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The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by JEAN PLANT for the degree of ARTIUM MAGISTER M.A. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of ARTIUM MAGISTER M.A.

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A CONTRIBUTION TO THE LIFE HISTORY OF THE WATER SCORPION

(Ranatra fusca, Pal.B.)

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O u t l i n e .

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(Ranatra fusca, Pal.B.)

Introduction.

Ranatra fusca, the water scorpion, which is one of the commonest and best known Hemipterous, affords an excellent opportunity for an ecological study. The aim of this work is to give the results of investigations made upon the adult from the standpoint of behavior, rather than to give any detailed account of the various stages in the life history. In its best sense ecology includes not only the study of an organism in its natural environment- that is the relation of organism to environment- but also the relation of environment to the organism- briefly speaking the inter-action of organism and environment. The ecology of the water scorpion would, in this sense, include the behavior of the insect in its natural habitat and also the study of the structure as far as it related to the peculiarities of the behavior.

The adults upon which these investigations were made were kept under conditions which as nearly as possible repeated the normal habitat. That is to say, that the aquaria were provided with floating bark, a sandy bottom, and a "shore" or bank that sloped gradually into the water. During the fall these were kept out-of-doors but in the winter were placed inside.

The earliest writers upon the Ranatra, which has been a fairly common subject of study, were interested only in the morphological aspect. As early as 1680 Swammerdam (6) describes the

Ranatra in his Bibel der Natur. He was followed in these descriptions by Frisch in 1728, and a little later by De Geer (2) who has a somewhat extensive account of Ranatra linearis (the European species) in his Memoirs. De Geer shows some knowledge of the natural history also, as well as of the morphology. More recently (1884) Ranatra has been a subject of investigation from an anatomical and physiological point of view. S. J. Holmes (3) (1906) made a study of certain phases of the behavior - carrying on some experiments relative to the peculiar reactions of Ranatra. This work will be referred to more particularly later.

About the same time J. de la Torre Bueno (7) made out the general features of the life history. A brief summary of the stages as observed by him is as follows: The eggs are laid in the Spring in the stems of water plants. They are white oval bodies with two filaments at one end that protrude from the stem in which the eggs are sunken. The time of hatching is from 15 - 20 days. The young when they emerge are very little different from the adult. The time between the hatching of the eggs and the last instar varies from 45 - 50 days. Altogether the time from ovum to adult is between sixty and seventy days.

A. Behavior.

1. General Responses under Normal Conditions.

The most striking thing about the behavior of the water scorpion is that it has apparently no behavior - just as the most noticeable thing about it is that in its natural habitat it is practically unnoticeable. It is the most sluggish and passive of creatures at nearly all times, often remaining immovable for hours, except perhaps for a swaying of its twig-like legs in response to currents in the water. Its remarkably close resemblance to a bit of dead vegetation- in which character it suggests the common phasmid, or"Walking Stick" - is greatly aided as a protective agency by this extreme passivity. At such times as it does become active it is noticeable enough, although these times are few.

Typical Positions. Often the Ranatra may be found upon the bottom of a pond or stream, or near the bottom, inclined head downward with its front legs folded upward and back or held straight before it. At other times, and this is apparently one of its most preferred positions, it is found half way between surface and bottom clinging to submerged water plants. Sometimes it rests upon the plant - always inclined head downward- or holds to a leaf or stem with one of its front claws. At times it rises to the surface where it remains with its breathing filaments protruding slightly, generally completely hidden among the vegetation of which it seems a part. When an unwary Backswimmer darts past this vegetation, however, the Ranatra converts the passerby into a meal with one lightning stroke of the upraised claw. During the winter months that the Ranatras have been in the aquarium they have shown a marked tendency to come to rest on the underside of pieces of floating bark. The probable explanation for this is that the bark afforded a better place of concealment than the slight aquatic vegetation that grew at the bottom. In the fall many of them came up on shore or out onto the bark; even in the early part of the winter a few came out on shore, and later also on occasional warm days. When a number are together they show a propensity for becoming entangled with each other- apparently they are very positively thigmotropic. Further evidence of this is shown by the fact that in nearly all characteristic positions assumed they rest on or against some object.

Locomotion and Respiration. The Ranatra is not adept at any form of locomotion- a very natural result of its customary habits of inactivity. At times it swims slowly from place to place- possibly in search of a more advantageous position as far as food is concerned. In swimming only the last two pairs of legs are used as a general thing- the first pair which have become modified for seizing and holding food, are occasionally employed to secure a more vigorous stroke. This occurs more often when the insect is disturbed by something unusual in its environment. Handling by a person for some length of time will for example, eventually make the Ranatra seek to escape by attempting to swim rapidly. For such an attempt, which is not very successful, the front legs are called into use. The method of swimming is rather peculiar. A slow forward motion is obtained by a simultaneous movement of the second pair of legs backward and the third pair forward.

If the Ranatra moves about while on the sandy bottom or over rocks, it walks slowly and awkwardly, and- as in swimming- uses only the second and third pair of legs. The legs are moved alternately, however, not simultaneously; the insect balances on the right of the second pair and left of the third while going forward with the others, and so on. Sometimes it attempts to walk by moving its legs as in swimming- a clumsy endeavor- but apparently swimming and walking are equally natural to it. The front legs are occasionally used as a prop, seemingly in an attempt to secure greater rapidity, as it was only when the insect had been taken out of the water and handled for a long time that it tried to scramble away in that fashion. Possibly with a manifestation of activity that may have been a primitive condition, comes also the earlier instinct to use three pairs of legs.

