A COMPARATIVE BEHAVIOURAL STUDY OF PREY CAPTURE, DRINKING AND DEFENCE IN THE SCORPIONIDAE AND BUTHIDAE

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A project submitted to the Zoology Department, Faculty of Science, University of the Witwatersrand, in part fulfilment of the third year for the degree of B.Sc.

1978

ABSTRACT

Prey capture, drinking and defensive behaviour were studied in the Scorpionidae and the Buthidae. Five typical positions of the scorpions were found.

In the prey-capture and defensive behaviour, it is found that the Scorpionidae rely far more on their chelae than do the Buthidae, who rely mainly on their metasoma and aculeus for subdueing the prey and warding off opponents. The theory of Hadley and Williams (1968) was confirmed, that scorpions do not necessarily feed at the point of capture. In both Scorpionidae and Buthidae, the prey is orientated to a head first position before being eaten.

Drinking is achieved by the movement of the chelicerae and pumping of water as indicated by movement of the first pair of legs. The behaviour of both families is very similar when drinking.

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INTRODUCTION

Structurally, the armament of scorpions of the two families Scorpionidae and Buthidae differ widely. Scorpionid scorpions have well developed pedipalps whereas the metasoma is weak and insignificant in comparison to the Buthid scorpion's, (of a relatively similar size), metasoma. The telson itself is very small being only one third of the size of the Buthid telson. Buthid scorpions have small pedipalps which function mainly to hold the prey so that it can be stung.

Due to these basic structural differences it can be expected that the prey-capture and defensive behaviour of the two families should be significantly different.

Satiation plays an important role in the reaction of scorpions to their environment. Any behavioural study thus has to take into account the state of their nourishment at the time of the observations. Satiated scorpions generally respond slowly or not at all to some stimuli, whereas hungry scorpions are extremely alert. A satiated scorpion may not respond to an insect crawling on it, while a hungry scorpion reacts to its presence by physical contact.

Scorpions sting both offensively and defensively. The cauda or metasoma (tail) has five segments whose joints each allow enough freedom for rotatory movement so that the aculeus can be directed in all directions except to the ventral surface.

Offensive and defensive stinging differs distinctly in the Buthid scorpions:- defensive stinging involves a series of flicking, chance thrusts of the aculeus, followed by attempts to escape:- the offensive sting involves a deliberate, thrusting action. This occurs when the prey is obstreperous and will not quietly submit to being devoured alive.

Offensive and defensive action in the Scorpionidae also differs distinctly:- the defensive action involves placing the pedipalps in front of the mouthparts or making abrupt movements towards the opponent with the chelae and fingers:- the offensive action involves the pedipalps being held out in front of the body, the chelae being slightly tilted toward the inside. The aculeus is only used when the prey is obstreperous, so that it will be subdued. In most cases the prey is tightly held and crushed by the chela.

Scorpions digest their prey outside or just inside of the buccal cavity and then ingest the resulting fluids. The prey is torn into tiny bits which are packed together as small pellets and may be literally thrown away, once sucked dry.

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In both Scorpionids and Buthids, the pedipalps move the prey to the chelicerae which pierce and cut and tear the soft and hard parts of the prey. As soon as the cheliceral activity begins, a large amount of opalescent liquid exudes from the buccal cavity. While the body fluids of the prey are abundant, a sucking action takes place as indicated by the back and forth movement of the first pair of legs. Once the body fluids cease flowing, the cheliceral action starts again - the chelicerae break the prey up into small particles which are packed between the coxa of the pedipalps. The body fluids are extracted and the dried pellet is then discarded. The process of sucking up free-flowing fluids, pressing out the fluid in the tiny pellets and casting out the resultant tiny, dried pellet is repeated until the prey is devoured.

Detection of the prey is not entirely due to sight since the eyes are too crude to be of much assistance and the scorpion is in any event a nocturnal animal. Other sensitive organs must therefore be employed, i.e. sensory hairs or trichobothria which are found only on the pedipalps. These trichobothria vary in position and number in different species of scorpions. They are recognized by the shape of their point of insertion which resembles the top of a well, their fineness and their direction of movement when blown upon - movement is in one direction only. By means of these, air movements produced by the prey are detected.

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The Scorpionidae have chela about one-third the body length (i.e. from head to aculeus) and are approximately as large as the carapace of the species. The Buthidae, however, have chelae only about one-fifth of the body length and which are approximately as large as half the carapace. The aculeus and metasoma of the Scorpionidae is as long as the mesosoma, and the segments are extremely small and narrow.

In the Buthidae, the aculeus and metasoma are as long as the mesosoma and carapace together. The segments are long and wide.

Experiments were carried out in order to compare the effect of these important anatomical differences on the prey-capture and defense of the two families. Since little work has been done on the drinking behaviour, this aspect was observed as well. Differences in the defence behaviour when different and similar species encounter one another were also noted.

MATERIALS AND METHODS

Representatives of the Scorpionidae used in the study were:-

2 x Opisthophthalmus glabrifrons Peters
2 x O. flavescens Purcell
2 x O. carinatus Peters

Representatives of the Buthidae used in the study were:-

5 x Parabuthus brachystylus Lawrence
1 x P. villosus Peters

All observations and experiments were carried out under laboratory conditions and at 15°C - 20°C. Scorpions were kept in glass jars of 9 cm diameter, except for the O. glabrifrons which were placed into 0,3 x 0,6 metres fish tanks simulating the environmental conditions in which they were found. All other species were obtained from the South African Institute for Medical Research, Johannesburg.

Experiments were conducted in a specially constructed container 11 x 19 x 38 cm, with two sides made of glass, the rest of wood.

The scorpions were fed with the cockroach - Leucophaea madierae, which were obtained from the South African Bureau of Standards, and were kept in a 0,3 x 0,9 metre fish tank and supplied with food and water.

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All scorpions were not fed or watered for three weeks prior to the execution of the experiments. (Their nutritional status before this time cannot be accounted for.)

a) EXPERIMENT 1 :- PREY-CAPTURE BEHAVIOUR

The scorpions were placed in the observation box singly and allowed to adjust to their new environment. No time limit was set for this adjustment, the time being determined by the scorpions. When the scorpions were in resting posture, a cockroach was introduced into the box, in a position the furthest away from the scorpion. All reactions and postures were carefully observed and noted. Upon prey-capture, the time was noted in which each sting was made. Fifteen minutes after the prey was subdued, the scorpion was replaced in its glass jar, where further observation was continued. The cockroach remnants, on feeding completion, were also noted.

Points noted were:- scorpion posture before, during and after prey capture;
number of stings per time interval (3 minutes);
cockroach remnants.

b) EXPERIMENT 2 :- DRINKING BEHAVIOUR

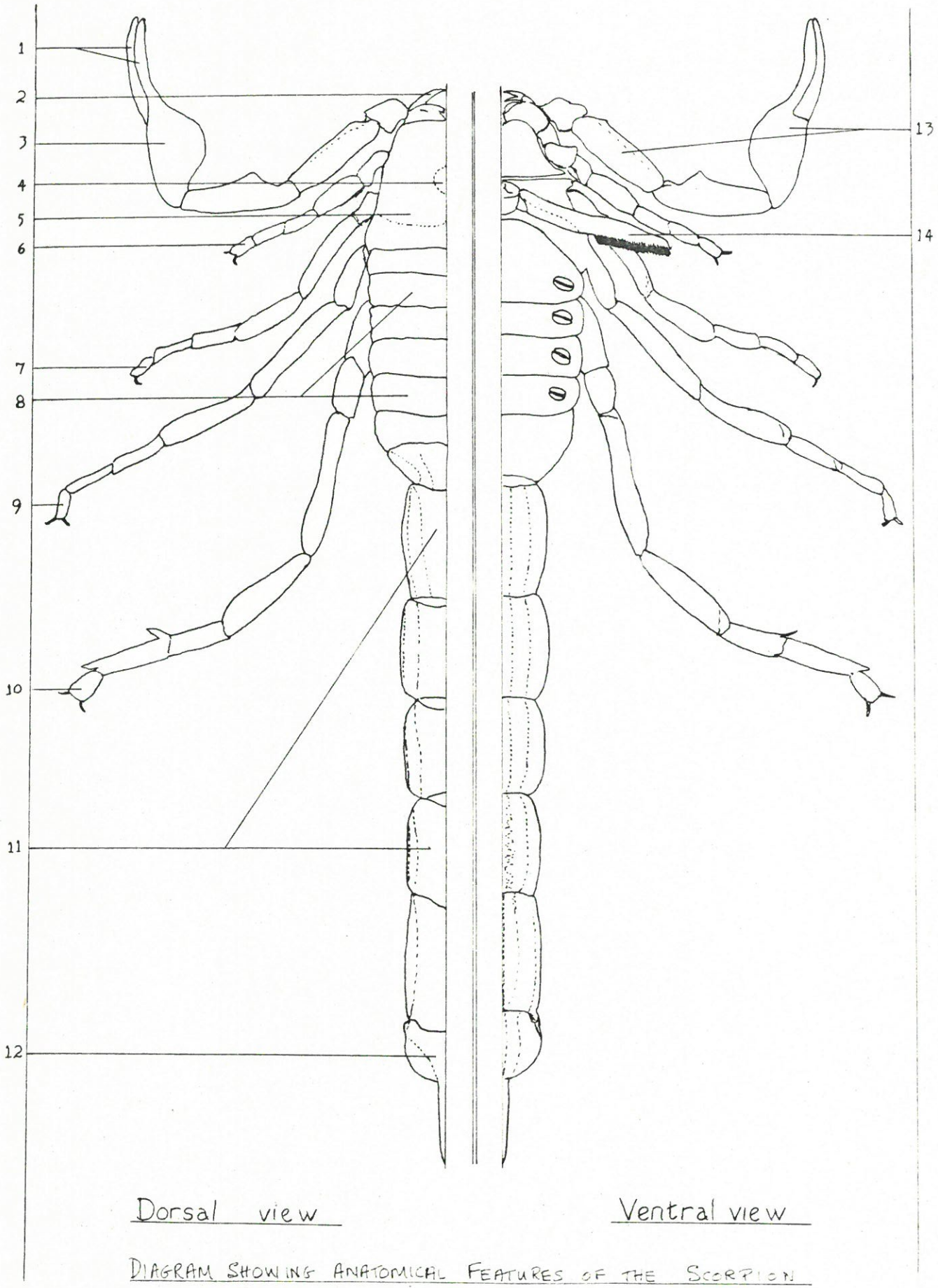
A petri dish of water was placed in the centre of the observation box and the scorpions then placed in the box one at a time. A number of observations were also made in a 0,3 x 0,3 metre fish tank with glass bottom, so that any mouth-part movements could be seen. As the scorpion began "drinking", a drop of green food colouring was added by means of a toothpick, in order to pick up any movement of water that occurred.

