Impact of predation and food utilization on reproduction of *Diplonychus indicus* and *Ranatra filiformis*

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Abstract. Impact of predation and food utilization on reproduction of the water bugs — *Diplonychus indicus* and *Ranatra filiformis* was studied. In *Diplonychus indicus*, the food quality affects the rate of predation as well as food utilization. Allometric growth of various body parts and the longevity of each nymphal instar of the bug showed distinct variation, when exposed to individual prey item viz *Culex*, *Anopheles* and *Aedes* larvae and fish fingerlings. In *Ranatra filiformis*, a distinct pattern of oviposition in relation to the increased rate of predation on *Culex* larvae was observed. The significance of such variations in reproductive activities of these water bugs was discussed.

Keywords. Allometric growth; longevity; energetics; oviposition.

1. Introduction

Nutritional ecology is central to proper interpretations of manner of feeding, reproduction, defense, habitat selection and such other life history phenomena in arthropods (Scriber and Slansky 1981). With regard to factors that promote oviposition, embryonic development, growth and sexual maturity, starvation or nutritional deficiency is felt to be a major cause. Davis (1964) has reported that resorption of oocytes in hemipterous insects is governed and promoted by the nutritional status even in mated females. When food quality is changed, the subsequent rate of development, body composition and growth of arthropods differed significantly (Waldbauer 1968; Mueller *et al* 1973; Blumberg and Swirski 1974). To predators, the mobility is vital among properties of the prey item. In aquatic hemipterous bugs, the predation is categorised as chase and capture the prey (Peckarsky 1982), sit and wait in ambush (Hoffmann 1927) and resting-questing attitude (Menke 1979).

If nitrogen proved to be a limiting nutrient for the growth as suggested in *Pieris rapae* (Slansky and Feeny 1977), then the first objective of the present study was to verify if growth during postembryonic development is related more closely to the nutritional status and to the energetics of an active predator — *Diplonychus indicus*. The second objective was to study the interaction between the sex of the bug and the efficiency of utilization of the food provided.

The third objective was to examine the impact of specific diet on life fecundity of a matured female and ovipositional strategy in *Ranatra filiformis*.

2. Materials and methods

2.1 Longevity and allometric growth

To record the impact of nutrition on longevity and allometric growth on *D. indicus*, the encumbered males were maintained in the laboratory. First nymphal instar that
emerged and its successive stages of development till adulthood were fed with *Culex*, *Anopheles* or *Aedes* larvae with fish fingerlings as control. The life span of each nymphal instar with specific diet was recorded. Various body measurements of all nymphal instars fed with specific diets were measured. Data obtained were fitted to Huxley’s (1924) exponential formula \[ Y = bX^k \], where \( Y \) is the allometrically growing organ, \( b \) the growth index, \( X \) the body length taken as reference measurement and \( k \) the equilibrium constant by which \( Y \) grows in relation to \( X \) throughout the ontogenetic stages and the significance of growth was derived statistically.

2.2 Energetics of nymphal instars

All nymphal instars of *D. indicus* were starved for 24 h prior to experiments. Their predatory efficiencies were tested against 4th age group of *Culex* and *Aedes* larvae at different densities. To assess the food utilization, the scheme of energy balance of Petrusewicz and Macfadyen (1970) namely \( C = P + R + F + U \) was followed, wherein \( C \), food consumed; \( P \), growth attained; \( R \), respiration; \( F \), faeces and \( U \), nitrogenous wastes. From the data obtained, the assimilation and the conversion efficiencies, rates of consumption, assimilation and conversion were calculated for all developmental stages. Tissue samples of these experimental ones were dried at 105°C. The calorific value of each sample was determined by incinerating them in a semi micro oxygen bomb calorimeter following the procedure of Pandian and Madhavan (1974).

2.3 Food utilization in adults

Freshly moulted males and females of *D. indicus* were maintained in the laboratory with 4th age group of *Culex* larvae. After feeding them for 20 days, the experiment was suspended and the bugs were treated to estimate the assimilation and conversion efficiencies, rate of feeding, assimilation and conversion as cited earlier.

2.4 Statistical analysis

Data obtained were subjected to statistical analysis of variance to derive the significance of differences in the above experiments.

2.5 Life fecundity and oviposition

Fifth nymphal instar of *R. filiformis* were collected and maintained in the laboratory with 4th age group of *Culex* larvae as the specific diet at 28 ± 1°C with a daily regime of 12 h light and 12 h darkness.

