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Morphometric Classification of the Subgenus *Parapagaronia* from Korea (Homoptera: Cicadellidae)

가시황백매미충아속의 계량형태학적 분류(매미목: 매미충과)

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ABSTRACT A morphometric analysis is used to clarify the interspecific relationship between 4 species of the subgenus *Parapagaronia* in *Pagaronia*. The quantitative distinctions are confirmed at 87.5% of correct assignment in male and 96.25% in female.

KEY WORDS Morphometrics, numerical taxonomy, multivariate analysis, discriminant analysis, *Parapagaronia*, Cicadellidae, Homoptera, Korea

초 록 가시황백매미충아속(*Parapagaronia*)의 計量形態學的 數理分類의 一環 으로서 4種을 대상으로 定量的 形態形質을 이용한 多變量分析을 시도 한 結果, 각 種間 平均分離率이 수컷에서는 87.5%였으나, 암컷에서는 96.25%로 더 높게 나타났다.

검색어 계량형태, 수리분류, 다변량해석, 판별분석, 가시황백매미충아속, 매미충과, 매미목, 한국

Most Far East Asiatic species of the genus *Pagaronia* resemble superficially each other and are often confused in external feature, unless examining male genitalic characters. Especially, most of the females can only be identified by their association with identified males, but in the case of sympatric species, the identification of species is nearly impossible.

As an effort to solve this taxonomic problem, Yoon (1989) already facilitated to discriminate 7 species of the subgenus *Pagaronia* s. str. by using the morphometric analysis. In the present paper, the discriminant analysis was also conducted to determine reliable quantitative characters and to clarify the interspecific relationships among 4 allopatric species of the subgenus *Parapagaronia* represented from different localities.

MATERIALS AND METHODS

Closely allied 4 species of the subgenus *Parapagaronia* were examined in the present investigation. The detailed process was mainly followed after Kwon (1988) and Yoon (1989) (*cf.* Huh, 1993).

A sample of 20 individuals for each male and female species was chosen at random from the appropriate collections (Table 1). All the characters measured here are shown in fig. 1. A total of 30 separate measurements on each individual were taken electronically (Table 2), with the aid of microscopes (stereo or compound microscope) interfaced with a microcomputer.

The image of the characters being measured were projected onto the digitizing pad (Summasketch plus 12"×12") and traced using a stylus. The information was fed into the computer, analyzed using a software package (Autocad V. 10), and the appropriate measurements printed out as a raw data file. This computerized electronic measuring system enables not only simple linear measurements to be made, but also the perimeter and the area such as those of the wings.

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Table 1. Data for specimens used in the morphometric analysis of the subgenus *Parapagaronia* (SEX: 1-male, 2-female, SPN: species No., IND: number of individual)

SEX	SPN	Species	IND	Data
1	1	*diversa*	20	Tŏgyusan, 19, VI, 1993
2	1		20	Ditto
1	2	*seungmoi*	20	P'algongsan, 6, VI, 1985
2	2		3	Ditto, 6, VI, 1984
			1	Ditto, 1, VI, 1985
			3	Ditto, 4, VI, 1985
			11	Ditto, 18, VI, 1985
			1	Ditto, 19, VI, 1985
			1	Ditto, 28, V, 1989
1	3	*elegans*	20	Chuwangsan, 11, VI, 1993
2	3		20	Ditto
1	4	*evansi*	10	Sobaeksan, 30, V, 1989
			10	Ditto, 31, V, 1989
2	4		20	Ditto, 12, VI, 1993

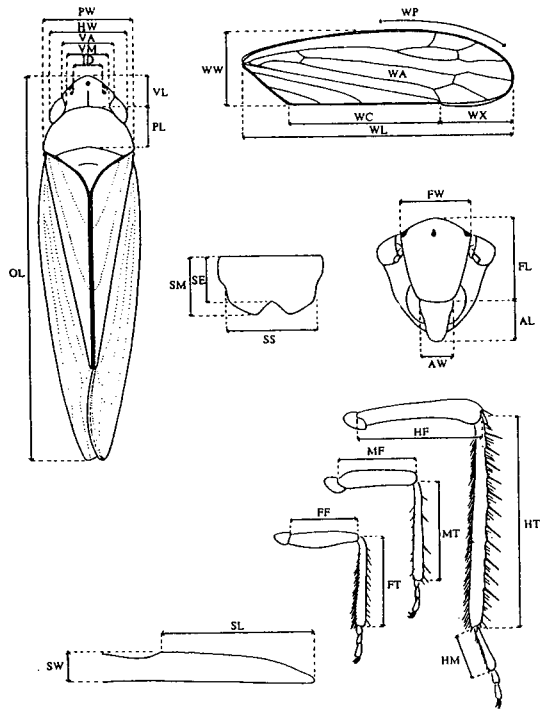

Fig. 1. Schematic drawing of the body parts used in the morphometric analysis (character codes as in the Table 2).