c) EXPERIMENT 3 :- DEFENCE BEHAVIOUR

Two scorpions were placed at opposite ends of the observation box, and reactions and postures upon contact noted. Time allowed for the development of any reactions, if not instantaneous upon contact, was ten minutes. Each of the tests, i.e. one species versus the same species or one species versus another species, was done in quadruplicate :- eg:

(a) P. brachystylus 1 versus O. glabrifrons 1
(b) P. brachystylus 2 versus O. glabrifrons 1
(c) P. brachystylus 1 versus O. glabrifrons 2
(d) P. brachystylus 2 versus O. glabrifrons 2

Points noted :- Scorpion posture before, during and after the encounter in each family. Posture displayed on harassment with forceps.



Dorsal view

Ventral view

DIAGRAM SHOWING ANATOMICAL FEATURES OF THE SCORPION PARABUTHUS BRACHYSTYLUS LAWRENCE AS MENTIONED IN THE TEXT

Key:

1 Fingers
2 Chelicera
3 Chela
4 Median eye
5 Carapace
6 1st leg
7 2nd leg
8 Mesosoma
9 3rd leg
10 4th leg
11 Metasoma
12 Aculeus
13 Pedipalp
14 Pectines

RESULTS

Postures seen to be displayed by the Parabuthus and Opisthophthalmus species before, during and after prey-capture and defence are described and discussed in the discussion.

The experiments showed that the prey-capture and defense postures of the two families were distinctly different. Each family, however, was seen to display the following posutres:-

resting

foraging

alert

aggressive

attack

defense.

a) EXPERIMENT 1 :- PREY-CAPTURE BEHAVIOUR

TABLE 1

PERCENTAGE PREY-CAPTURES OBSERVED IN EACH SPECIES

SPECIES	REJECT	ACCEPT	ATTACK-REJECT
Scorpionidae			
O. glabrifrons	1	1	0
O. carinatus	1	0	1
O. flavescens	0	1	1
%	33,3	33,3	33,3
Buthidae			
P. brachystylus	1	3	1
P. villosus	1	0	0
%	33,3	50	16,6

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TABLE 2

PROCEDURES CARRIED OUT DURING PREY-CAPTURE BY OPISTHOPHTHALMUS AND PARABUTHUS

SPECIES	STRIDULATION	STINGING	ORIENTATION TO HEAD HOLD	PREY EATEN NEW LOCATION
O. glabrifrons	+	+	+	+
O. flavescens	+	-	+	-
P. brachystylus	-	+	+	+
P. brachystylus	-	+	+	+
P. brachystylus	-	+	+	-
PERCENTAGE (+)	40	80	100	60

TABLE 3

POSITIONS FAVOURED BY SCORPIONS FOR STINGING PREY DEPENDING ON HOLD (OF % STINGS IN EACH HOLD).

GENUS	HEAD HOLD		SIDE HOLD		POSTERIOR HOLD		
	Neck	Tergum	Neck	Tergum	Neck	Tergum	Sternum
Opisthophthalmus	71,4%	28,6%	25%	75%	0	0	0
Parabuthus	33,3%	66,6%	12,5%	87,5%	0	15,4%	84,6%

TABLE 4

% CASES IN WHICH FINGERS WERE OPEN OR CLOSED IN RESTING AND FORAGING POSTURES

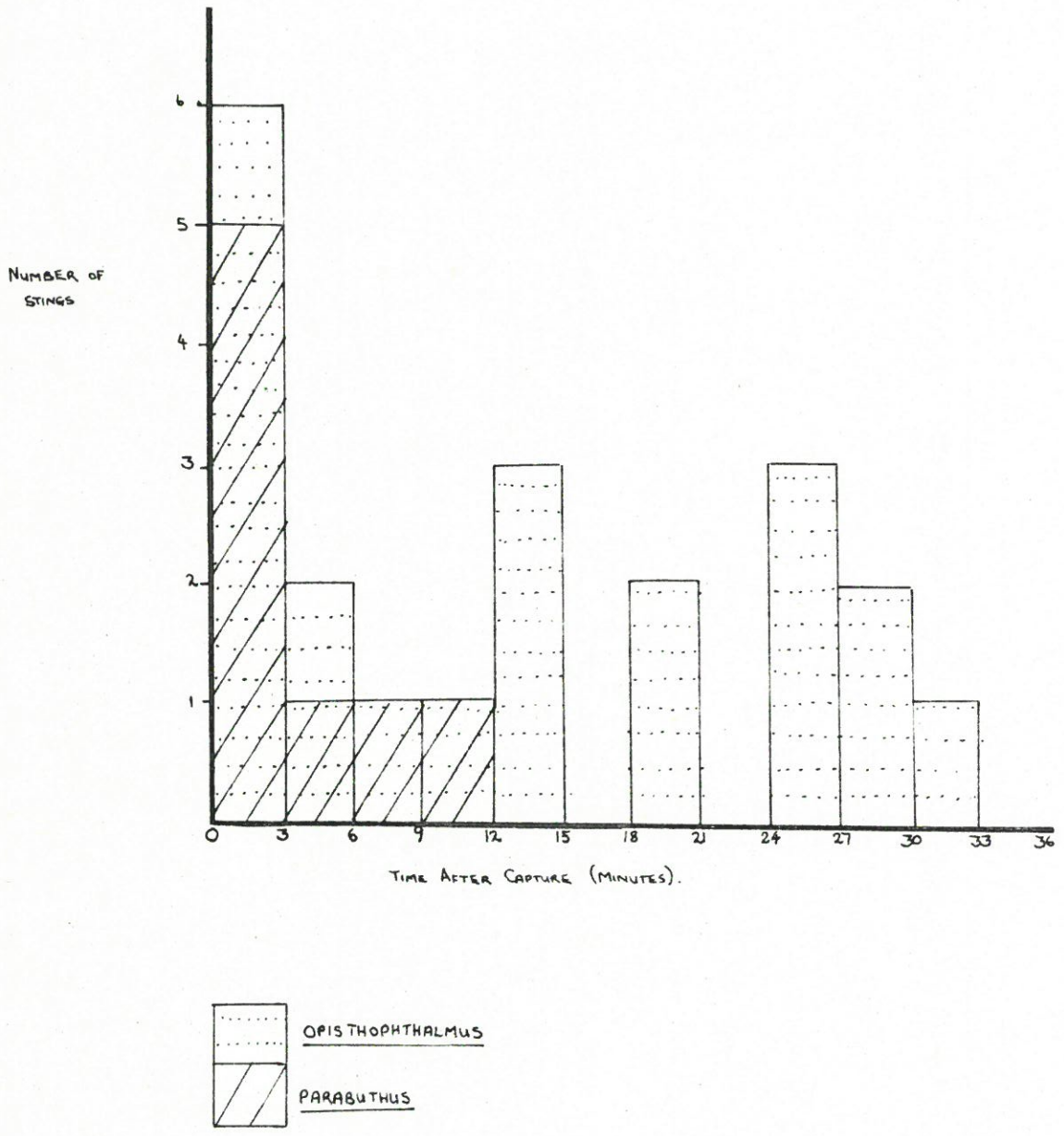
GENUS	RESTING:- FINGERS AS IN THE 3 RESTING POSITIONS NOTED					
	*FIG 1 POSITION		*FIG 2 POSITION		*FIG 3 POSITION	
	Open	Closed	Open	Closed	Open	Closed
Opisthophthalmus	0	60	0	16,7	16,7	6,7
Parabuthus	6,7	76,6	6,7	10,0	-	-

	FORAGING:- PEDIPALPS HELD IN FRONT OF BODY	
	Closed	Open
Opisthophthalmus	36,6	63,4
Parabuthus	13,4	86,6

*Refer to these figures in the discussion on resting posture.

