STUDIES IN INTRASPECIFIC VARIATION.

V.—Statistical supplement to the analysis of biometrical data on body-size, etc., of various types of individuals of the Desert Locust, presented in Part III.[1]

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Contents.

I.—Introduction.

In Part III (Roonwal, 1949*a*) of this series, detailed biometrical data were published in regard to the more important types of individuals of the Desert Locust, *Schistocerca gregaria* (Forskål) [Orthoptera, Acrididae], *viz.*, phase *gregaria* 6-eye-striped,[2] phase *solitaria* 6-eye-striped and phase *solitaria* 7-eye-striped (Roonwal, 1936-1947). The biometrical data referred to the size of certain body-parts, *e.g.*, the length of the elytron (E), the hind-femur (F), etc., and the ratios of some of these, *e.g.*, E/F, etc. The main conclusions reached (Roonwal, 1949*a*, pp. 163-164) were as follows :—(i) " Regarding the length of the elytron (E) and that of the hind-femur (F), *gregaria* individuals were the smallest (except in male E), 6-striped *solitaria* larger, and 7-striped *solitaria* the largest." (ii) " Within each group, the females are larger than males in respect of all the body-parts, the sexual dimorphism being greatest in 7-striped *solitaria* and least in *gregaria*." (iii) " The mean E/F ratio is lowest in 7-striped *solitaria* (2·02), higher in 6-striped *solitaria* (2·07), and highest in *gregaria* (2·22). It also exhibits sexual dimorphism, being higher in females than in males ; the dimorphism is greatest in *gregaria*, and least in 7-striped *solitaria*."

[1] For Parts I-IV, see References, at the end of this paper, under Roonwal (1946*a*-1949*b*).

[2] The expression " 6-eye-striped " and " 7-eye-striped " have, in this paper, often been abbreviated to " 6-striped " and " 7-striped ".

In the present part, the data given in Part III have been subjected to more rigid statistical tests. As a reuslt, it has been confirmed that the above mentioned results stand unchanged in all essential respects, except in the few cases which are pointed out.

The mean values given here in Table 1*a* agree essentially with those given in the earlier paper, the only noticeable difference being in two cases as follows :—In phase *gregaria* males (6-eye-striped) the mean of elytron-length is 52·85 mm. here as against the earlier 53·03 mm. ; and the mean of hind-femur length is 24·32 mm. against the earlier 24·4 mm. The present values may in all cases be taken as the more accurate.

In addition, the biometrical statistics of the fawn-type *solitaria* forms are also given here. Owing to the small number of observations that are available for this type, it is considered desirable to give only the probable limits of mean value (known as the ' confidence ' or ' fiducial' limits, *vide infra*), rather than the precise means ; nearly 95 per cent of means of such populations are expected to fall with these confidence limits.

This opportunity is also taken to point out certain printing errors that have occurred in the Tables in Part III (Roonwal, 1949*a*). These are as follows :—

Page 155, Table 3, solitaria : 7-striped, ♀♀ :

Value of E/F, under category " 2·17—2·19 " *For* " 3 " *read* " 1 ".

Same, last column (Total).—*For* " 34 " *read* " 84 "

In the following account, except where otherwise stated, the statistics regarding the *solitaria* phase refers to the blue-grey type (often abbreviated to ' blue type ') of individuals.

The *original data* (Tables 1-10) of the individual measurements on which the present analysis, as well as that given in Part III (Roonwal, 1949*a*), are based, have been deposited in the Library of the Zoological Survey of India, Indian Museum, Calcutta, and may be consulted with the permission of the Director.

II.—SIZE OF BODY-PARTS.

(*a*) *Length of elytron* (*E*) *and hind-femur* (*F*).

The mean length (in mm.) of the elytron in males is 52·85±0·52 in phase *gregaria* (6-eye-striped), 52.15±0·24 in 6-eye-striped *solitaria* and 52·38±0·42 in 7-eye-striped *solitaria*. The corresponding mean lengths in females are 58·01±0·81, 61·56±0·31 and 62·90±0·26 mm. respectively (Table 1).