All the electronic measurements adopted here are presented in either unit 10 μm for the linear measurement or μm^2 for the area. The raw data were standardized and fed into the Wilks' lambda stepwise discriminant analysis (Norušis, 1985; SPSS Inc., 1988).

Table 2. Codes for characters used in the morphometric analysis of the subgenus *Parapagaronia* (*: selected characters in female only)

No.	Code	Character
1	OL	Overall length
2	HW	Head width
3	VL	Vertex length
4	VA	Vertex anterior width between eyes
5	VM	Vertex minimum width between eyes
6	ID	Inter ocelli distance
7	FL	Frontoclypeus length
8	FW	Frontoclypeus width between antennae
9	AL	Anteclypeus length
10	AW	Anteclypeus basal width
11	PL	Pronotum length
12	PW	Pronotum width
13	WL	Fore wing length
14	WW	Fore wing width
15	WA	Fore wing area
16	WP	Fore wing perimeter
17	WC	Fore wing commissure length
18	WX	Fore wing appendix length
19	FF	Fore femur length
20	FT	Fore tibia length
21	MF	Middle femur length
22	MT	Middle tibia length
23	HF	Hind femur length
24	HT	Hind tibia length
25	HM	Hind metatarsus length
*26	SS	7th sternum anterior width
*27	SM	7th sternum maximum length
*28	SE	7th sternum median length
*29	SL	2nd valvulae toothed part length
*30	SW	2nd valvulae toothed part width

RESULTS

Some basic morphometrical data for the whole characters represented by the total range, mean, and standard deviation were shown in Fig. 2.

1. Analysis for male

The first step of the main analysis was carried out for all 4 male populations: *P. diversa* from Tŏgyusan, *P. seungmoi* from P'algongsan, *P. elegans* from Chuwangsan, and *P. evansi* from Sobaeksan.