TABLE 5

NUMBER OF STINGS APPLIED TO PREY AFTER CAPTURE IN SCORPIONIDAE AND BUTHIDAE



b) EXPERIMENT 2:- DRINKING BEHAVIOUR

TABLE 6

PROCEDURES CARRIED OUT DURING DRINKING

SPECIES	H_2O PERCEPTION BY PEDIPALPS	H_2O PERCEPTION BY LEGS	BODY TILTED	CHELICERAL ACTION	LEG MOVEMENT	CURRENT
O. glabrifrons	+	-	-	+	+	+
O. flavescens	+	-	+	+	+	+
O. carinatus	+	-	+	+	-	-
P. brachystylus	+	-	-	+	-	-
P. brachystylus	+	-	+	+	-	-
P. brachystylus	+	-	-	+	+	+
P. brachystylus	-	+	+	-	+	+
P. villosus	+	-				
% (+)	87,5	14,2	57,1	85,7	57,1	57,1

c) EXPERIMENT 3:- DEFENSIVE BEHAVIOUR

TABLE 7: Reaction of species to each other as recorded in ten minute periods for each observation

SPECIES	POSTURE	REACTION	OBS.NO.	REACTION	POSTURE	SPECIES
O. carinatus	alert chelae closed	hold other's pincers retreat	1&2	hold other's pincers approach	alert chelae open	O. carinatus
O. carinatus	aggressive	approaches avoid other more bold than other	1	rapid retreat avoid other	aggressive	O. glabrifrons
	alert		2	retreat, approach push other, retreat	alert	
O. glabrifrons	aggressive	approach retreat	3	retreat	defensive	O. flavescens
	aggressive	retreat	4	retreat		
O. carinatus	defensive		1		defensive	O. flavescens
		retreat after delay	2	approach, attack	aggressive	
		attack	3		alert	
			4	attack		
O. carinatus	defensive	retreat	1	retreat	alert	P. villosus
	aggressive chelae closed		2		alert chelae open	
	alert chelae open alert	approach retreat retreat	3	approach relax	alert chelae open alert	
O. carinatus	alert	approaches no fighting	1	no fighting	alert	P. brachystylus ♂
	alert		2		aggressive	
		approach retreat, move behind other approach	3	approach approach, retreat		
O. carinatus	alert → aggressive	retreat	1		alert	P. brachystylus ♀
	alert	no attack, no retreat	2	no attack, no retreat	alert	
O. glabrifrons		retreat approach → continue retreat approaches, tries to push other retreat	1	approach, retreat retreat retreat knocks other off with metasoma	alert	P. villosus

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SPECIES	POSTURE	REACTION	OBS. NO.	REACTION	POSTURE	SPECIES
O. glabrifrons (contd.)	alert	alert, walk around approach	2	 retreat, knock with metasoma	alert	P. villosus (contd.)
O. glabrifrons	defensive alert	rapid retreat	1 2	approach chela holding leg of other	aggressive → alert	P. brachystylus ♀
O. glabrifrons	defensive	retreat	1&2	retreat	defensive	O. glabrifrons
O. glabrifrons	defensive		1		aggressive	P. brachystylus ♂
	aggressive		2		aggressive	
	alert	approach, retreat	3	retreat	alert	
	alert, chalae open	approach, retreat approach, retreat approach	4	approach, retreat approach	alert	
O. flavescens	aggressive	fight try to sting other clasp other's chelae	1&2	fight clasp other's chelae	aggressive	O. flavescens
O. flavescens	alert defensive, chalae open	climb over other	1	becoming cross, sting forward try to avoid other retreat	alert chelae open	P. villosus
	alert, chelae close → open		2	crawl over other	alert chelae open	
	alert	 fight retreat	3	motionless try to sting other, relax move away, approach. fight try to sting other retreat	alert aggressive, raised on 4th leg	
O. flavescens	alert alert	no movement avoid other	1 2	no movement avoid other	aggressive alert	P. brachystylus ♂
	alert	approach	3	approach	alert	
	alert alert	approach walk past other	4	approach walk past other	alert alert	
O. flavescens	alert		1	sat on other	alert	O. brachystylus
	alert	uninterested	2		alert → aggressive	
	alert	grab others aculeus	3	try to sting other irritated	aggressive chelae open	

SPECIES	POSTURE	REACTION	OBS.NO.	REACTION	POSTURE	SPECIES
P. villosus	aggressive, chelae open aggressive	push other away	1	push other away retreat	alert, chelae open aggressive	P. brachystylus ♂
	alert chelae open	retreats turn around moves	2	follows, holds chelae of other rapid retreat touches other rapid retreat	alert chelae open	
	aggressive, chelae open	approach, stay alongside other move beyond other	3	approach, stay alongside other move beyond other	alert, chelae open	
P. villosus	alert, chelae open	approach ready to sting, avoid other	1	knocked other with metasoma avoid other	aggressive, chelae open	P. brachystylus ♀
	defensive, chelae open	walk on other	2	walk on other	aggressive, chelae open	
	alert, chelae open		3	approach other ready to sting	defensive chelae open	
P. brachystylus ♂	alert raised on 4th legs	no reaction, hold others chelae pull on other push other become irritated	1&2	no reaction, holds others chelae pull on other push other pull other	alert	P. brachystylus ♂ smaller
P. brachystylus ♂	alert	retreat	1	retreat	aggressive	P. brachystylus ♀
	alert	approach ♀ , un-interested	2	moves metasoma around holds ♂ chelae	alert	
	alert	crawl over other retreat	3	crawl over other retreat	aggressive	
	aggressive	hold others chelae pull other around	4	hold others chelae pull other around	aggressive, aculeus out alert→aggressive	
P. brachystylus ♀	alert	retreat	1&2	retreat	aggressive	P. brachystylus ♀
P. brachystylus ♀			3		alert raised on 4th legs	O. carinatus
	alert	moves metasoma around	4	approach other retreats	alert	
P. brachystylus ♀	chelae open alert		3		aggressive	O. glabrifrons

TABLE 8: Stance shown by scorpion of given species in the presence of scorpions of other species as shown.

Stance of:	In the presence of: Parabuthus brachystylus ♀	Parabuthus brachystylus ♂	Parabuthus villosus	Opisthophthalmus flavescens	Opisthophthalmus glabrifrons	Opisthophthalmus carinatus
Parabuthus brachystylus ♀	1	1	3	2	2	1	2	1	4	
		2	4	1	3		3		3		4
Parabuthus brachystylus ♂	3	1	1	1	2	1	3	1	2	2	2	1
		4	2		3		4		4		3
Parabuthus villosus	2		1	2			2	1	2		3	
	1	3	3		0		3		2		3
Opisthophthalmus flavescens	3		4		2			2	1		2	1
		3	4		1	3		2	1	2	1	4
Opisthophthalmus glabrifrons	1	1	2	1	2			2			1	1
	1	3	1	4		2		2	2	2		2
Opisthophthalmus carinatus	3	1	3		1	1	3		1	1	2	
		4		3	1	3	1	4		2		2

neutral stance | aggressive stance

defensive stance | number of observations undertaken

"Neutral stance" indicates that the animal is not given to aggression or defence stance.

Figure 4: Aggressive and defensive postures displayed in each genus - Parabuthus and Opisthophthalmus:

a) Frequency of defensive posture shown in each genus with induction of defensive posture in the other genus.

b) Frequency of aggressive posture shown in each genus with induction of aggressive posture in the other genus.