Males and females obtained soonafter moultng from 5th nymphal instar were kept in pairs and were fed normally with *Culex* larvae. Stems of *Hydrilla* were provided as ovipositional cites in order to record the percentage of ovipositive females, rate of reproduction, total number of eggs produced during its life time, distribution of eggs on the floating vegetation, adult longevity and the percentage of hatching success. Number of eggs per batch of a female served as the index of reproductive potential. First nymphal instar that emerged and the successive stages it moulted with *Culex* larvae as diet were also recorded.
3. Results

3.1 Nutrition and life span

Table 1 shows that the duration of post embryonic stages of *D. indicus* in the laboratory reared population simulating natural conditions and providing food *ad libitum* varies from 80–90 days. The longevity of I nymphal instar and II were 8·7 days, III for 10·6 days, IV for 24·5 days and V for 37·5 days. However, when they were fed with a specific test food, the longevity of each nymphal instar varied significantly. On comparison, the duration of *Culex* fed ones was higher throughout the post embryonic development than those fed with other test food. Duration of development of all nymphal instars was found to be very low when fed with fish fingerlings.

3.2 Allometric growth in *D. indicus*

Figure 1 shows the measurement of the total body length of all nymphal instars plotted against time in days of the predator stages. Second and third instars of *D. indicus* showed maximum body length when fed with Culicine larvae. The fourth nymphal instar showed maximum body length when fed with anopheline larvae. The fifth nymphal instar showed maximum body length when fed with culicine larvae. The second and third instars showed minimum body length when fed with anopheline larvae and fish fingerlings. The fourth nymphal instar showed minimal body length when fed with aedes larvae and the fifth nymphal instar with anopheline larvae. Measurement of individual organ was subjected to statistical analysis of variance. The rostrum length, head width, 1st leg, 2nd leg and 3rd leg showed statistically significant differences among the members of third nymphal instars that were fed on different test food. At other nymphal stages such differences were not observed.

3.3 Food utilization in the post embryonic development

Data on energy budget of nymphal instars of *D. indicus* when fed with different test

<table>
<thead>
<tr>
<th>Nymphal instar</th>
<th>Mixed diet</th>
<th>Culicine larvae</th>
<th>Anopheline larvae</th>
<th>Aedes larvae</th>
<th>Fish fingerlings</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>8·7±0·49</td>
<td>4·9±0·49</td>
<td>6·0</td>
<td>6·1±0·35</td>
<td>5·4±0·53</td>
</tr>
<tr>
<td>II</td>
<td>8·7±1·29</td>
<td>5·9±0·7</td>
<td>5·0±0·33</td>
<td>5·55±0·74</td>
<td>4·5±1·12</td>
</tr>
<tr>
<td>III</td>
<td>10·6±2·11</td>
<td>8·6±2·07</td>
<td>12·1±3·84</td>
<td>11·73±1·94</td>
<td>6·47±1·51</td>
</tr>
<tr>
<td>IV</td>
<td>24·42±1·0</td>
<td>22·42±1·0</td>
<td>11·0±2·56</td>
<td>23·33±5·75</td>
<td>7·55±0·62</td>
</tr>
<tr>
<td>V</td>
<td>37·67±6·06</td>
<td>35·33±6·62</td>
<td>18·36±1·8</td>
<td>11·27±3·0</td>
<td>13·0±1·61</td>
</tr>
</tbody>
</table>

| Total          | 90·09      | 77·15           | 52·46             | 57·98       | 36·92           |
foods were recorded. In general, assimilation efficiency was almost 90% in the first nymphal instars of the predators and remain constant with others. In particular, assimilation efficiency of fifth nymphal instar of the predator was 82% with aedes larvae, 90% with anopheline larvae and 93% with culicine larvae (figure 2); whereas
the conversion efficiency at all stages of development was almost constant except the fifth nymphal instar but it is inversely related to the assimilation efficiency when fed with fish fingerlings (figure 3). The feeding rate was minimum when fed with fish fingerlings and maximum with culcine larvae. Among all nymphal instars, the second one showed the highest rate of feeding with culex and anopheles larvae. However, the feeding rate declined in other developmental stages (figure 4). The assimilation rate was almost equal in those fed on culex larvae, anopheles larvae or fish fingerlings; but those fed with aedes larvae showed 2 peak values with the first and third nymphal instars (figure 5). Similarly, the conversion rate was also noted to vary in relation to the quality of food provided, being higher at the second nymphal instar

![Conversion efficiency graph](image)

**Figure 3.** Effect of specific diet on the conversion efficiency of *D. indicus.*

![Feeding rate graph](image)

**Figure 4.** Effect of specific diet on the feeding rate of *D. indicus.*
when fed with larvae of *Culex*, *Anopheles* or fish fingerlings. It was considerably high when fed with fish fingerlings at all stages (figure 6).