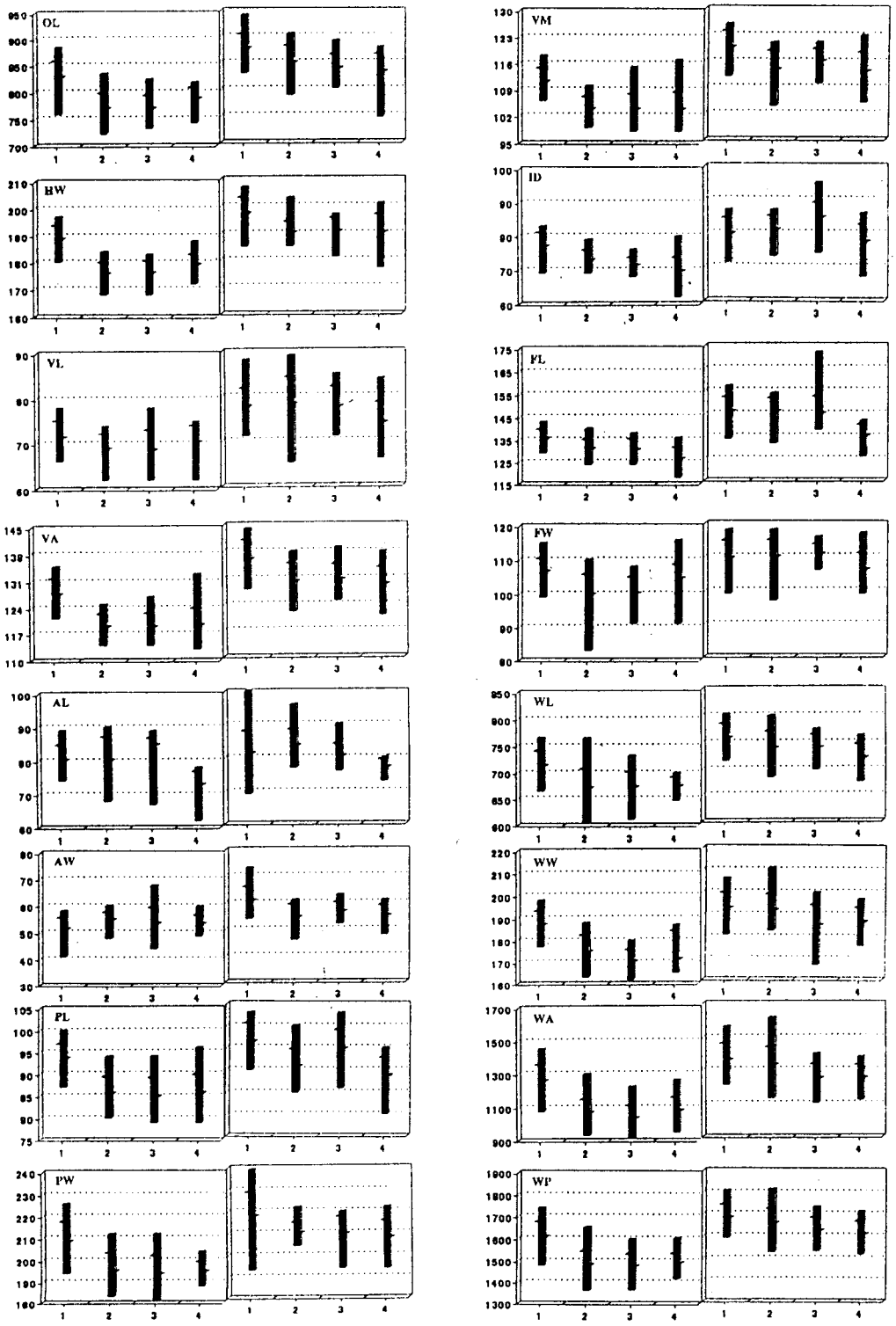

Fig. 2. Some basic data for 30 character-variables (left vertical line represents standard deviation, right vertical line represents mean for each population, thick bar total range, left: male, right: female).