The mean length (in mm.) of the hind-femur in males is 24·32±0·20 in phase *gregaria* (6-eye-striped), 25·4±0·12 in 6-eye-striped *solitaria* and 26·13±0·21 in 7-eye-striped *solitaria*. The corresponding mean lengths in females are 26·44±0·37, 29·37±0·18 and 30·92±0·13 mm. respectively (Table 1).

TABLE 1.—*Schistocerca gregaria* (Forsk.), ph. *gregaria* and ph. *solitaria* (grey-blue type).

[From Tables 1, 2, 5, 6, 9 and 10 of original data.]

Statistical constants relating to the lengths (in millimetres) of elytron and hind-femur and their ratios in phase gregaria *and phase* solitaria *(grey-blue type) individuals.*

Abbreviations :—*Greg.*, phase *gregaria*; *Sol.*, phase *solitaria* ; *No. of obs.*, number of observations (individuals measured) ; *6- or 7-striped* 6- or 7-eye-striped.

Phase, sex, and number of eye-stripes	Elytron (E)		Hind-femur (F)		Ratio	
	No. of obs.	Length of elytron (E) (in mm.)	No. of obs.	Length of hind-femur (F) (in mm.)	No. of obs.	E/F
			(a) Means, with standard errors.			
Greg. ♂♂ (6-striped)	14	52·85±0·52	25	24·32±0·20	11	2·17±0·02
Sol. ♂♂ (6-striped)	89	52·15±0·24	89	25·40±0·12	89	2·05±0·01
Sol. ♂♂ (7-striped)	25	52·38±0·42	25	26·13±0·21	25	2·00±0·01
Greg. ♀♀ (6-striped)	26	58·01±0·81	34	26·44±0·37	23	2·25±0·02
Sol. ♀♀ (6-striped)	63	61·56±0·31	63	29·37±0·18	63	2·09±0·01
Sol. ♀♀ (7-striped)	84	62·90±0·26	84	30·92±0·13	84	2·03±0·007
			(b) Standard deviations, with standard errors.			
Greg. ♂♂ (6-striped)	14	1·93±0·36	25	0·99±0·14	11	0·08±0·02
Sol. ♂♂ (6-striped)	89	2·23±0·17	89	1·12±0·08	89	0·06±0·004
Sol. ♂♂ (7-striped)	25	2·10±0·30	25	1·04±0·15	25	0·06±0·01
Greg. ♀♀ (6-striped)	26	4·12±0·57	34	2·13±0·26	23	0·08±0·01
Sol. ♀♀ (6-striped)	63	2·49±0·22	63	1·44±0·13	63	0·06±0·01
Sol. ♀♀ (7-striped)	84	2·42±0·19	84	1·21±0·09	84	0·06±0·01
			(c) Coefficients of variation, with standard errors.			
Greg. ♂♂ (6-striped)	14	3·65±0·69	25	4·07±0·58	11	3·69±0·79
Sol. ♂♂ (6-striped)	89	4·28±0·32	89	4·42±0·33	89	2·93±0·22
Sol. ♂♂ (7-striped)	25	4·01±0·57	25	3·98±0·56	25	3·00±0·42
Greg. ♀♀ (6-striped)	26	7·10±0·98	34	8·06±0·98	23	3·51±0·52
Sol. ♀♀ (6-striped)	63	4·04±0·36	63	4·90±0·44	63	2·87±0·26
Sol. ♀♀ (7-striped)	84	3·85±0·30	84	3·92±0·30	84	2·96±0·23

The variabilities in the lengths of the elytron and the hind-femur are more or less uniform in almost all cases. The coefficients of variation (Table 1) lie between 3·65 per cent and 4·90 per cent in all cases, except in the case of phase *gregaria* females (6-striped) where the coefficients are 7·10 per cent and 8·06 per cent in the lengths of the elytron and hind-femur respectively.

The significance of differences (as judged by Fisher's *t* test of significance) in the lengths of the elytron and the hind-femur among the various types of individuals is given in Table 2. It will be seen that, except in the following 3 cases, all the differences are significant at one per cent level of probability; in other words, they are highly significant. The 3 exceptional cases refer to the elytron-length of males, where it is not significantly different (i) between phase *gregaria* and 6-striped *solitaria* individuals; (ii) between phase *gragaria* and 7-striped *solitaria* individuals; and (iii) between 6-striped *solitaria* and 7-striped *solitaria* individuals. This lack of significant difference in the 3 cases just mentioned was not appreciated in the earlier account (Part III, Roonwal, 1949*a*, p. 151), where it was stated that " the male elytron of *gregaria* is, however, exceptional in being longer "; in the light of the present analysis, this statement should now read as follows :— " The male elytron is, however, exceptional in not showing any significant differences in length between the three types of individuals."