When the Ranatra comes out of the water of its own accord- as it was frequently seen to do both on the floating bark and on shore, though this does not accord with Holmes' observation (3), that such a thing rarely or never occurs- it moves about very little. When it does seek another place it walks- crawls is a word more suggestive of its gait- slowly in the manner described above. Usually, unless it has come to shore for the purpose of flight, it remains quiet, dries off and returns to the water. The probability is that this frequent coming ashore which was observed is rather abnormal. Certainly the Ranatra is very seldom found on the shore, though whether it may not seek the air oftener than is known, hidden by the vegetation that grows in the stream, cannot be said. It may also come out at night. But whether the frequency of its occurrence is a normal thing or not, the reason for it is clearly connected with the function of respiration.

It would scarcely seem necessary for an insect supplied with breathing filaments, which however slightly protruded from the water will allow air to enter the tracheae, to come to land to breathe. Observations have shown that renewal of air is not a frequent necessity. Ranatra will stay at the bottom of a pool for hours. The general inactivity of the insect makes this appear natural rather than otherwise, but if it were only supplied with air by the spiracles at the base of the breathing tubes it would probably be obliged to come to the surface much oftener. The fact is that there are two pairs of thoracic spiracles which function in providing an additional air supply, though only Torre Bueno (7) has recognized the existence of these. He speaks of them, however, as being used in flight only, but while they undoubtedly do function then, they are also of use in taking in air from the air chamber under the wings. That is, these spiracles are located on the thorax under the anterior wings, which when the insect is in the water, are securely fastened down, enclosing a chamber that contains air which must enter these spiracles. It is most likely this additional air supply that enables the Ranatra to stay completely submerged for so great a length of time. But this air also would have to be renewed, which could only take place while the insect was out of the water. Even normally then it must come to shore at times- the frequency with which that took place in the laboratory aquarium may have been due to the fact that the water conditions were not as favorable as they would be in a pond or stream. It is scarcely possible, however, that Holmes (3) is correct in his assumption that "it rarely or never comes to shore of its own accord". At certain times it must, merely for the necessity of refilling this air chamber.

There is another purpose for which it comes to shore, however,- that is for flight. But this method of locomotion is not a common one and occurs only at certain times. It will be considered later, therefore, with the special reaction with which it is closely connected.

Response to various Stimuli. From the fact that Ranatra is found in secluded places, in rather shadowed corners, it might be inferred that it reacts negatively to light. This is especially true when in its natural habitat. In its usual resting attitude when quiet and sluggish it is prevailingly negative in reaction. With an increase of temperature it often becomes positive, especially if it has been wrought up to any degree of excitement. In such a condition, in which it is attuned to thermal stimuli, it is markedly positive. Normally the reaction varies, then, under certain usual conditions being negative, under exciting conditions positive. Certain phases of the positive reaction are very curious- they will be considered more extensively later.

Ranatra apparently does not distinguish objects as definite objects. For example, if a fly on the end of a needle or forceps is held motionless in front of the water scorpion the latter will make no attempt to seize it. But if it be moved about in the water it will soon be clasped in the knife-like front claws of Ranatra; the motion evidently having attracted notice. One writer suggested that the contact stimulus was necessary to make the Ranatra seize its prey. This is not the case. Tangled up in the aquatic vegetation it is always ready to grasp any passing insect. It may not do so for hours together, but when it is hungry the first unlucky insect that swims by is quickly seized. The victim may have unsuspectingly come into direct contact with the weapons of Ranatra, but those that pass near enough to be seized are taken quite as readily as those that actually enter the grasp.

The Ranatra does not follow the insects upon which it preys. At certain intervals while resting quietly among the water weeds it snatches one of the passing insects. The act of seizing in itself is done with such startling rapidity that it is difficult to see the motion. One moment a Notonecta is darting past the ever-upraised claw, and the next it is firmly clasped, without an onlooker being able to see the lightning downward stroke that imprisons it. When the water scorpion has seized its food it usually holds it with one claw and runs its beak over the body seeking for a place to pierce and suck. It may shift it from claw to claw, or, after once piercing it, often holds it impaled on its beak- while devourring one victim it is still free then to seize another. They feed on Notonectas which were about the only insects in the laboratory aquarium which were available for food, but doubtless they eat almost any soft bodied insects.

Some of those in the aquarium appeared to grow more hungry toward spring- during the cold winter months they showed little disposition to eat. But in the spring they would continually snatch at anything that passed them. They struck at the Zaithas which were not only quite useless to them as food, but which were even in the habit of themselves dining off the Ranatras. Pieces of paper were held in front of them on needles and were seized, but almost immediately discarded. Leaves moved in front of them were taken also, and an attempt was made by Ranatra to pierce and suck them, but they were shortly cast aside. When bits of raw beef were offered to them, however, they not only seized them but continued to suck them for some time. Evidently the same enjoyment was derived from the beef juice as from the blood of the insects which more customarily constitute their meals. They would nab at anything in motion but only in two instances out of many experiments were they seen to <u>follow</u> the moving objects. Normally they wait for the prey to come to them; and in the pools and streams which they inhabit they are well supplied by the unfortunates that mistake them for vegetation. The instinct to seek deliberately for food is overshadowed by that for concealment.

Another indication of their sensitivity to moving objects is seen in the fact that if a person comes toward a glass aquarium in which they are, or passes a large object near it, they immediately cease even the slight swaying motion of the legs often observed as they cling to the weeds. This cessation of all movement has been called "deceptive quiet". It is not particularly marked, however, when the insects have become accustomed to anyone's being near the aquarium. It could not be induced in those which had been kept in captivity for some time. It is probably a reaction due to fear, at least it is a natural way for these insects, that depend upon concealment and waiting for food and safety, to react when governed by fear. Caution must be their watchword if they are to succeed in maintaining life amongst other insects which are equipped for an active condition. In the lines in which this insect has developed, loss of ability to move swiftly, together with great specialization of external form that insures protective resemblance, such a reaction may very well have been evolved as a benefit to the species. Certainly it would aid in its protection. The Ranatra that responded to fear as other insects do, by trying to escape rapidly, must have been early eliminated- anything could catch a water-scorpion- and the reaction shown in loss of motion of all kinds would have been an aid at least, if not a necessity, for the perpetuation of the species.