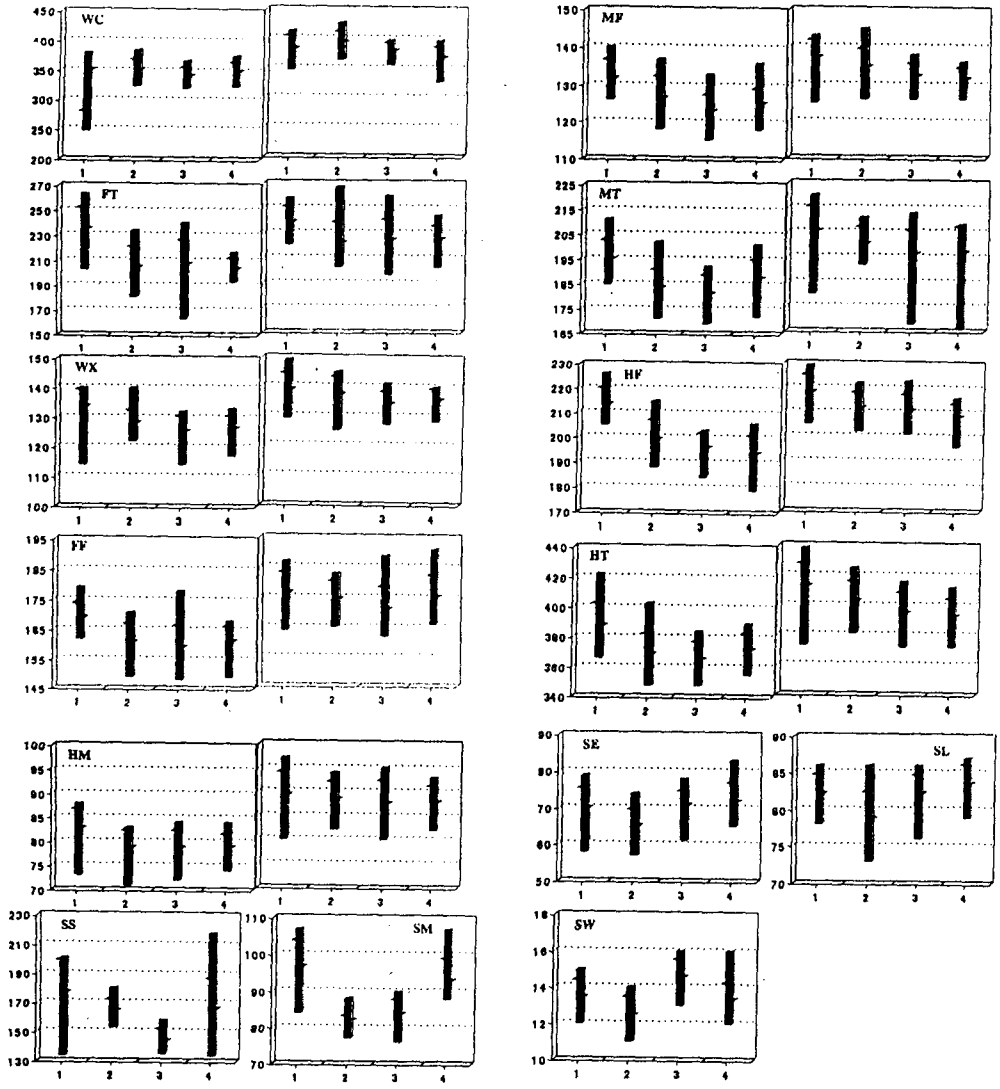

Fig. 2. Continue (2).

For this analysis, a total of 25 external characters covering 10 from head, 1 from thorax, 6 from fore wing, 7 from legs, and finally overall length were used.

The purpose of this analysis is to evaluate any morphological distinctions among the 4 different species belonging to the same subgenus.

As the result, 3 canonical discriminant functions were derived in the analysis. The first 2 functions revealed an accumulative variance of 95.34%, and were also used for the all-group scatterplot (Fig. 3).

The group centroids were plotted 3-dimensionally against function 1, 2 and 3, as they had high variances and large ratios between groups to within groups sum of squares (Fig. 4).

Tests of significances between pairs of group centroids using F-statistics were carried out after step 14. The significance between groups were all highly apparent ($P<0.001$), except for between group 2 (*P. seungmoi*) and group 3 (*P. elegans*) which were slightly lower than other groups (Table 3).

Smaller Wilks' lambda value and larger univariate F-

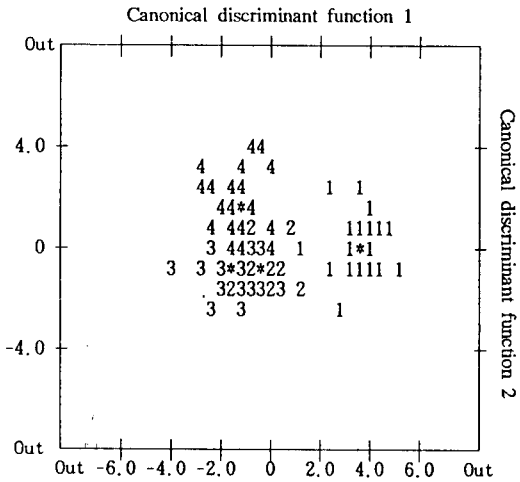

Fig. 3. All-group scatterplot of cannonical discriminant function 1 against function 2 for 4 allopatric species in male.

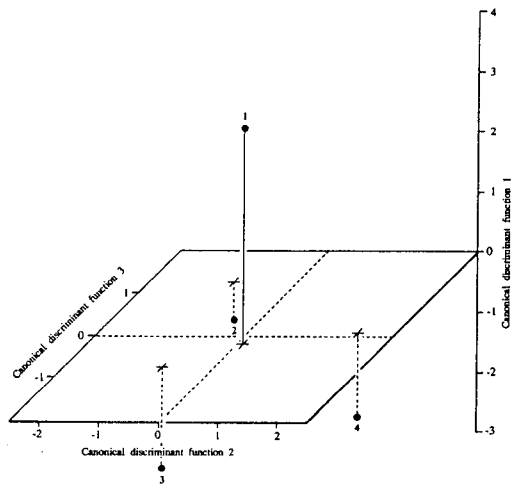

Fig. 4. 3-dimensional plot of the first 3 canonical discriminant functions by group centroids for 4 allopatric species in male.

ratio revealed that the width of the hind wing was the most powerful discriminator, whereas the basal width of the anteclypeus was the least, and most of the characters were significant ($P<0.001$) to the discrimination (Table 4).