Leaving aside the exceptional cases of the male elytra, the following conclusions are valid for the elytron and hind-femur lengths, the two sexes being separately analysed (Table 2) :—

TABLE 2.—*Schistocerca gregaria* (Forsk.), ph. *gregaria* and ph. *solitaria* (grey-blue type).

Significance of differences (as judged by Fisher's t *test) in mean values, given in Table 1, regarding statistics of lengths (in millimetres) of elytron and hind-femur and their ratios.*

Abbreviations :—As in Table 1.

Difference between	Length of elytron (E)		Length of hind-femur(F)		Ratio E/F	
	Mean	Fisher's *t*	Mean	Fisher's *t*	Mean	Fisher's *t*
(i) *Sol.* ♂ (6-striped)	52·15	1·11	25·36	4·22*	2·05	5·96*
and						
Greg. ♂ (6-striped)	52·85		24·32		2·17	
(ii) *Sol.* ♀ (6-striped)	61·56	5·00*	29·37	8·03*	2·09	9·66*
and						
Greg. ♀ (6-striped)	58·01		26·44		2·25	

* Significant at one per cent level of probability, *i.e.*, highly significant.

Table 2 continued on next page.

TABLE 2. *contd.*—*Schistocerca gregaria* (Forsk.), ph. *gregaria* and ph. *solitaria* (grey-blue type).

Difference between	Length of elytron (E)		Length of hind-femur (E)		Ratio E/F	
	Mean	Fisher's *t*	Mean	Fisher's *t*	Mean	Fisher's *t*
(iii) *Sol.* ♂ (7-striped)	52·38	0·69	26·13	6·30*	0·09	7·01*
and						
Greg. ♂ (6-striped)	52·85		24·32		0·06	
(iv) *Sol.* ♀ (7-striped)	62·90	7·50*	30·92	14·41*	2·03	14·61*
and						
Greg. ♀ (6-striped)	58·01		26·44		2·25	
(v) *Sol.* ♂ (6-striped)	52·15	0·46	25·36	3·09*	2·05	3·62*
and						
Sol. ♂ (7-striped)	52·38		26·13		2·00	
(vi) *Sol.* ♀ (6-striped)	61·56	3·28*	29·37	7·07*	2·09	5·90*
and						
Sol. ♀ (7-striped)	62·90		30·92		2·03	
(vii) *Greg.* ♂ (6-striped)	52·85	5·36*	24·32	5·04*	2·17	3·57*
and						
Greg. ♀ (6-striped)	58·01		26·44		2·25	
(viii) *Sol.* ♂ (6-striped)	52·15	24·01*	25·40	18·35*	2·05	2·84*
and						
Sol. ♀ (6-striped)	61·56		29·37		2·09	
(ix) *Sol.* ♂ (7-striped)	52·38	21·30*	26·13	19·39*	2·00	0·42
and						
Sol. ♀ (7-striped)	62·90		30·92		2·03	

* Significant at one per cent level of probability, *i.e.*, highly significant.

(i) Among *solitaria* phase, the 7-striped individuals are slightly larger than the 6-striped ones. (ii) The *gregaria* phase individuals (all 6-striped) are considerably smaller than the 6-striped *solitaria* and even more so than the 7-striped *solitaria* individuals. The statistically significant differences between the 6-striped and 7-striped *solitaria* individuals are of particular interest because the populations analysed were taken from the same area (Mekran Coast, S. Baluchistan) and at the same period (during the year 1936). The differences, therefore, cannot reasonably be attributed to different origins of the samples, and should be regarded as genuine differences correlated with eye-stripes.

The actual degree of significant difference varies between the sexes and the types of individuals. Taking the 6-eye-striped *solitaria* at 100, the degree of difference, expressed as a percentage, is as follows (Table 3), the plus and minus signs indicating excess and defect respectively over the standard value of 100 :—

TABLE 3.—*Schistocerca gregaria* (Forsk.), ph. *gregaria* and ph. *solitaria* (grey-blue type).