2. Special Reactions.

The two most noticeable phases of the Ranatra's behavior that have been designated as "special reactions" are the death feint and the phototactic response. Some observations made in the laboratory here appear to be explanatory of certain points that have been misunderstood or unnoted before. It is with the view to the possible value of such explanation as these afford, that the reactions are considered here as they have been discussed fully before by Holmes (3)- as mentioned above- though from a different standpoint.

(1) Death feigning.

The general behavior of Ranatra shows very clearly that its whole course of action, so to speak, is one of inaction. The instinct of "watchful waiting" so controls it that for the most part an inanimate stick shows about as much activity as a water-scorpion. It is not peculiar then that the death feigning instinct is remarkably developed in this insect. Holmes (3) has conducted numerous experiments in this connection. Similar ones carried on here show practically the same results. A summary of the important factors is as follows:

When picked out of the water or thrown out by means of forceps the Ranatra almost immediately becomes motionless. At times this response is not elicited, but handling or rolling about in one's fingers never fails to call forth this "death feint" unless the insect has become accustomed to such a stimulus. The positions assumed by Ranatra at this time may be any awkward or unnatural one, but the usual one is that with the front legs stretched directly out in front and the second and third pair held straight back underneath the abdomen. The general resemblance of Ranatra to a stick is increased by this- the stick is straight now without even the twigs of legs showing.

Holmes (3) has pointed out that the condition of the insect at this time is one of "complete tetanus". The body and legs are in a state of great rigidity. When a death feigning Ranatra is picked up by the outstretched front legs it may be held so a long time without the legs bending. It is difficult to tell whether this is true when the insect is under water or not. It is possible to bring one up from the bottom to the top of the acquarium by a stretched out leg without that leg's bending. Still the rigidity of the legs evidenced by the inability on the part of a person to move them from the position assumed in the death feint, is not seen in those in the water- in the condition of "deceptive quiet" the legs may easily be moved about with a needle or forceps.

In certain experiments Holmes (3) carried on, he found that the death feint practically removed sensibility to pain. He tried cutting off their legs, bits of the abdomen, even the thorax, but they gave, as he said- "not even a wince". Apparently the death feint dominates for the time all the normal responses.

The duration of this condition is lessened by repeated feints. As an ordinary thing the feint continues from a quarter to three quarters of an hour- less at times. One or two observed here feigned death for an hour and a quarter at a time. It was found that continued eliciting of the feint made the duration of each succeeding one less and finally the insect refused to feign any longer. This is suggestive of the facts in connection with the deceptive quiet in the water, which was an attitude no longer assumed after the Ranatra had become accustomed to a person's being near the aquarium. Apparently they also become used to being handled out of the water.

The conclusion that Holmes (3) comes to in connection with this strongly marked instinct- that it can scarcely be of any use to the insect- does not seem tenable. He of course based this upon the supposed fact that Ranatra did not come to shore and the death feint only took place when it was out of the water. The fact that it does come to shore of its own accord- and also the necessity for its so doing- has already been explained. An insect so modified as Ranatra, such an awkward and slow walker, would have no chance of escape from land enemies in the usual insect way. But a stick lying upon the bank would be likely to escape entirely the notice of any bird or animal in search of prey; and a stick is all that Ranatra appears to be when in the death feint. The same stick in motion would be a fairly easy prize. So that at least it seems a little hasty to say that the death feint can be of no use, considering that it obviously affords protection when the Ranatra is out of water. Such a conclusion based upon the supposition that it does not leave the water is not unreasonable; but since it has been found to be contrary to the facts, there is reason for believing that the instinct which results in the evident protection of Ranatra is of use and has been of evolutionary value.

The question of what the death feint really is is another matter. It might be assumed to be the result of fear and there seems to be no good objection against this assumption. It has been stated that "of fear in the ordinary sense the Ranatra shows no sign"- what was meant by this was that it does not try to run or fly when handled. It might, however, be just as truly said that of hunger, in the ordinary sense, the Ranatra shows no sign; certainly it does not actively go in search of food as do most insects. The general reactions are so modified by the dominant instinct for concealment and inactivity that it would be strange if the response to fear alone were similar to that of other insects and contrary to its habitual methods of response. The function of fear is primarily protective- in the presence of an unknown or dangerous object an animal reacts in a way that eliminates the danger as far as possible. The locust, which has strong wings and is in the habit of using them , flies away. The water scorpion, which has neither strong legs nor wings, nor is in the habit of using them, remains even more quiet than usual. It is difficult to see why this is not as much a result of fear as the other. The phenomenon of deceptive quiet in the water has been described. Holmes (3) states that this "may have some relation to what is spoken of as the paralyzing effect of fear in higher animals". If the reaction in the water can be ascribed to fear it seems scarcely necessary to go any farther than such an explanation for the very similar reaction of the death feint out of water.

There is, of course, the fact that the Ranatra does not "feign death" in the water, meaning by this that the peculiar muscular rigidity of the so-called death feint is not a characteristic of deceptive quiet. Still it is possible that this may be only a difference in degree. The Ranatra is less accustomed to being out of the water and the stranger stimulus might well result in greater fear which shows itself in the insects not only becoming motionless but thrown also into a state of extreme tensity. That the effect of both wears off under familiarity bears this out-though of course in the case of the death feint it might also be attributed to exhaustion. Those that became indifferemt to handling showed activity, however, rather than exhaustion.