Data on the energetics of the predator stages throughout their feeding periods is summarised in table 2. It may be noted that the feeding rate was minimum (1060 mg/g live insect/day) in fingerling fed individuals and very high (4300 mg/g live insect/day) in those fed with *Culex* larvae but the assimilation rate was maximum in *Aedes* fed ones and minimum when fed with *Anopheles* or fish fingerlings. The conversion rate was highest (171 mg/g live insect/day) when fed with fish fingerlings.
Table 2. Energy budget of the nymphal instars of *D. indicus* fed with specific diet.

<table>
<thead>
<tr>
<th>Quality of food</th>
<th>Culicine larvae</th>
<th>Anopheline larvae</th>
<th>Aedes larvae</th>
<th>Fish fingerling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (days)</td>
<td>77-15</td>
<td>52-46</td>
<td>57-98</td>
<td>36-92</td>
</tr>
<tr>
<td>Feeding rate (mg/g-live insect/day)</td>
<td>4300</td>
<td>2532</td>
<td>1550</td>
<td>1060</td>
</tr>
<tr>
<td>Assimilation rate (mg/g live insect/day)</td>
<td>955</td>
<td>841</td>
<td>1170</td>
<td>845</td>
</tr>
<tr>
<td>Conversion rate (mg/g live insect/day)</td>
<td>128</td>
<td>143</td>
<td>124</td>
<td>171</td>
</tr>
<tr>
<td>Assimilation efficiency (%)</td>
<td>95.2</td>
<td>92.8</td>
<td>89.6</td>
<td>68.8</td>
</tr>
<tr>
<td>Conversion efficiency (%)</td>
<td>5.0</td>
<td>7.0</td>
<td>9.6</td>
<td>29.4</td>
</tr>
<tr>
<td>Calorific value of the converted food (g cal)</td>
<td>234.85</td>
<td>185.81</td>
<td>115.1</td>
<td>154.9</td>
</tr>
</tbody>
</table>

Table 3. Energy budget of adult (male and female) *D. indicus* fed with culicine larvae.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Conversion efficiency ± Standard Error</th>
<th>Assimilation efficiency ± Standard Error</th>
<th>Feeding rate ± Standard Error</th>
<th>Assimilation rate ± Standard Error</th>
<th>Conversion rate ± Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>20.36 ± 2.62</td>
<td>47.28 ± 2.66</td>
<td>497.24 ± 65.14</td>
<td>233.81 ± 17.67</td>
<td>45.6 ± 5.85</td>
</tr>
<tr>
<td>Female</td>
<td>18.75 ± 4.25</td>
<td>38.92 ± 5.03</td>
<td>558.11 ± 140.08</td>
<td>213.09 ± 34.74</td>
<td>41.98 ± 9.54</td>
</tr>
</tbody>
</table>

and lowest (124 mg/g live insect/day) in *Aedes* fed ones. The calorific value of the converted body tissue was 234.85, 185.81, 115.1 and 154.9 g/cal with *Culex*, *Anopheles* and *Aedes* larvae and fish fingerlings respectively.

3.4 Energy budget in adult

Table 3 shows that the assimilation efficiency of the male was 47.28% which is higher than that of the female. Similarly, the conversion efficiency was 20.36 in males and 18.75 in females but the feeding rate was low in males than in females. However, the assimilation and conversion rates were noted to be higher in males than in females.

3.5 Egg viability in *Ranatra*

The hatching success of eggs deposited by *R. filiformis* was recorded (figure 7). There was a great difference between the number of eggs laid among the batches. The number of eggs in 4 batches was 7, 86, 9, 93, 4, 07 and 0, 14 respectively. Also, the time interval between any 2 batches of the eggs varied significantly. The percentage of hatchability ranged from 64-82 in these batches. Data shows that the time interval between batches of eggs and percentages of hatchability were found to be inversely proportional with first and the last batch of eggs. Of the eggs laid in each batch, the hatching success was 74%, 62%, 78% and 84%, respectively.
3.6 Rate of oviposition in Ranatra

The number of batches of eggs laid by a female during its life time ranged from 17–23. The number of eggs laid was from a maximum of 12.33±4.4 in the first batch to a minimum of 2 in the 23rd batch (figure 8). However, the trend in the fluctuation of number of eggs deposited batchwise during the life span of Ranatra was not highly significant; whereas the time interval between successive batches of eggs laid was significantly high. Generally, the hatching period was noted to be more or less constant. The bug took 5.987±3.585 min to get acclimatised for oviposition. Time taken for actual oviposition of any egg in one batch ranged from 0.56–1.17 min. However, the time interval between successive eggs laid increased from the first to the last egg deposited (figure 9). When the percentage of success of successive stages of development and the percentage of success of development of egg to adult were
Nutrition and reproduction in water bugs

Figure 9. Time interval between successive eggs laid, actual oviposition period and number of eggs laid by a female *R. filiformis*.