Percentage of differences in the means (see Table 1) of the lengths of the elytron (E) and hind-femur (F) and the ratio E/F in various types of phase gregaria *and phase* solitaria *(grey-blue type) individuals, taking 6-eye-striped* solitaria *as 100.* (Cf. *Table 6 of Part III, Roonwal, 1949a, p. 159*). (*All the values of difference given here, except those marked with an asterisk*, are significant at one per cent level of probability.*)

Abbreviations :—As in Table 1.

Phase, sex and number of eye-stripes.	E	F	E/F
Greg. ♂♂ (6-striped)	+1·34*	—4·25	+5·85
Sol. ♂♂ (6-striped)	100	100	100
Sol. ♂♂ (7-striped) . .	+0·44*	+2·87	—2·44
Greg. ♀♀ (6-striped)	—5·77	—9·98	+7·66
Sol. ♀♀ (6-striped)	100	100	100
Sol. ♀♀ (7-striped)	+2·17	+5·28	—2·87

* Not significant at one per cent level of probability (Table 2).

Elytron length.—Ph. *gregaria* (6-striped): ♀♀, —5·77 per cent; ph. *solitaria* (7-striped): ♀♀, +2·17 per cent. The males, as already mentioned, are not significantly different.

Hind-femur length.—Ph. *gregaria* (6-striped): ♂♂, —4·25 per cent; ♀♀, —9·98 per cent; ph. *solitaria* (7-striped): ♂♂, +2·87 per cent; ♀♀, +5·28 per cent. It is noteworthy that the degree of difference is more pronounced (irrespective of direction) in females than in males.

A comparison of the exceptional behaviour of the male elytron-length in *Schistocerca gregaria* with the condition obtaining in other Acrididae is of interest and has already been referred to in Part III (Roonwal, 1949*a*, p. 151).

TABLE 4.—*Schistocerca gregaria* (Forsk.), ph. *solitaria* (fawn type).

[From Tables 3, 4, 7 and 8 of original data.]

Confidence limits of the means relating to the length (in millimetres) of elytron (E) and hind-femur (F) and their ratio (E/F) in phase solitaria *(fawn type) individuals.*

Abbreviations :—As in Table 1.

Character	No. of obs.	Range	Means, with standard errors	Confidence limits of mean
		(*a*) *Males.*—6-eye-striped.		
E (mm.)	8	51·0—57·0	53·25±0·67	51·67—54·83
F (mm.)	8	24·0—28·0	25·85±0·52	24·62—27·08
E/F	8	1·96—2·23	2·06±0·03	1·99— 2·13
		(*b*) *Males.*—7-eye-striped.		
E (mm.)	5	49·0—56·5	52·80±1·25	49·33—56·27
F (mm.)	5	24·0—28·0	25·80±0·68	23·91—27·69
E/F	5	1·97—2·11	2·04±0·02	1·98— 2·10
		(*c*) *Females.*—6-eye-striped.		
E (mm.)	5	59·5—64·2	62·14±0·89	59·67—64·61
F (mm.)	5	29·3—31·7	30·50±0·47	29·20—31·80
E/F	5	1·96—2·13	2·03±0·03	1·95—2·11
		(*d*) *Females.*—7-eye-striped.		
E (mm.)	5	61·0—66·0	63·80±0·90	61·30—66·30
F (mm.)	5	29·5—31·5	30·70±0·34	29·76—31·64
E/F	5	2·01—2·12	2·07±0·02	2·01— 2·13

Fawn-type, phase solitaria (Table 4).—Since the mean values in the case of the ' fawn types ' phase *solitaria* individuals are estimated from very small samples (the number of observations not exceeding 8), the confidence limits (or ' fiducial interval ' of Fisher, 1933) (*vide* Snedecor, 1946) of the means are shown. The *t* ratio of small sample theory is defined by the formula :—

$$\pm t = \frac{x-m}{s_x},$$

where x is the sample mean, s_x the standard error of the mean and m the population-mean for which the confidence limits are to be found out.