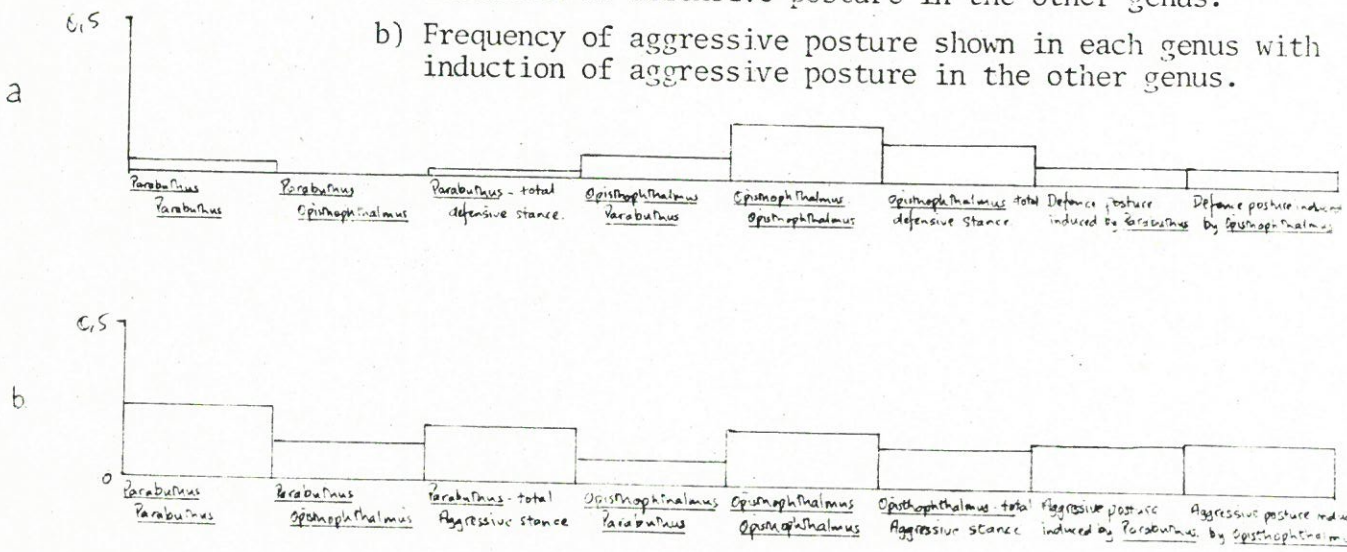


TABLE 9: Behaviour displayed by scorpions of given species in the presence of scorpions of other species as shown.

Behaviour of	In the presence of: Parabuthus brachystylus ♀		Parabuthus brachystylus ♂		Parabuthus villosus		Opisthophthalmus flavescens		Opisthophthalmus glabrifrons		Opisthophthalmus carinatus	
Parabuthus brachystylus ♀	2		1	2	1	2	2	1	3		4	
		2	1	4		3		3		3		4
Parabuthus brachystylus ♂	3	1	1	1	1	1	4		4		3	
		4		2	1	3		4		4		3
Parabuthus villosus	2	1	2	1			1	2		2	3	
		3		3		0		3		2		3
Opisthophthalmus flavescens	2		4		2	1		2	2		2	2
	1	3		4		3		2		2		4
Opisthophthalmus glabrifrons	2		4		2		2		2		2	
	1	3		4		2		2		2		2
Opisthophthalmus carinatus	4		3		3		3	1	2		2	
		4		3		3		4		2		2

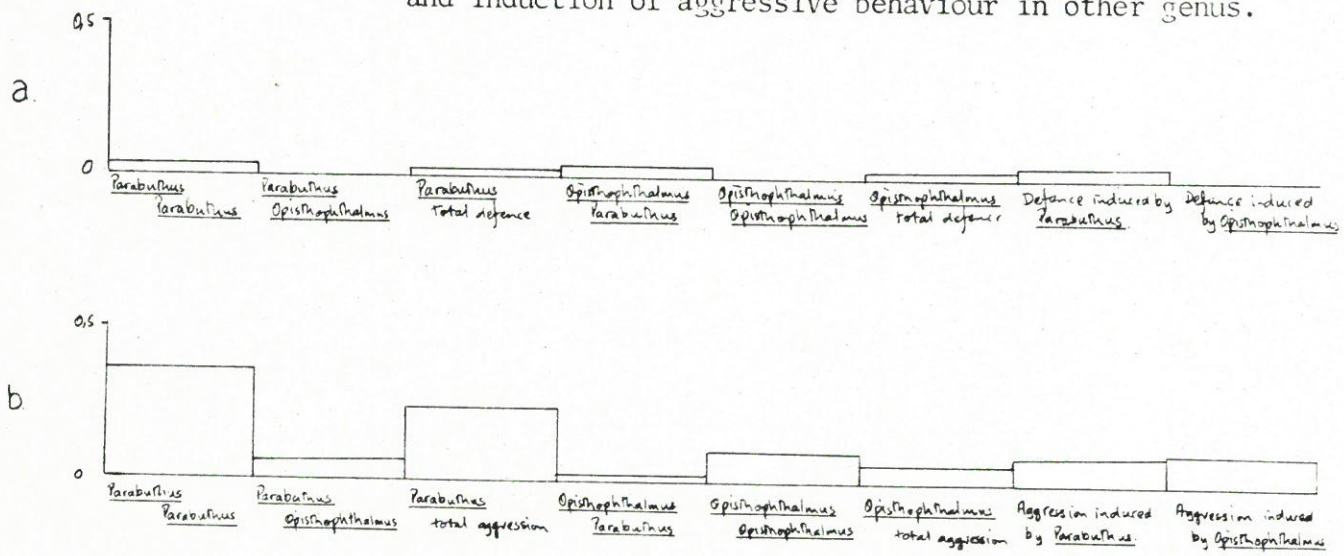
neutral behaviour	aggressive behaviour
defensive behaviour	number of observations undertaken

Neutral behaviour indicates that there was tolerance toward the other scorpion, or no aggression.

Figure 5: Aggressive and Defensive interaction of each genus- Parabuthus and Opisthophthalmus:

a) Frequency of defensive behaviour shown in each genus and induction of defensive behaviour in other genus.

b) Frequency of aggressive behaviour shown in each genus and induction of aggressive behaviour in other genus.



DISCUSSION

a) EXPERIMENT 1:- PREY-CAPTURE BEHAVIOUR

As can be seen from table 1, there was only a 33,3% prey-capture recorded in Opisthophthalmus. The low prey-capture rate could be due to the scorpions not being hungry due to feeding at the S.A.I.M.R. and scorpions can survive for up to six months without anything to eat once they have been well-fed. The scorpions may also have been too disturbed by the transfer from their jars to the observation box. A 50% prey-capture success was recorded for the Parabuthus. All prey-capture behaviour patterns were thus obtained from these observations. A number of distinct postures were seen in both genera studied and could be categorized into the following:-

rest
foraging
alert
aggressive
attack.

As will be seen, the postures exhibited by each of the genera is directly related to the type of pedipalps or metasoma present.

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RESTING POSTURE

In the Buthidae, the metasoma lies flat on the ground, curled and to the left of the body. The aculeus is held flat against the segment to which it is attached. The pedipalps are varied in their position:- they tend to be in a position at the sides of the carapace, the chelae lying just in front of the mouth-parts, as in FIG. 1. - or they may be laterally extended away from the body as in FIG. 2. FIG. 1 represents the entirely relaxed state, when the scorpion is not disturbed or aware of what is happening around it.

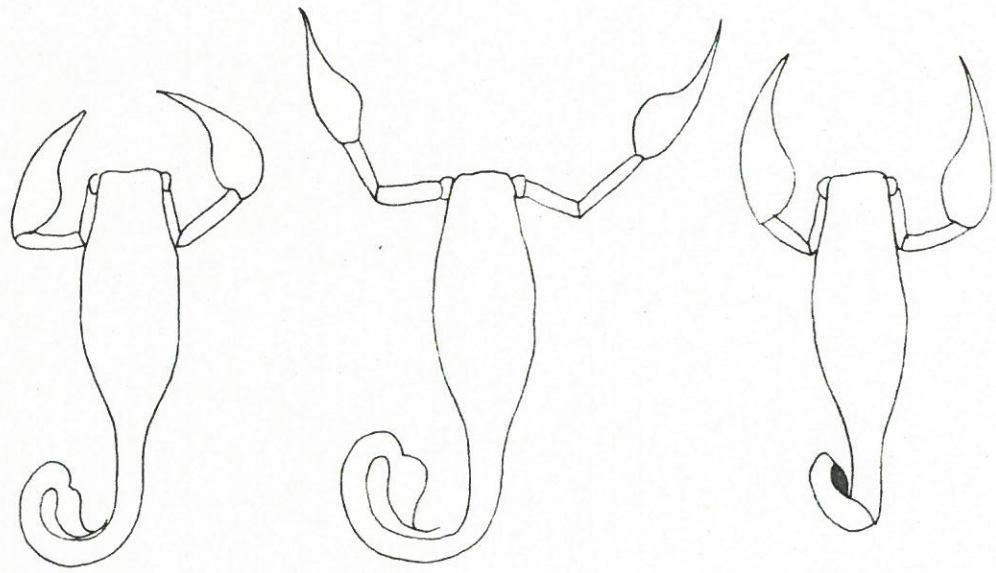

FIG. 1 FIG. 2 FIG. 3

DIAGRAMMATIC REPRESENTATION OF THREE RESTING POSITIONS OCCUPIED BY THE SCORPIONIDAE AND THE BUTHIDAE.