The death feint would not be as useful in all insects as in Ranatra. Belostoma (5), in which this reaction is fairly common, would scarcely be so benefited in a protective way. Combined as in Ranatra, however, with the external resemblance to sticks or twigs, it becomes a definite protection. There is no reason why this might not have been evolved as a beneficial reaction for the species, considering its evident usefulness. It seems probable that the death feint and deceptive quiet are merely different manifestations of the same thing, varying as the insect may be on land or in the water. In whatever way they have become established they are quite in accord with the general responses, which all tend toward increasing the efficiency of a mode of life dependent upon powers of concealment.

(2) Reaction to Light.

The reaction of Ranatra to light presents a different problem. The behavior of the insect when wrought up by certain stimuli of light and heat is curiously at variance with its general sluggish stolidity. The reason for the unusual activity will have to be found elsewhere than in the customary peculiarities of behavior. The results of experiments which were carried on in the coldest part of winter are as follows:

In the large glass aquarium the Ranatra were negative or indifferent in response to light,-they remained in the dark or moderately lighted parts in contact with some object in the water. Holmes (3) showed this to be due to the effect of contact stimuli which always induced a negative response.

When swimming in a small glass dish one or two once showed a faint positive response toward an electric light held in different positions near them but this occurred once only, out of many experiments. They appeared to be negative almost entirely, or indifferent. This is not in accord with Holmes' experiments for he obtained almost invariably positive responses. The difference can probably be attributed to the fact that the extremely low temperature at the time of my experiments would influence their reactions- lowering the temperature directly, always induces a negative response. In the fall and toward spring those in the smaller dishes gave a positive reaction- seeking the side of the dish upon which the light from the window fell.

When taken out of the water and laid on a table they first feign death. After coming out from this they react positively. They first walk and then fly toward the window and buzz there a moment, when they fall and remain quiet for some time, after which they seek the light once more. The flight is rather weak under these conditions.

If an electric light is passed back and forth over an insect that is out of the water, it will respond at first by turning the head from side to side. Then it will begin to follow the light in any direction it may be held - going in a forward direction or around in circles. It walks toward the light at first, scrambling hastily along in a very different manner from its customary aimless crawl. Soon it begins to fly, and reaching the light flies frantically around it, until it finally may fall, when it begins the whole performance over again. Though the positive phototaxis was evident enough in those stimulated by the ordinary daylight, it was much more marked and dominant when the stimulus was an artificial light- electricity or gas.

When it once begins to react positively it is worked up to such a state of excitement that handling at this time very seldom elicits the death feint though it did in one or two cases. The flight was very well sustained, apparently the more excited they become the more activity and strength they gain.

Holmes carried on many more experiments, all of which show practically the same main features - the entire dominance of the insect by the light, and the violent and continuous efforts to reach it when out of the water and subjected to the stimulus of strong artificial light. He concludes that the strong positive reaction is a reflex response of the pleasure-pain type and particularly useless in Ranatra. The creature merely seeks the light because it is so constituted that it derives a pleasurable sensation from the "stupid performance". It is of no use whatever, he thinks, in no way related to any customary activities of the water-scorpion, and only remarkable for the strength of its manifestation. Observations of some actions of the Ranatra in the natural environment, however, (in as far as the laboratory conditions may be said to correspond to these) indicate that the reaction has a definite value and place in the life history of this form.

The Ranatras brought into the laboratory all showed unmistakable tendency, in the warm days of late fall, to seek the shore. This common coming ashore was combined with the flight toward the window of several and attempts at flight of others. This took place in the daytime. The flight was not long nor particularly well sustained in any case. After reaching the window they usually buzzed there a moment, then fell to the floor. These had, of course, come to shore of their own accord. A couple which had been left in an aquarium, which was uncovered and placed outside the window, at this same time disappeared one bright moonlight night. They apparently took unto themselves, not only wings, but a strong power of flight. Such a disappearance might have been accidental, of course, but a repetition of the same thing occurred during a season of warm weather in January, when two left a small uncovered aquarium inside the laboratory one moonlight night. They must have flown about the laboratory for some time- no trace could be found of them on the floor under the windows where they would have fallen had their flight been weak. There were others in a covered aquarium at the time but of course it could not be stated whether or not they attempted flight. A third instance which gave unmistakable evidence that Ranatra not only leaves the water of its own accord but seeks the light at night, which the disappearance of these others plainly indicated- was observed in a warm night in February. At this time one came out from the water while it was being watched- dried off on the shore, and flew around a gas light in the middle of the room, the flight being strong and continued for some time.

It had been well enough shown, of course, that Ranatra would fly to a light when taken out of the water, but the fact that at certain seasons, at least, it came out naturally and sought the light at night was not recognized. The establishment of this fact shows that seeking the light is not a phenomenon unrelated to any other activity as Holmes supposed, but definitely connected with the flight which observation would indicate occurs in the fall and spring. A possible explanation for this habit is that of its connection with the instinct for distribution and reproduction. This instinct, which is a fundamental one in all insects is periodic in its functioning. For aquatic insects the spring and fall are the seasons for its appearance. The activity of the Ranatra, noticed both in those which came to shore in unusual numbers and in those that flew away, suggests the appearance of this instinct.

The arousal of the positive response at these seasons is undoubtedly due to the appearance of this instinct which creates a degree of excitement in the insect. Then when the positive phototaxis begins it continues- the Ranatra comes to shore, and, guided by the light flies to its destination. That such a sequence of events takes place is conclusively established by those that flew away on bright nights. The light to which they normally respond is apparently moonlight, certainly not daylight. This is suggestive of a certain general fact in regard to the phototactic response of any insect. It is probably not the <u>light</u> that attracts insects, but that the light is to them (under certain attuned conditions) a means of guidance to desired places. We scarcely could suppose that insects fly to the moon though we know they fly in the moonlight. But if it were the source of light that they "liked", if the light really attracted them (as we seem to assume about their flight into a flame or electric light) they would logically have to fly directly to the moon. Probably the actual fact is that the positive response in natural conditions leads them to seek open places in the woods or along streams which are more brightly lit than the surrounding regions; and where they find their fellows or a more favorable habitat. Thus their flight in perfectly normal conditions, tho directed no doubt by the positive phototaxis, shows that a greater intensity of light in one region than another is merely a guide to them in reaching what they desire. In all likelihood the artificial light into which they fly directly, deceives them. It presents a greater degree of illumination than the surrounding areas and they might very naturally mistake it for the kind of a region that they normally seek. But that they simply like an artificial light and so fly to their death, is an unreasonable supposition. The development of such an instinct merely to seek light regardless of consequences would be unnatural. In all probability the artificial light deceives them as explained and the normal positive phototaxis which has been developed enables them to use greater intensity of light as a guide to different habits.