The probability distribution of t has been found out and the probability values of t are given by Fisher (1933). By choosing the 5 per cent level of probability, the values of t corresponding to the appropriate number of degrees of freedom are noted from Fisher's table. Then the confidence limits of m are given by the formulae :—

$$l_1 = x - t_{0\cdot05}s_x \text{ ; and } l_2 = x + t_{0\cdot05}s_x,$$

where l_1 and l_2 are the lower and upper limits respectively. If we say that the population mean, m, lies between these limits, the probability of being misled by the sampling is only 0·05. The statistical constants of the fawn type of phase *solitaria* individuals are given in Table 4, from which it is not possible to discern any marked departures from the corresponding values in the blue-grey types of phase *solitaria* individuals discussed above.

TABLE 5.—*Schistocerca gregaria* (Forsk.).

[From Table 9 of original data.]

Statistical constants, of phase gregaria *(6-eye-striped) individuals from swarms, relating to the (i) maximum width (in mm.) of head in the genal region* (C) ; *(ii) length (in mm.) of pronotum at the keel* (P) ; *(iii) height (in mm.) of pronotum* (H) ; *(iv) width (in mm.) of pronotum at the construction* (M) ; *and (v) the ratios* P/C, H/C *and* M/C.

Abbreviations :—As in Table 1.

Character	No. of obs.	Means, with standard errors	Standard deviations, with standard errors	Coefficient of variation, with standard errors
		(a) Males.		
C	34	7·55 ±0·04	0·26 ±0·03	3·44 ±0·42
P	31	9·87 ±0·08	0·44 ±0·06	4·46 ±0·57
H	34	8·39 ±0·05	0·32 ±0·04	3·81 ±0·47
M	34	5·86 ±0·04	0·26 ±0·03	4·44 ±0·54
P/C	31	1·305±0·011	0·063±0·008	4·828±0·618
H/C	34	1·112±0·008	0·045±0·005	4·047±0·494
M/C	34	0·779±0·008	0·045±0·005	5·777±0·706
		(b) Females.		
C	40	7·89 ±0·07	0·47 ±0·05	5·96 ±0·67
P	40	10·49 ±0·13	0·84 ±0·09	8·01 ±0·90
H	43	8·92 ±0·10	0·64 ±0·07	7·17 ±0·78
M	42	6·36 ±0·08	0·49 ±0·05	7·70 ±0·85
P/C	37	1·324±0·009	0·055±0·006	4·154±0·486
H/C	40	1·126±0·007	0·045±0·005	3·996±0·450
M/C	40	0·805±0·005	0·032±0·004	3·975±0·447

(b) Measurements of head and pronotum.

For the head and pronotum, measurements are available only for phase *gregaria* individuals, the number of observations being 31-43. The mean values, with standard errors, etc., will be found in Table 5 ;

they do not show any material departure from the values given in Part III (Roonwal, 1949*a*, p. 151, and Table 4).

III.—SEXUAL DIMORPHISM.

As shown in Part III (Roonwal, 1949*a*, pp. 160-163), within each type, females are significantly larger than males as regards the absolute length of the elytron and hind-femur (Table 2, items vii-ix). The degree of sexual dimorphism in E and F, whether expressed as " sexual dimorphism ratio " or as " sexual dimorphism percentage ", is, as shown in Part III (Roonwal, 1949*a*, pp. 160, 161, Tables 7 and 8), nearly double (*ca.* 18-20 per cent in E and *ca.* 16-18 per cent in F) in the *solitaria* phase as compared to *gregaria* phase individuals (*ca.* 9 per cent in E and 8 per cent in F). Regarding other body-measurements, *viz.*, C, P, H and M, the degree of sexual dimorphism within the *gregaria* phase (for which alone values are available) is less pronounced but follows the same significant pattern as in E and F (Table 6).

TABLE 6.—*Schistocerca gregaria* (Forsk.), *phase* gregaria.

Significance of sexual differences (as judged by Fisher's t) *in mean values, given in Table 5, of the characters* C, P, H *and* M *and the ratios* P/C, H/C *and* M/C.