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In the positions shown by FIG. 1 and FIG. 2, the legs are always folded in such a way that the first and second segments of legs III and IV, lie on the dorsal abdominal surface. The fingers of the chelae may either be open or closed, the latter position representing the more relaxed state. It was found that in Buthids in the FIG. 1 position 76,7% had the fingers closed and only 6,7% had the fingers open. In the FIG. 2 position, 10% of the scorpions had the fingers closed and 6,7% had the fingers open (as seen in TABLE 4). It can thus be concluded that FIG. 1 is the position taken up during complete relaxation and FIG. 2, when the scorpion is wary of what is going on around it.

In the Scorpionids studied, the metasoma does not lie completely flat on the ground, but remains between 0,5 cm - 1,5 cm above the ground, lying to the left side of the body. The metasoma was also seen to remain erect, but the aculeus was then held flat against the segment to which it is attached. The pedipalps were found to be held in three different positions - FIG. 1, 2 and 3. FIG. 1 position occurred in 60% of all resting posutres noted. In all 60% of the cases, the fingers were always found to be closed, thus representing the complete relaxed state, as in the Buthidae. In all FIG. 2 postures, the fingers were found to be open, showing that the scorpion was aware of its surroundings. FIG. 3 posture, is probably an intermediate between FIG. 1 and FIG. 2 postures, but is most likely to be a transition from the FIG. 1 to the FIG. 2 posture, when something has disturbed it.

In the majority of cases recorded with open fingers in FIG. 2 posture for the Scorpionidae correlates with the fact that the pedipalps are used in all combat and prey-capture, whereas in the Buthidae, the tail is mainly used and hence the observed observations of open and closed fingers. The pedipalps are thus maintained ready for action.

FORAGING POSTURE

This posture was found to occur when the scorpions were placed in the box and allowed to move around freely in their new surroundings. In Parabuthus, the pedipalps were held out in front of the body, the fingers open in 86,6% of the cases recorded, and the metasoma curved over - as in Plate 1. The posterior part of the mesosoma and metasoma were slightly elevated by the IV pair of legs. Closed fingers were noted in 13,4% of the cases recorded. The scorpion thus moves in such a manner that it is ready to grab hold of anything that crosses its path. Another function of holding the pedipalps outstretched in this manner is that the trichobothria are situated on the pedipalps and are used to pick up air-currents caused by any other moving animal in its vicinity. The aculeus is positioned in an anterior-facing direction - which is seen to contrast with the manner in which the Scorpionidae carry the aculeus.

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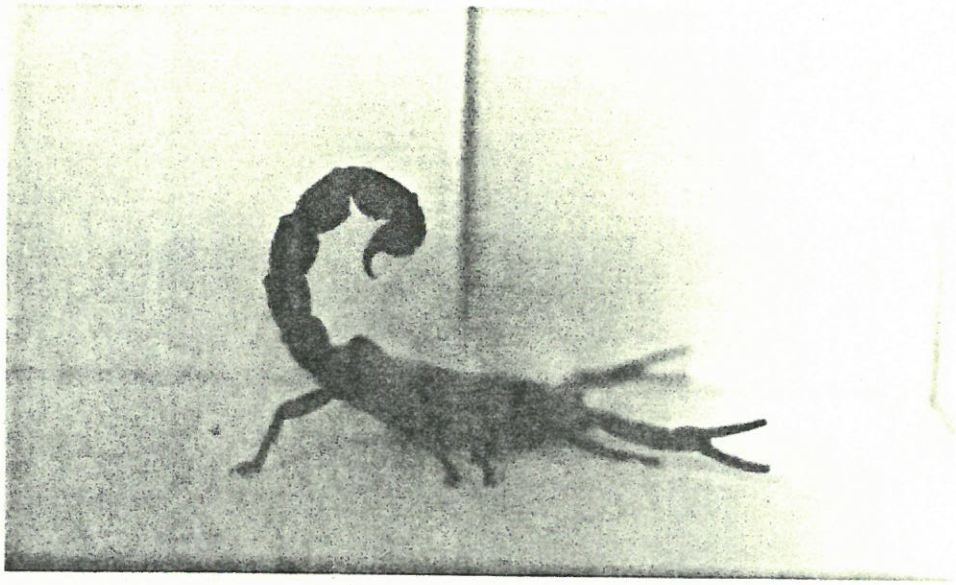

PLATE 1 FORAGING STANCE - P. brachystylus.

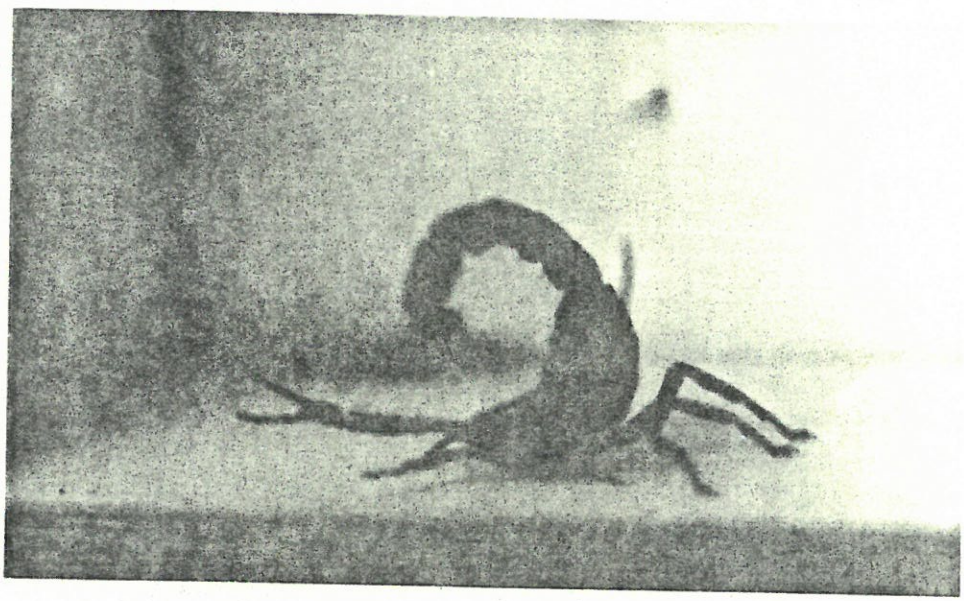

PLATE 2 ALERT STANCE - P. brachystylus

In Opisthophthalmus, the foraging posture was very similar as regards the positioning of the pedipalps, but a major difference was noted in the position of the metasoma. The mesosoma and metasoma were not elevated and only the last two metasomatic segments were curled over, the rest of the metasoma remain straight and horizontal to the ground. Cruising with the fingers open, was found in only 63,4% of the cases noted. When the functions of the pedipalps in the Scorpionidae and Buthidae is considered, it seems strange that the Buthids more often forage with the fingers open than the Scorpionids.

ALERT POSTURE

Parabuthus, when alert has the pedipalps spread apart widely, the fingers open and the metasoma is brought up in an arc above the carapace as in Plate 2. The aculeus also is held horizontal to the ground in a posteriorly-directed position so that it can be rapidly brought forward with force when needed. This position was seen in all alert postures noted. The metasoma and mesosoma are raised slightly above the ground, in order to give the striking metasoma enough forwardly directed strike area.

