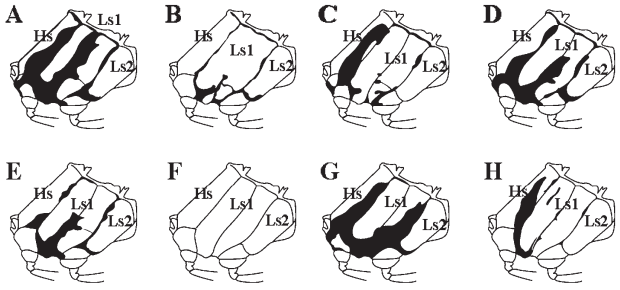

Fig. 4. Schematic drawings of the thorax morphology of the genus *Sympetrum*. A, *S. infuscatum*; B, *S. striolatum*; C, *S. eroticum*; D, *S. risi*; E, *S. darwinianum*; F, *S. uniforme*; G, *S. speciosum*; H, *S. kunckeli*. Hs: Humeral suture, Ls1: 1 Lateral suture, Ls2: 2 Lateral suture.

Conversely, the thin black stripe in the humeral suture and the second lateral suture was observed in *S. striolatum*. In addition, the first lateral suture had a black stripe that extended from the abdomen one third of the way across the thorax and was connected to the second lateral suture (Fig. 4, B). Based on these results, there were no or few variations in the patterns of the first lateral suture, the second lateral suture, and the humeral suture within each species (Fig. 4). Therefore, they were considered to be useful indicators to distinguish species within *Sympetrum*.

Finally, Group Ⅲ, which included Corduliidae, was divided into *Epophthalmia elegans* and *Macromia amphigena* in Macromiinae, and *Somatochlora graeseri* and *S. clavata* in Cordulinae. A notable feature is that *Epophthalmia* and *Macromia* have a high relationship despite belonging to different genus for each. On the other hand, *Epophthalmia elegans* collected in an altitude lower than 200 m from the sea level, while *Macromia amphigena* found over 650 m from the sea level, so it is deemed that there is a need to consider the matter from multifarious approaches through further studies on the ecological characteristics in later years. Some similarities were found between *S. clavata* and *S. graeseri*. For example, both had bluish green colored and metal glossy frons on which yellow hair grew in thick clusters, and they also both had club–shaped 1st, 2nd, and 3rd abdominal segments. However, yellow dots were observed in epimeron$_2$ and epimerion$_3$ in *S. clavata*. *Somatochlora graeseri* has been reported to be distributed in the northern and central region of Korea including Gangwon–do and Mt. Songni, whereas *S. clavata* was distributed throughout the country from Mt. Baekdu to Geoje Island (Jung, 2007). *Somatochlora graeseri* and *S. clavata* were confirmed to be unregistered species in Jeju Island. Therefore, a further detailed review of *Somatochlora* should be conducted using polyphasic taxonomy that includes ecological, physiological and molecular biological methods.

In order to construct a more straightforward and definite phenogram in the study of the phenetic analysis of Anisoptera in Jeju Island, we elected to review the following conditions. Primarily, we conducted a phenetic analysis study via the securement of a sufficient

species. In the current study, we were unable to prepare a more objective phenogram by securing sufficient species of Korean Anisoptera and Zygoptera. If enough species could be secured, it would be expected that a more objective phenogram could be prepared. Secondly, it is necessary to conduct a more versatile character analysis. In the current study, we conducted phenetic analysis using only the external characteristics of Anisoptera, and if various physiological or ecological characteristics could be assessed, it might be possible to perform a more credible phenetic analysis.

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