The activity shown in the phototactic response of Ranatra which is extraordinary for this insect, is not so remarkable when considered as a coordinate of the functioning of the instinct of reproduction and distribution. That there should be a reversal of the ordinary mode of action is scarcely peculiar considering that the appearance of such an instinct arouses physiological complexes that are unusual enough themselves to produce reactions indicative of excitement.

The act of flight in itself is always accompanied by definite preliminary preparations. The Ranatra never flies when the upper wings are wet, It lies perfectly flat on the shore with its front legs straight out in front of it and its hind legs back - much as in the death feint- until it is dry, when it rises on its legs. While in this position it opens its anterior wings slightly, first raising the covering membranous flap of prothorax. This is accompanied by respiratory movements of the abdomen,- the breathing filaments are worked vigorously up and down on each other. Then the body sinks until it touches the ground. During this time it rubs its eyes in a singular fashion with the tarsi and spineson its front legs as though scraping off anything that might cling to the eyes and hinder sight. It also rubs its anterior wings with one of its hind legs. Then it moves its head rapidly from side to side as it did in response to a swaying light. Immediately after this it doubles its front legs up and backward and flies.

One that was observed went through some of this preparation but could not seem to separate the anterior wings. It rubbed them vigorously but they still remained closed. The struggles the Ranatra went through with were comically suggestive of a person attempting to unfasten a garment fastened behind. The manner of folding back the front legs when flying is interesting, the same movement takes place when the Ranatra is handled beyond the death feigning limit- it is as though it were protecting its eyes and ready to strike a blow.

The positive reaction to light is obviously useful to the water-scorpion at the time of seasonal flight in being the factor that controls the direction of flight. The insect must be guided eventually by the light to another pond or stream. Enough is not known of the mating habits of this form to say to how great an extent the reproductive instinct is involved but the instinct of reproduction and of distribution are very closely connected. Whether it be for a nuptial flight, as in the case of the moth, or whether a means of direct guidance by reflected light to another stream as in the case of Belostoma, the reaction to light serves to direct the seasonal flight. The response can no more be considered useless than can the positive reaction that serves a similar purpose in the moth or electric light bug.

B. Structural Modifications.

While the study of behavior is the important aspect of any ecological consideration, the question of how far the structure has kept pace with the behavior during the history of the creature is of moment. All organisms show adaptions of course,-the aquatic insects as a group display remarkable fitness structurally for their mode of life. Ranatra is a good example of this, illustrating the general modifications natural to the aquatic tribe as well as the individual adaptations peculiar to this species.

Naturally the most obvious and striking modification is that of its general appearance. With its stick-like behavior Ranatra has developed also an external likeness to a stick. It is not perhaps quite so perfectly modified in this respect as the phasmids which are known of course as the "walking sticks". The resemblance is remarkable though, and effective in securing the concealment that is a necessary accompaniment of a life of inactivity.

The peculiar position assumed by Ranatra, invariably inclined upside down in the water, arouses the question of how it maintains its equilibrium. Baunache (1) has shown that aquatic insects are either passive or active in regard to equilibrium. Most are passive, that is maintain a position without any effort on their part, but merely by means of the shape of the body, by "distribution of the masses". Those whose bodily shape does not insure equilibrium possess special static organs and sometimes even those with passive equilibrium also possess such organs. Baunache pointed out that this was the case in Nepa; and their function in that insect is to give awareness of positions assumed when the Nepa is crawling over the stream bottom and up and down banks. The organs are three pairs of stigmata- like structures on the ventral side of the abdomen. Ranatra possesses these same organs (Plate I) and the function is undoubtedly the same as in Nepa- they are organs of equilibration. Locy (4) considered them to be spiracles and functional, which is hardly possible as they are quite unconnected with tracheae. Torre Bueno (7) recognized that they were not ordinary spiracles but says that their function is unknown, suggesting that "they may be used in extracting oxygen from the water by osmosis." But Baunache (1) proved beyond doubt that they are static organs, and serve to orient the body when the insect crawls over inclines in the water bed. The fact too, that Ranatra for the most part lives in streams where there is a continual source of food supply constantly passing its hiding place suggests another reason for the possession of these static organs. In the running water, if it is to remain quiet and concealed as it must to secure its food, and at the same time upside down, it would obviously be in need of such organs to maintain its equilibrium.

Another modification related to the habit of waiting in concealment for food to come to it is seen in the structure of the head and eyes. (Plate II) The head may move freely from side to side, but furthermore the eyes are almost stalked and nearly spherical so that the insect can observe motion from any direction. Besides the ability this furnishes to detect food it also provides a means for looking out for enemies in all directions.

An adaptation to the aquatic mode of life which is not peculiar to Ranatra but present in this form, is the way in which the antennae are carried in pits on the ventral side of the head. (Plate II) In Belostoma they are sunk in much deeper pockets. Of course this disposal of the antennae avoids friction in swimming. The occurrence on the antennae of a few sensory hairs indicate that they still function during flight. The mouth parts of Ranatra are typically Hemipterous and not modified from the suctorial type.