In the classification result the predicted group membership gave an average of 87.5% of individuals classified to their known group. The group 1 (*P. diversa*) revealed 95% correct assignment, with 5% predicted for group 2 (*P. seungmoi*), whereas the remainder showed 85% respectively.

Accordingly, the interspecific morphometrical distinction in male was proved to be significantly recognizable, although slightly overlapped in most groups by maximum of 15% (Table 5).

Table 3. F-statistics and significances between pairs of 4 allopatric species in male after step 14 (each F-statistic has 14 and 63 degrees of freedom, P<0.001)

Group		1	2	3
2	*P. seungmoi*	11.3870		
3	*P. elegans*	16.6780	1.9515	
4	*P. evansi*	15.8790	5.6015	4.8901

Table 4. Tests for univariate equality of group means for 4 allopatric species in male

Variable	Wilks' lambda	F	Sign.
OL	.51295	24.05	.0000
HW	.38164	41.05	.0000
VL	.90916	2.531	.0633
VA	.50726	24.61	.0000
VM	.57987	18.35	.0000
ID	.56200	19.74	.0000
FL	.64342	14.04	.0000
FW	.94067	1.598	.1969
AL	.95119	1.300	.2807
AW	.98683	.338	.7979
PL	.50789	24.55	.0000
PW	.59276	17.40	.0000
WL	.69549	11.09	.0000
WW	.58975	17.62	.0000
WA	.44047	32.18	.0000
WP	.50389	24.94	.0000
WC	.95048	1.320	.2742
WX	.56870	19.21	.0000
FF	.66571	12.72	.0000
FT	.67087	12.43	.0000
MF	.66592	12.71	.0000
MT	.64436	13.98	.0000
HF	.72581	9.570	.0000
HT	.66607	12.70	.0000
HM	.78543	6.921	.0004

2. Analysis for female

This analysis was conducted for the 4 populations in female using a total of 30 characters covering 25 ext-

Table 5. Predicted group membership for 4 allopatric species in male

Actual group	No.of cases	Predicted group membership			
		1	2	3	4
1 *P. diversa*	20	19	1	0	0
		95%	5%	0%	0%
2 *P. seungmoi*	20	0	17	3	0
		0%	85%	15%	0%
3 *P. elegans*	20	0	3	17	0
		0%	15%	85%	0%
4 *P. evansi*	20	0	2	1	17
		0%	10%	5%	85%

Percent of "grouped" cases correctly classified: 87.5%

ernal characters same as in case of male, and additionally 5 female genitalic characters.

As the result, 3 canonical discriminant functions were derived from the analysis, and all were statistically very significant (P<0.001). The first one was a variance of 52.41%, and the first 2 functions revealed an accumulative variance of 80.43%, which were used for the all-group scatterplot (Fig. 5).

The function 1, 2 and 3 with an accumulative variance of 100% were plotted 3-dimensionally (Fig. 6).

Tests of significances between pairs of group centroids using F-statistics were carried out after step 20. All the groups (P<0.001) were significantly different (Table 6). Most of the characters were significantly entered into the discrimination (P<0.001).

The most powerful discriminator was the maximum length of the 7th sternum as it had the smallest Wilks' lambda (0.39669) value and the largest univariate F-ratio (38.53), whereas the length of the hind metatarsus was the least (Table 7).

In the classification result, the average predicted group membership was improved, and 96.25% of all individuals were correctly assigned to their known groups. Both the group 3 (*P. elegans*) and the group 4 (*P. evansi*) revealed 100% correct assignments, and the remainder showed 90% in the group 1 (*P. diversa*) and then 95% in the group 2 (*P. seungmoi*), respectively.

Therefore, the interspecific morphometrical distinction in female was improved to an average of 8. 75% higher than those result of male. Thus, it was also

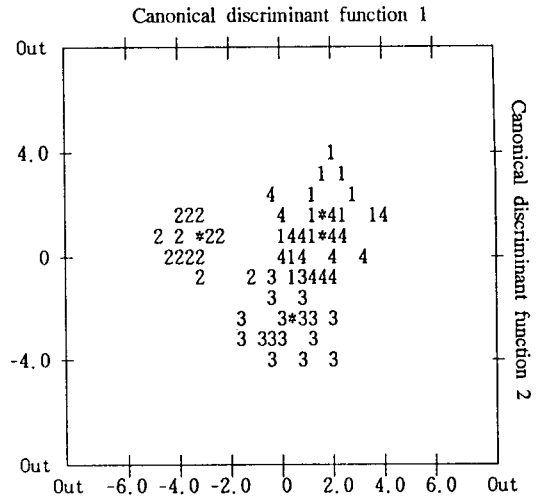

Fig. 5. All-group scatterplot of cannonical discriminant function 1 against function 2 for 4 allopatric species in female.