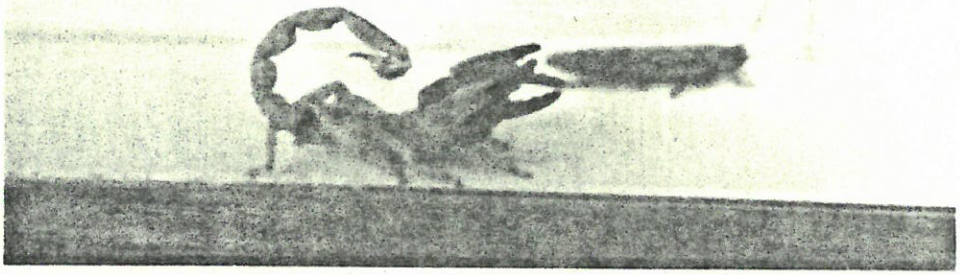

PLATE 3 ALERT STANCE – O. glabrifrons

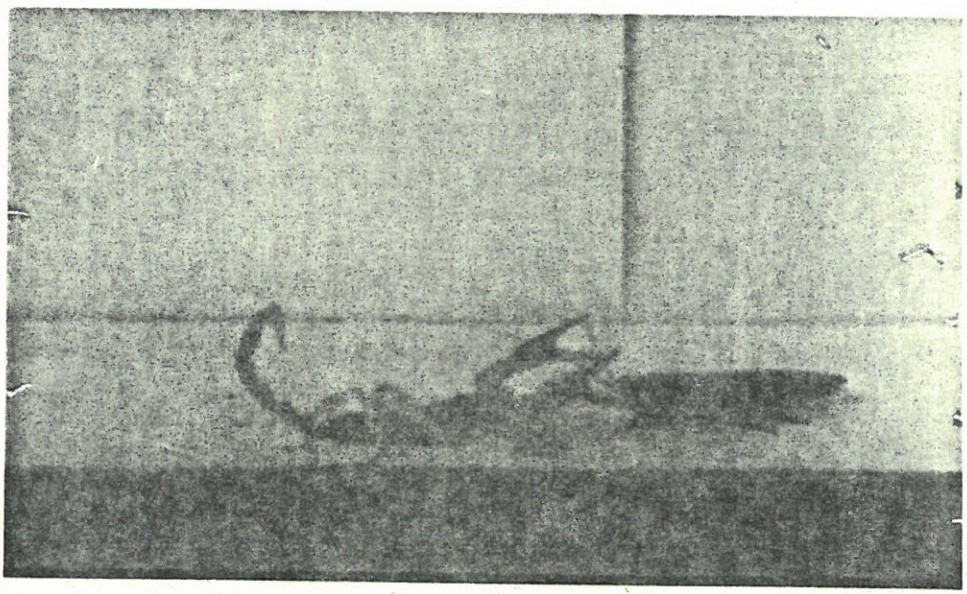

PLATE 4 ALERT STANCE – O. glabrifrons

In Opisophthalmus, the alert posture causes the pedipalps to be carried in a forward outstretched manner, but the chela are held in an upwardly directed angle of about 20° from the ground. (In Parabuthus, they were carried horizontal to the ground.) The fingers are held open and the pedipalps are not carried to the side of the body as in Parabuthus, but in front of it as in Plate 3. The aculeus is carried parallel to the ground and posteriorly-directed as in Parabuthus. Plate 4 shows the alert posture on encountering a cockroach in which the scorpion is not interested for food and has established that it presents no danger. The fingers are in the open position. Note how the tail has straightened out and the telson is held in a downward position, similar to the resting position.

AGGRESSIVE POSTURE

Aggression is shown in both genera on confrontation with another species or another genus or on harrassment by forceps. Aggression is also seen just prior to attack of a cockroach.

In Parabuthus, aggression was shown in all cases studied to be very similar to the alert posture. The pedipalps are, however, held out in front of the body and not to the side, and the fingers are open. The metasoma is curved forward in an almost complete circle, the aculeus being brought into such a position that it faces anteriorly and is almost touching the carapace.

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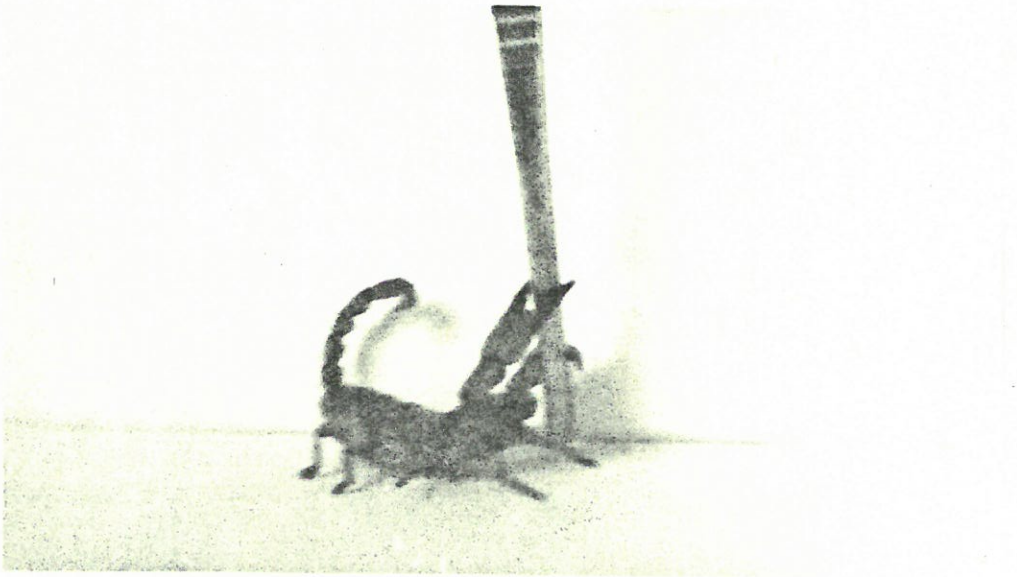

PLATE 5 AGGRESSIVE STANCE – O. flavescens.

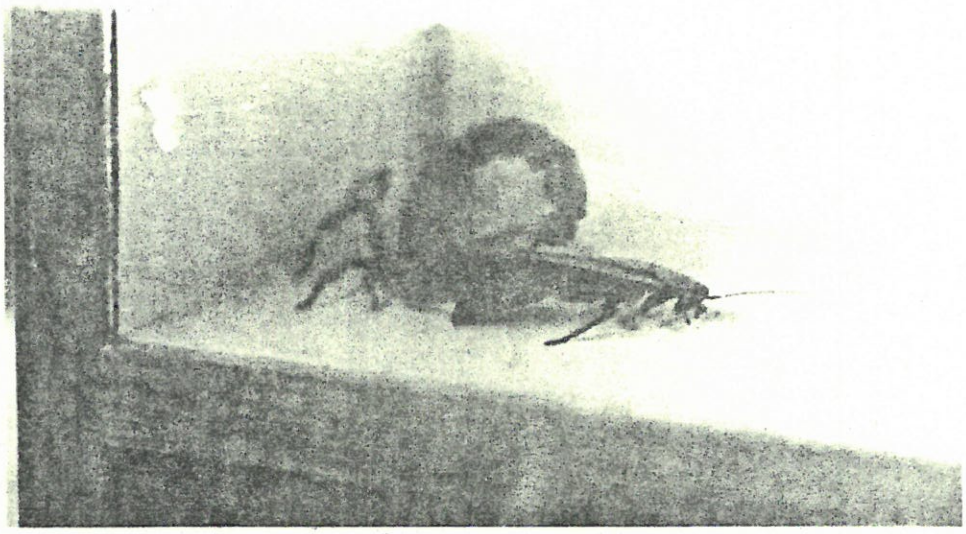

PLATE 6 STINGING – P. brachystylus

In Opisophthalmus, aggressive postures result in the pedipalps being brought to the side of the body with the chela held almost in front of the mouth parts. The posterior part of the mesasoma is raised and the metasoma is held in an arc above the body, the aculeus being held perpendicular to the ground in a state of readiness in the event of its being needed. Plate 5. On attacking, the pedipalps grasp hold of the opponent which is held away from its mouth parts or pulled nearer to enable it to be stung if too much harassment is caused. When a pair of forceps were used to antagonize the scorpion, definite attempts were made at crushing the forceps or pulling them closer in order to apply the sting.

When the Parabuthus were antagonized with forceps, their aggression immediately lead to stinging or attacking the forceps with the powerful tails. (The tail muscles in the Parabuthus were found to be extremely strong, as compared to those of Opisophthalmus.)

STINGING POSTURE

In both Opisophthalmus and Parabuthus, stinging of the prey occurs in an identical manner. The prey is held by both pedipalps and brought closer toward the chelicerae. The metasoma is then brought forward, either to the left or the right of the body, depending upon where the greater weight of the prey i.e. the cockroach, lies. The aculeus searches for an opening between the first and second pairs of wings of the cockroach, or the dorsal surface of the abdomen.