Active locomotion being a rare matter with Ranatra, one would expect that the legs would be modified, as is the case. The long twig-like legs do not serve particularly well for walking and swimming but their manner of modification does contribute to the resemblance of Ranatra to a piece of dried vegetation. This type of modification differs essentially from that found in the legs of many aquatic insects which develop as very good oars- needed by active swimmers. The front pair (Plate III) are modified very effectively as grasping organs. When waiting for prey the tibia and tarsus are usually held slightly raised, (Plate III-A), sometimes they lie in the groove of the femur. To seize anything the upraised joints close swiftly; and the insect is securely pinned in the knife-like clasp. (Plate III-B) The projecting hook on the femur renders the grasp even more sure.

In connection with the respiratory system the Ranatra has two very long filaments united into a tube, at the base of which is a pair of large spiracles protected by hairs. The other pairs of functional spiracles discovered have already been described. (Plate IV-A) The protection of these by the wings and prothoracic membrane is an adaptation to the aquatic condition. They must be made secure from entrance of the water while the insect is in the stream. The raising of the anterior wings early in the preparation for flight is probably for the purpose of more completely filling the tracheae connected with these spiracles- at that time the insect needs more oxygen.

Ranatra has performed a greater feat than the Phasmid by achieving resemblance to a stick yet at the same time retaining its wings which some of the walking-sticks have lost. There is an interesting device- found also in other aquatic insects- for protecting the posterior wings from water. The anterior wings, one of which folds over the other at the apex, fit so securely over the posterior that they completely conceal and protect the functional wings underneath. They are fastened in a curious way. A pair of button-like projections on the sides of the thorax (Plate IV, B) slide into depressions on the wings much as a glove button works, making a very secure clasp. It is important that the posterior wings should not be wetted; and this button clasp arrangement for fastening the wings provides the necessary safeguard against the entrance of water into the air chamber in which the hind wings lie. The pressure of water on the outside keeps the air from escaping.

Adaptations such as these are curiously interesting, but there is nothing very remarkable in the fact that these aquatic insects are well adapted. They must of necessity be modified to live in an environment so different from their original terrestrial one. Those that failed to become differentiated must have been eliminated early in the history of the insect invasion of the waters. Again, unless the structural modifications of such an insect as Ranatra had kept pace with its habits, it would either have been forced to alter its habits or altogether abandon the struggle of life. The waiting instinct is a good enough controlling element for an insect that is well-nigh indistinguishable from adjoining vegetation when at rest. But if one can imagine such an instinct becoming dominant in the conspicuous Hydrophilus, for example, it is easy to believe that the species would soon cease to exist unless its structure were to undergo a great transformation.

Summary and Conclusions.

1. The general responses of the water-scorpion all show the complete dominance of the instinct for concealment and inactivity.

2. Contrary to what was formerly supposed, the Ranatra comes to shore habitually both for renewal of air supply and for flight.

3. The phenomenon of deceptive quiet exhibited when Ranatra is in the water, may be considered as a reaction due to fear; and is in accord with the general responses as indicating dependence upon concealment.

4. The extremely developed death-feigning instinct noticed when Ranatra is out of water is of benefit to it at this time in rendering it more inconspicuous. It is probably a reaction similar to that of deceptive quiet- evincing a greater degree of fear than that shown by the latter.

5. The marked phototactic responses which are only given when Ranatra is out of the water are apparently a reversal of the general habit of inactivity of the insect. They are closely connected with the periodic functioning of the instinct for distribution and reproduction. The reaction to light is of great benefit at the time when the Ranatra comes to shore in response to this instinct, in guiding it into other ponds and streams.

6. Structurally the Ranatra shows almost perfect adaptation to its mode of life. Its general resemblance to the vege-

tation in which it lives affords it protection from enemies and aid in securing its own prey. It is these structural modifications which make it possible for the inactive Ranatra to live in a community of other insects which are active but differently equipped.

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Plate I

Abdomen - Ventral View

S 2	=	Segment 2 of abdomen
S 3	=	Segment 3 of abdomen
S 4	=	Segment 4 of abdomen
St. O	=	Static organs
Br.Fil.	=	Base of breathing tube

Plates and Frontispiece by G. H. Childs.