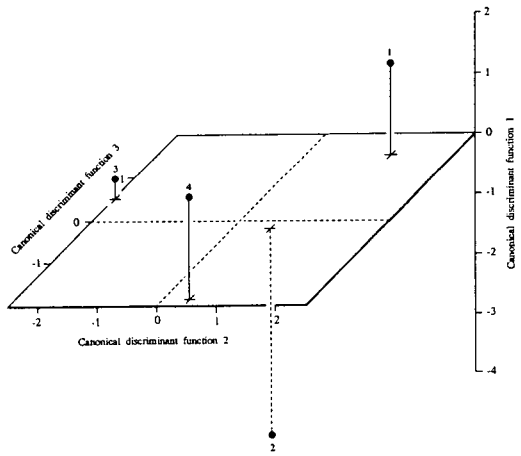

Fig. 6. 3-dimensional plot of the first 3 canonical discriminant functions by group centroids for 4 allopatric species in female.

Table 6. F-statistics and significances between pairs of 4 allopatric species in female after step 20 (each F-statistic has 20 and 57 degrees of freedom, P<0.001)

Group		1	2	3
2	*P. seungmoi*	9.8550		
3	*P. elegans*	8.3217	9.0258	
4	*P. evansie*	7.4718	10.3482	5.7046

proved to be highly recognizable though slightly overlapped by maximum of only 5% (1 individual) in

Table 7. Tests for univariate equality of group means for 4 allopatric species in female

Variable	Wilks' lambda	F	Sign.
OL	.73876	8.958	.0000
HW	.75072	8.412	.0001
VL	.88177	3.397	.0220
VA	.72985	9.377	.0000
VM	.74420	8.708	.0000
ID	.95880	1.089	.3591
FL	.63031	14.86	.0000
FW	.86638	3.907	.0119
AL	.78460	6.955	.0003
AW	.73106	9.320	.0000
PL	.93912	1.642	.1867
PW	.80829	6.008	.0010
WL	.78056	7.122	.0003
WW	.81763	5.651	.0015
WA	.76037	7.984	.0001
WP	.81320	5.819	.0012
WC	.78265	7.035	.0003
WX	.80294	6.217	.0008
FF	.87717	3.547	.0184
FT	.91168	2.454	.0696
MF	.74125	8.843	.0000
MT	.85095	4.437	.0063
HF	.73353	9.203	.0000
HT	.72103	9.802	.0000
HM	.97895	.544	.6532
SS	.64107	14.182	.0000
SM	.39669	38.531	.0000
SE	.94725	1.412	.2462
SL	.70293	10.716	.0000
SW	.59391	17.323	.0000

some groups (Table 8).

DISCUSSION

In the above morphometric analyses, some approaches in the aspects of numerical classification based on the quantitative characters confirmed the morphometric distinctions at interspecific level in both sexes of the 4 species of *Parapagaronia*, although some groups overlapped partially between them.

The result detected that the interspecific differences of female populations treated here were higher than those of male, as represented by 87.5% correct assignment in males and 96.25% in females.

Table 8. Predicted group membership for 4 allopatric species in female

Actual group	No.of cases	Predicted group memberships			
		1	2	3	4
1 *P. diversa*	20	18	0	1	1
		90%	0%	5%	5%
2 *P. seungmoi*	20	0	19	1	0
		0%	95%	5%	0%
3 *P. elegans*	20	0	0	20	0
		0%	0%	100%	0%
4 *P. evansi*	20	0	0	0	20
		0%	0%	0%	100%

Percent of "grouped" cases correctly classified: 96.25%

This may be due to the reason that 5 more female genitalic characters were added for females than in case of males, and thus these genitalic characters affected strongly to the discrimination. Moreover, the maximum length of the 7th sternum in female was turned out to be the most powerful discriminator.

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