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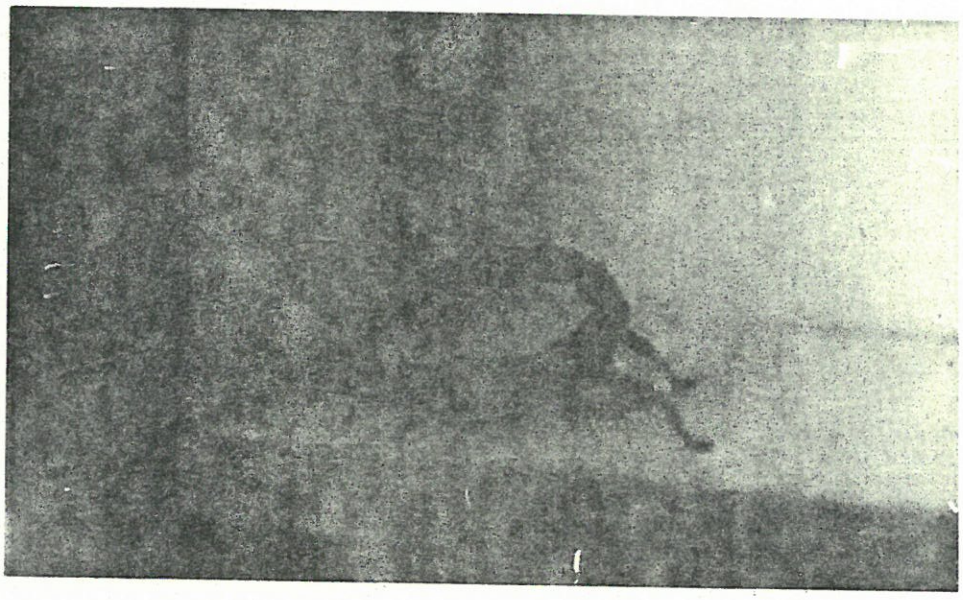

PLATE 7 STINGING - P. brachystylus

When this is located, attempts are made at penetrating the area between the integuments (Plate 6).

The stinging position aimed for in all cases, depends on the way in which the cockroach is held. If it is held sideways, the telson searches for a position of injection on the abdomen, generally the dorsal surface as is seen by the results in Table 3. If the hold is posterior to the head, with the cockroach's head facing the chelicerae, the neck is the favoured injection point in the Scorpionidae as seen by 71,4% of stings being in the neck. However, in the Buthidae, the tergum is still the favoured site of injection, with this injection position occurring 66,6% of the time (Plate 7). This is probably due to the force with which the metasoma is brought forward and why in the aggressive posture the aculeus lies so far forward (on the carapace).

If prey-capture is from the rear end, the injection point favoured is the sternum, in the Buthidae, 84,6% of all posterior holds, resulted in sternum stings. No recordings of posterior holds in the Scorpionids were made.

The sting was mainly used in the Scorpionids to subdue the prey when its protestations became too energetic, otherwise, the prey was crushed by the pedipalps until it had quietened down enough for feeding to commence. In the Buthidae, all fighting was done with the metasoma, the pedipalps serving only to hold the prey in position.

GENERAL OBSERVATIONS:

O. glabrifrons was fed in a fish tank in which it had established a territory. On capture of the cockroach, the scorpion stridulated for the first 15-20 seconds, after capture, while it tried to gain control of the cockroach. This stridulation took place by rubbing the chelicerae together. The scorpion then dragged the cockroach to the lair it had made, a distance of 22 cm from the point of capture. Once in its lair (under an aloe) the prey was stung a number of times in order to subdue it. During the struggle the alert posture was maintained and this then changed to a resting posture as the cockroach quietened down. Throughout the entire struggle the cockroach was held behind the thoracic shield and all stings were directed at the abdomen or pronotum. The most frequent amount of stinging took place in the first seven minutes after capture, when the cockroach was struggling furiously. Table 5. The prey was eaten in a head-first position.

Observation of prey capture by O. flavescens showed an identical series of events as in O. glabrifrons - Table 2. Posture was from alert to aggressive, as has been described, but no stinging took place because the cockroach used in this case was a second instar and thus did not struggle much. All other cockroaches used were 3,5 cm long. The prey was captured in a head hold, and eating was from a head-first position.

In the Parabuthus observations, capture was also in the described postures of alert to aggressive to stinging. In the Parabuthus, the prey was held by the pedipalps and the aculeus immediately used to sting the prey. It was noted that if the prey struggled too violently, the prey could escape the grip of the pedipalps. The scorpion then merely moved forward to grab hold of the prey again. The positioning of the sting in relation to the type of hold was noted. (Table 3)

In side holds of the prey, the abdomen was favoured for injection by both genera because of the sting having easier access to it, since the prey is held behind the thoracic shield with the pedipalp and at the hind legs and posterior part of the abdomen with the other pedipalp. (The wings were always left free, so that they could be lifted by the aculeus when searching for the abdomen.

The sternum was favoured in posterior holds because of easier access by the aculeus to this region.

In Parabuthus the greatest number of stings also took place in the first eight minutes after capture, as seen in table 5.

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The length of time in which the sting was left inserted in the cockroach depended entirely on the amount of struggling by the cockroach and the firmness of the hold on the cockroach.

In Parabuthus, the longest time was 15 seconds and the shortest 0,5 seconds, when the cockroach was struggling fiercely.

In 100% of the cases where the cockroach was held in a sideways position, prey orientation took place - the cockroach being turned such that the head was facing the chelicerae of the scorpion. This thus confirms A. Alexander's (1972) observations on prey orientation, and is probably due to the geometrical shape of the cockroach rather than by harrassment due to the hind legs or unpleasant odours released by the cockroach posteriorly. This statement is made from an observation of one of the prey captures when a Parabuthus caught a cockroach in a posterior position. Since the scorpion was relatively small, and the cockroach very active, there was much struggling. Consequently, each new capture, when the cockroach escaped, was posterior and usually by the IV legs. When the struggle continued, the scorpion held down the cockroach's posterior abdomen with its chelicerae, and this position was maintained by the cockroach for 2,5 hours. At the end of this time, the scorpion released the cockroach and turned it around so that the head was facing the chelicerae. It then began to eat.

In 60% of the prey-captures noted, the scorpion carried the cockroach around for 1-2,5 hours, before finally settling down to eat. Thus scorpions probably do not necessarily feed on the prey at the point of capture, as pointed out by Hadley and Williams (1968).

Table 5 shows the number of stings applied to the prey every three minutes after capture. It is seen that Parabuthus stings more often during the first 6 minutes than does Opisthophthalmus. This is explained again by the different anatomies, i.e. the powerful, venomous metasoma of the Parabuthus and the strong pedipalps of Opisthophthalmus. The latter scorpions thus fight mainly with the pedipalps, crushing the prey, whereas, the Parabuthus rely on the aculeus. The number of stings decreased as time after capture increased due to the submission of the cockroach.

REMNANTS OF COCKROACH NOTED ON COMPLETION OF FEEDING

The remnants of the cockroach were identified at the completion of feeding and the following were found:-

2 pairs of wings
thoracic shield
mandibles
1st pair of legs
2nd pair of legs
antenna (1 or 2)
dry pellets (one of which was found still to contain

a recognizable part of a 3rd leg.)

The origin of these pellets has already been described.

When a scorpion is satiated, it will just ignore the prey, taking up either a defense or alert posture, or if the prey becomes a "nuisance", it is flicked away by the pedipalps of Opisthothalmus and by the tail of Parabuthus. On no occasion in any of the captures did the scorpion actively chase after the cockroach.

b) EXPERIMENT 2:- DRINKING BEHAVIOUR

Very little work has been done on the drinking mechanism of scorpions and none at all on the drinking behaviour. As can be seen from table 6, a distinct type of behaviour can be associated with drinking in both genera of scorpions. The behaviour in each case is identical.

In seven of the cases studied, the perception of the presence of water was by the ventral surface of the chelae touching the water surface. The scorpion in each case, then moved forward and positioned itself with its first pair of legs (I) in the water and in 25% of the cases, the II legs were also seen to be in the water.

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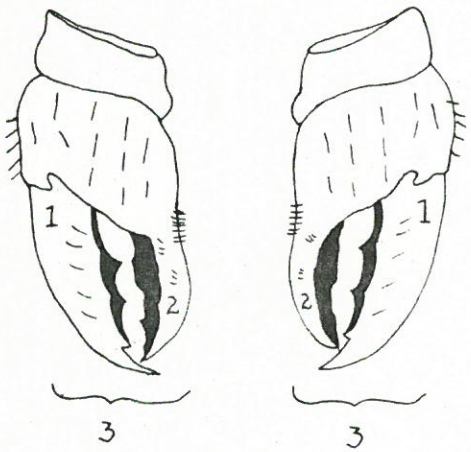
On initial contact of the water with the mouth parts, the chelicerae were seen to act in a particular fashion in 85,7% of the cases.

The basic structure of the chelicera is as follows:-



The sequence of action of the chelicerae was:-

(i) The chelicerae (3), were brought forward and segments (1) and (2) separated.

(ii) Segments (1) and (2) were then closed and (3) simultaneously withdrawn back towards the mouth. This cheliceral action took place only in the first one minute or less, of contact with the water.

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Simultaneously with the cheliceral action, the body was seen to be distinctly orientated to a 45° slope with the water. The significance of this is probably to bring the feeding organs closer to the water.

After the cheliceral action, the I legs were seen to pulsate backwards and forwards at varying speeds. This pumping action has also been seen when the scorpion is feeding (Stahnke, 1966) when the body liquids of the prey are sucked up. The water could thus also be sucked up since a definite current towards the mouth could be seen when green dye streaks were placed around the scorpion in the water. When no pumping action was seen, no current occurred either. The 45° slope thus brings the mouth into contact with the water so that it can be pumped in. During feeding, the tilt is not observed, because the food is positioned between the coxae of the pedipalps and is thus in the right position for sucking up of juices.