Plate I

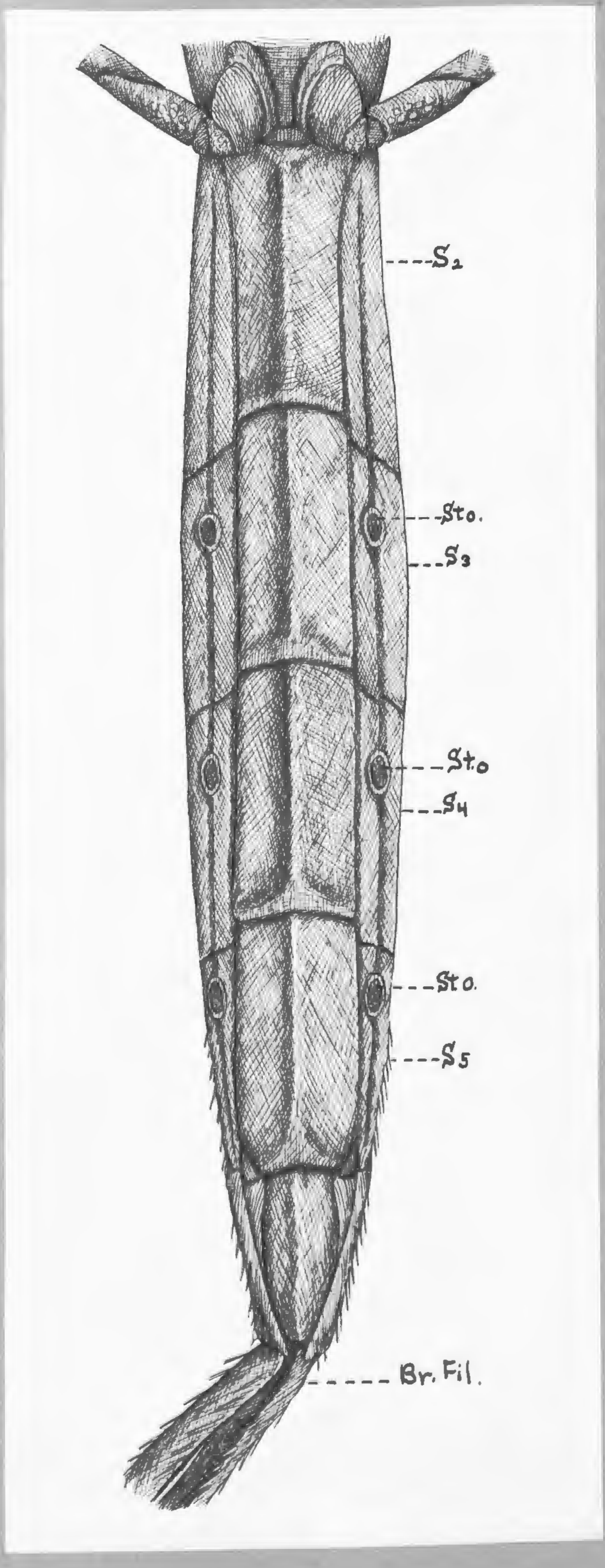


Plate II

Head - Ventral View

L = Labium

E = Eyes

A = Antennae

S = Sensory Hairs

Mp = Base of Mouth Parts

Plate II

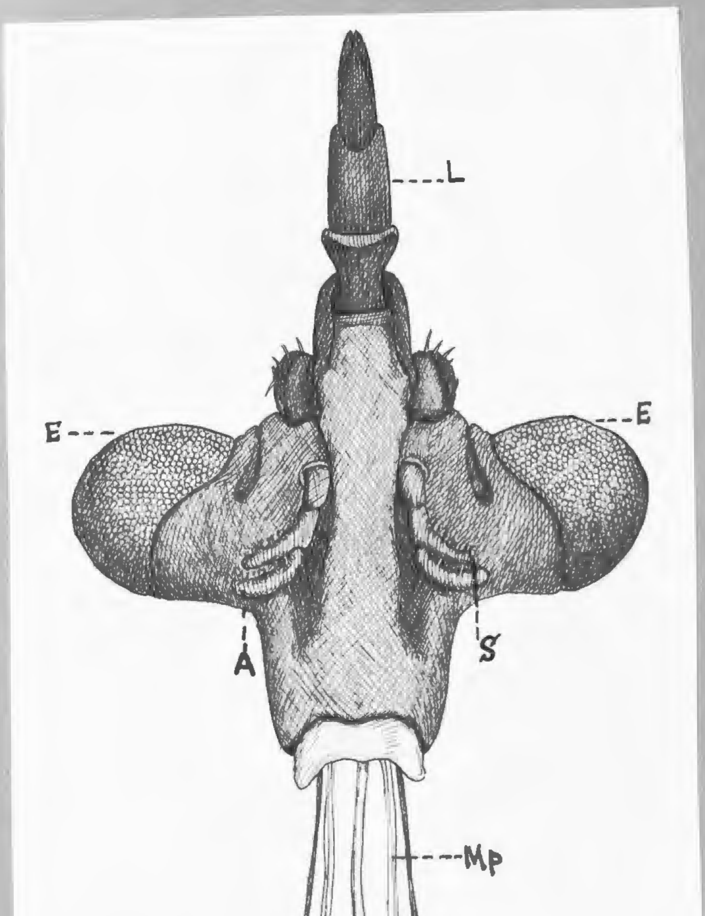


Plate III

Grasping Leg

C = Base of Coxa

G = Groove

F = Femur

T = Trochanter