Character	Mean (*Male*)	Mean (*Female*)	Mean difference	Standard Error of Difference	Fisher's *t*
C . . .	7·55	7·89	0·34	0·08	4·25*
P . . .	9·87	10·49	0·62	0·15	4·13*
H . . .	8·39	8·92	0·53	0·11	4·82*
M . . .	5·86	6·36	0·50	0·09	5·56*
P/C . .	1·305	1·324	0·019	0·014	1·36
H/C . .	1·112	1·126	0·014	0·010	1·40
M/C . .	0·779	0·805	0·026	0·009	2·89*

* Significant at one per cent level of probability, *i.e.*, highly significant.

In E/F ratio also a certain degree of sexual dimorphism is observable, as already mentioned in Part III of this series. Within each type of individuals, females have slightly but significantly higher E/F ratios than males, except in 7-striped *solitaria* where the difference between the two sexes is not significant.

In regard to other ratios, in phase *gregaria*, females have slightly but significantly higher ratios than males for the ratio M/C; the sexual difference in other ratios, *viz.*, P/C and H/C, is not significant at one per cent level of probability. For phase *solitaria* these ratios are not available.

IV.—BIOMETRICAL RATIOS.

(*a*) *Elytron/hind-femur (E/F) ratio.*

The mean E/F ratio in males is 2·17±0·02 in phase *gregaria* (6-striped), 2·05±0·01 in 6-eye-striped *solitaria* and 2·00±0·01 in 7-striped *solitaria* individuals. The corresponding values in females are 2·25±0·02, 2·09±0·01 and 2·03±0·007. The significance of the differences (as judged by Fisher's *t* test of significance) in the mean values between the various types of individuals is given in Table 2. It will be seen that all the differences are significant at one per cent level of probability; in other words, they are highly significant. The actual degree of significant difference varies between the sexes and the types of individuals. Taking the 6-striped *solitaria* at 100, the degree of difference, expressed as a percentage, is as follows (Table 3), the plus and minus signs expressing excess and defect respectively over the standard value of 100:— Phase *gregaria* (6-striped): ♂♂, +5·85 per cent; ♀♀, +7·66 per cent. Phase *solitaria* (7-striped): ♂♂, —2·44 per cent; ♀♀ —2·87 per cent.

It is thus possible to confirm the previous conclusions (Part III, Roonwal, 1949*a*, p. 162), *viz.*, that (i) irrespective of sexual variation, the 6-striped *solitaria* individuals have a significantly higher mean E/F ratio than 7-striped *solitaria*; and (ii) the *gregaria* (6-striped) individuals have a higher ratio than even the 6-striped *solitaria*. Irrespective of direction, the degree of difference is, in both cases, slightly more marked among females than in males.

(*b*) *Other ratios.*

The mean values of other ratios, *viz.*, P/C, H/C and M/C, for phase *gregaria* only, will be found in Table 5, and do not call for further comment.

V.—SUMMARY.

1. The present part deals with a more rigid statistical analysis than was previously done, of the same data on biometry of the Desert Locust as was presented in Part III (Roonwal, 1949*a*). The statistics refer to the length, etc. of the various body-parts, *viz.*, the elytron, hind-femur, pronotum and head, and the various ratios of these measurements.

2. The significance of differences between the mean values of elytron-length, etc., is judged from Fisher's *t* test. In the case of the 'fawn' type of *solitaria* phase individuals, where the number of observations is very small, the confidence (or fiducial) limits of means are given in addition to the calculated means.

3. As a consequence of this more rigid analysis it has been possible to confirm, on a more firm basis, nearly all the conclusions arrived at in Part III, except a few which are mentioned.

4. The exceptional cases refer to the length of the male elytron which was formerly considered longer in phase *gregaria* than in phase *solitaria* individuals. The present results, however, show that the male elytron does not show any significant difference between the three types of

individuals, *viz.*, phase *gregaria* (6-eye-striped), phase *solitaria* (6-eye-striped), and phase *solitaria* (7-eye-striped).

5. Marked sexual dimorphism (significant at one per cent level of probability) exists within each type, females having higher values than males in E, F, C, P, H, M, and the ratios E/F and M/C. In P/C and H/C no significant difference is noticeable. Regarding E and F, the degree of sexual dimorphism is nearly double in the *solitaria* phase individuals as compared to *gregaria* phase individuals.

VI.—REFERENCES.

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