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c) EXPERIMENT 3:- DEFENCE BEHAVIOUR

It can be noted that generally the members of one species do not act consistently. In most cases, if aggression was shown, it was not in all observations of that species, and not even in all cases when considering interactions with a particular species. For example one can see in Table 7 that for O. carinatus, in 18 observations aggression was displayed in 4,3% of the cases, defence in 0% of the cases and that aggression was in only one of four tests with O. flavescens.

O. flavescens frequently displayed agression (30,5% of the time) and was in fact the most aggressive species tested and yet in only one case was it consistent in aggression towards the other scorpion and that was with a member of its own species.

It can be seen that some species (e.g. O. glabrifrons) showed no aggression and some (e.g. P. villosus) showed no defensive behaviour. However, the numbers of observations were too small to state conclusively that, for example, O. glabrifrons never shows aggressive behaviour towards the other species with which it was allowed to interact.

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From Figs. 4 and 5 it can be seen that the aggressive interaction, both posture and behaviour was greatest between like genera than between Parabuthus and Opisthophthalmus. The defence displayed was not so clearly different except that Opisthophthalmus species displayed the most defensive posture and otherwise very little defence was shown.

It can further be seen from Figs. 4 and 5 that there was really no difference between the amount of aggressiveness or defensiveness shown towards the two different genera, or induced by each.

Defence posture in Parabuthus was the same in all cases studied - the pedipalps were extended laterally beyond the head, and the fingers held open and pointing towards the prey or opponent. The position of the chelae is such that the position of the opponent can be determined by means of the trichobothria, and that they are not in the way of the aculeus when the opponent is struck at. The metasoma is held in an arc over the body of the scorpion, with the aculeus touching the carapace or slightly above it, and in a vertical, upwards pointing position. When the Parabuthus strikes, it is with great speed and force, and unless the scorpion is holding the prey, the prey is flicked backwards. The aculeus is able to spray its

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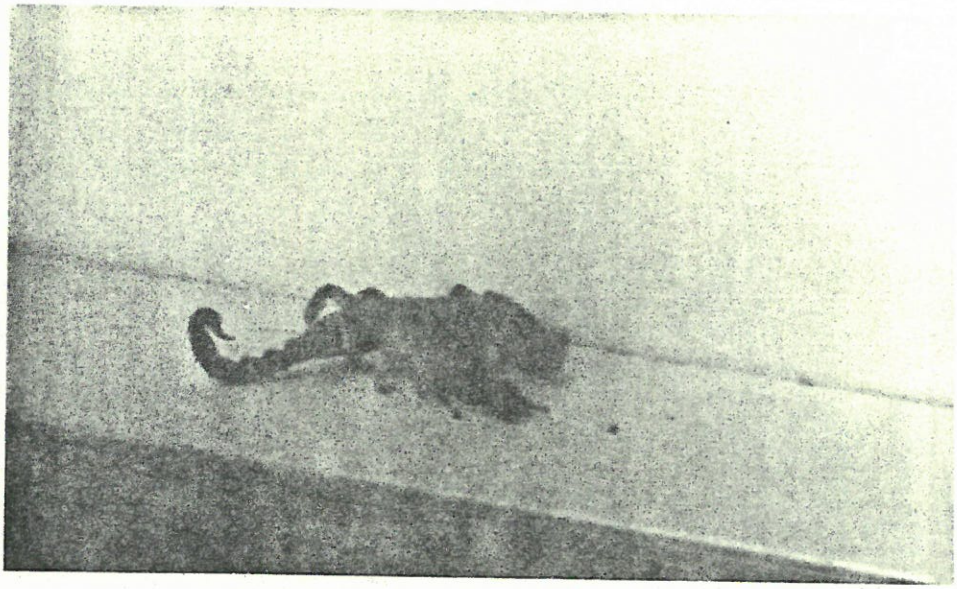

PLATE 8 DEFENSE STANCE – O. flavescens

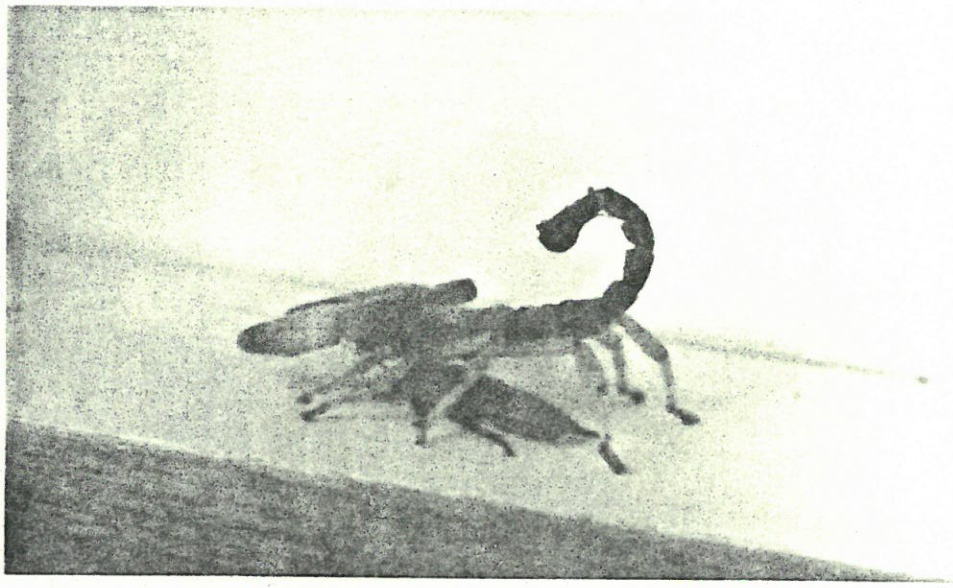

PLATE 9 DEFENCE STANCE – O. flavescens

venom in a 180° path for up to one metre - as seen when attempts were made at lifting the scorpion up with forceps.

The metasoma is also used in lateral strikes at opponents standing to one side of the scorpion.

In the Opisthophthalmus the main defensive structures are the pedipalps and consequently its defensive posture makes the most use of these.

The chelae have an extremely large surface area, as already mentioned, and this is used to shield the mouth parts of the scorpion, by placing the chelae in front of them with the fingers slightly apart. Often the pedipalps were used to push the antagonist away, as the metasoma of the Parabuthus is used to push the antagonist away.

In Opisthophthalmus, the aculeus is held either straight out posteriorly, parallel to the ground as in Plate 8, or else curved with the aculeus pointing toward the posterior as in Plate 9, as they rely more on their pedipalps than the Parabuthus, as a method of defence.

Thus, distinct differences in defence behaviour occur in the Buthidae and the Scorpionidae, as governed by the metasoma and the pedipalps respectively.

CONCLUSION

The major anatomical differences between the Scorpionidae and Buthidae are those of the pedipalps and metasoma. These differences have an effect on the behaviour of the scorpion. Prey capture, drinking and defensive behaviour were studied in order to determine these. Five scorpion positions were recognized. They are: resting, foraging, alert, aggressive and stinging positions.

In the first experiment Leucophaea madierae were fed to the scorpions. In both Opisthophthalmus and Parabuthus the alert, aggressive and stinging postures were displayed. Parabuthus was found to sting the prey more often that Opisthophthalmus, as Opisthophthalmus relies mainly on the chelae to subdue the prey while Parabuthus relies on the aculeus. In all cases of capture in this experiment, prey orientation took place, confirming Alexander's (1972) observation on prey orientation. The scorpions also carried the prey around before eating it, thus implying that they probably do not necessarily feed on the prey at the point of capture, upholding Hadley & Williams' (1968) theory. Remnants of the prey were found to consist of all the scleratised parts which, obviously, neither scoprion ate.

The second experiment shows that both Cheliceral and "pumping" action are used when drinking water, and in all species used in the experiment, the body was orientated at a 45° angle with the water. In this experiment no major differences due to anatomy were observed because the metasoma and pedipalps are

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in no way directly involved with drinking behaviour.

The final experiment was to indicate differences in defence in relation to anatomical differences. It is found that both genera were equally aggressive and defensive, but their aggression or defence is displayed in different ways. The Opisthophthalmus rely mainly on the pedipalps for protection and to express aggression, while Parabuthus rely on the metasoma.

One may thus conclude that while the species studied showed similar behaviour patterns, the way that they are expressed depends entirely on their anatomical structure.

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ACKNOWLEDGEMENTS

We would like to express our appreciation and many thanks to Mr. Gerry Newlands for all the advice and guidance during the course of execution of the experimental work.

Grateful thanks also go to Miss L. Lowenberg for the typing of this project.

Mr. Hugh Robertson also is thanked for useful advice given.

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