Ta = Tarsus

Ti -= Tibia

Plate III

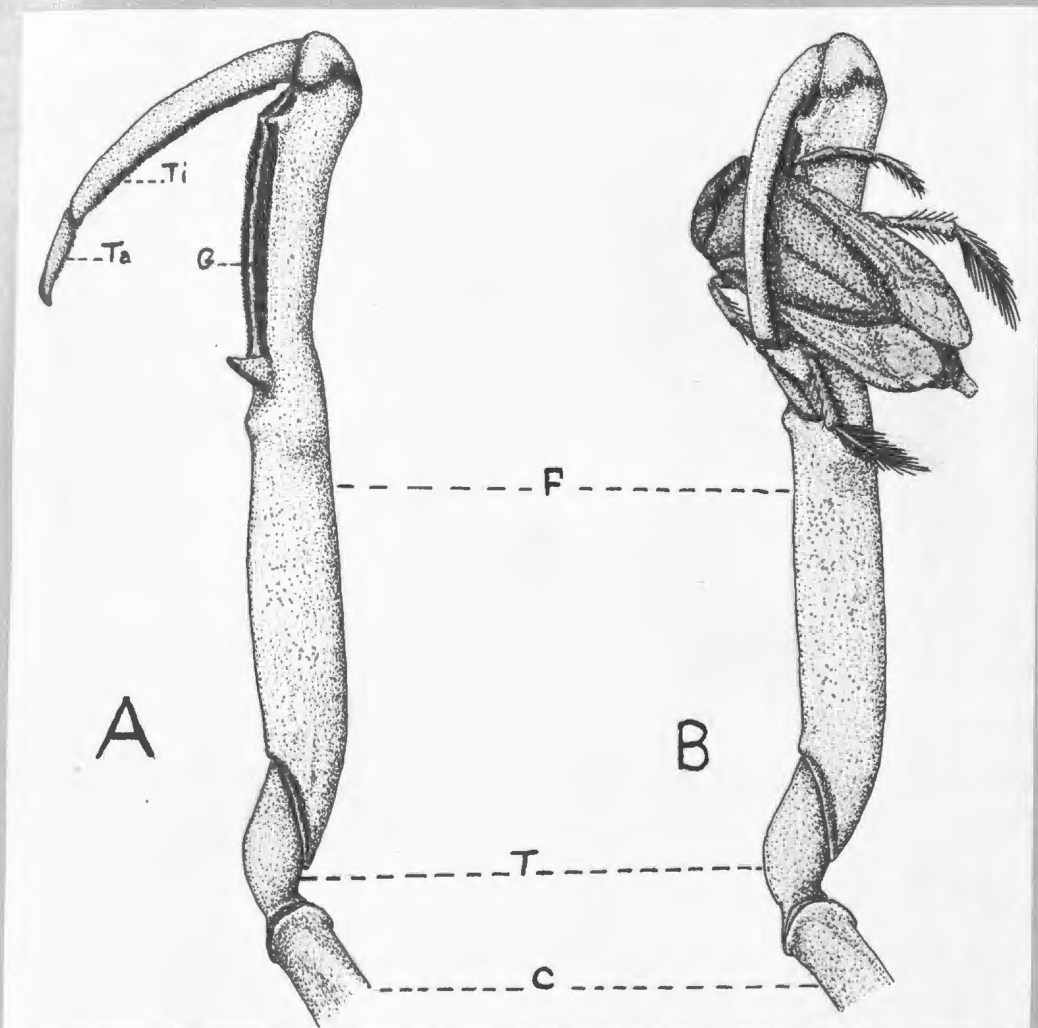


Plate IV.

A. Thorax - Dorsal Aspect - Wings Removed

B. Anterior Wing - Ventral View.

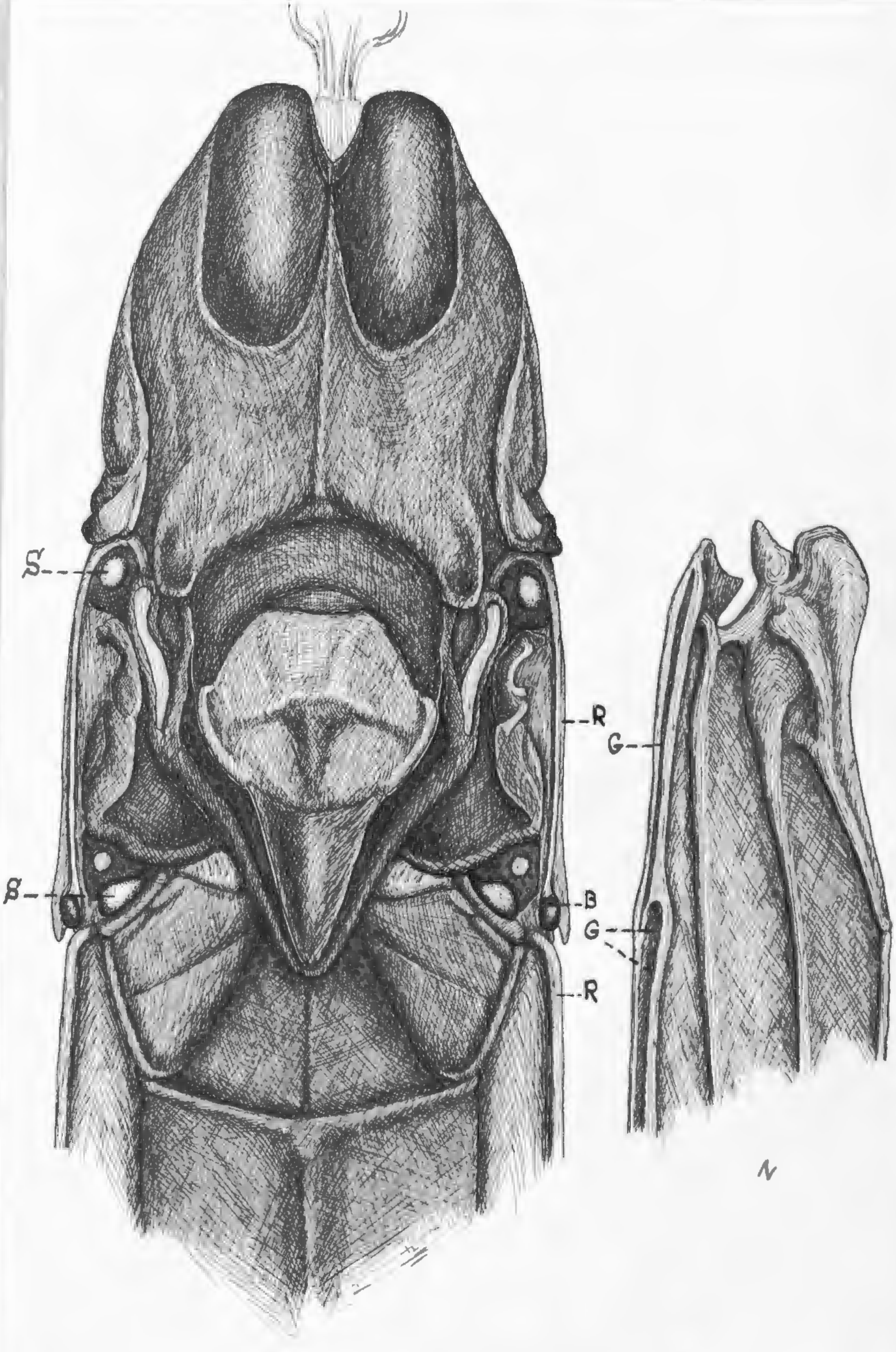
S = Spiracles

B = Button-like Projections

R = Ridge

G = Groove

Plate IV



A

B