Table 4. Success (%) of successive stages of development and of egg to adult in *R. filiformis*.

<table>
<thead>
<tr>
<th>Stages of development</th>
<th>Egg to I</th>
<th>I to II</th>
<th>II to III</th>
<th>III to IV</th>
<th>IV to V</th>
<th>V to Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg to adult</td>
<td>89.0 ± 5.95</td>
<td>91.96 ± 2.65</td>
<td>81.36 ± 3.60</td>
<td>78.42 ± 4.80</td>
<td>74.78 ± 4.70</td>
<td>19.67 ± 3.53</td>
</tr>
</tbody>
</table>

calculated, it was noted to be more or less constant, till the fifth nymphal instar but there was a sudden decline from fifth nymphal instar which was recorded as 19.6% irrespective of the sex moulted (table 4).

4. Discussion

Aquatic insects exhibit the ability to use a wide variety of food sources, exploit and develop them into a variety of macro- and microfeeders that operate from deep within the substrate to the top of the surface film (Resh and Solem 1978). Results of the present study reveal the ability of belostomatid bugs feeding on variety of prey items. However, a preferential selection was noted which has a direct influence on their longevity. Probably, prey mobility and morphology may suppress the predatory efficiency of the bugs concerned. Difference in mobility between *Ephemerella altana* and *Bactis tricaudata* was pivotal in producing the higher consumption of the stoneflies (Molles and Pietruszka 1983).

Rate of predation and food quality were observed to alter the duration of post-embryonic development in *D. indicus*. Clark (1963) has shown that some strains of *Habrobracon* females when fed on white cloves honey, lived much longer than *Ephestia* fed females. But in other strains, the adult life span was identical on either diet. Report of Alpatov (1930) on *Drosophila* and Strong and Kruitwagen (1969) on
Lygus support the present observations of the impact of nutrition on the life span and ageing of insects.

The results of energetics of developmental stages of *D. indicus* in relation to food quality show many interesting observations. When feeding is greater with *Culex* than with *Aedes* larvae, the conversion and assimilation efficiencies do not show much difference but with fish fingerlings, the conversion and assimilation efficiencies during development differed significantly. Such a feature is not uncommon in herbivorous insects as is known from the report of Bailey and Mukerji (1976) on *Melanoplus sangrinipes* and Smyth (1962) on *Analis mali*. However, there appears to be no relationship between rate of feeding with that of rate of assimilation and conversion. But the finding that the high conversion rate of second nymphal instar that fed on culicine larvae is reflected in the increased body size of the penultimate instar is of considerable interest. Also, relationship between conversion rate and allometric growth including total body length was noted. This may be due to the difference in the nutritive requirements responsible for the growth of various organs (Kasting and Mcginnis 1959; Rockstein 1964).

Results on egg viability of *R. filiformis* show that the number of eggs laid in earlier batches is more than that in the later ones. The prolonged period of mating in the early period might have resulted in such increased oviposition and on experience, the females might have avoided repeated copulation which is well reflected in the minimum number of eggs laid in the later batches. Siew (1966) in *Galeruca tenaceti* has suggested that ovipositing females possess neurosecretory cells that produce more neurohormones resulting in an increased production of batches of eggs than do those of maturing females which further supports the present view that oviposition is frequent at a later stage irrespective of the number of eggs laid in each batch.

Results further indicate that the time interval between oviposition of successive batches of eggs is less in the later batches. This may reflect on the ability of females to store sperms (Parker 1970) and ageing (Spence and Scudder 1980). Data on ovipositional period show that the bug takes a minimum time to lay the eggs in the beginning and a maximum period at the end in a single batch. Demand for floating vegetation, energy lost during oviposition and the mobilisation of the matured eggs from the terminal part of the ovariole may be attributed as the causal factors for such variations in oviposition period during oviposition of eggs in a single batch. However, such an interpretation needs to be confirmed based on histological and histochemical studies.

Among the successive instars, a sudden fall is noted in the percentage of emergence of adults from fifth nymphal instar. This may be owing to an increased rate of mortality during the moulting of adults from fifth nymphal instar. This in turn may be either owing to the influence of increase in temperature that can eliminate a species by disrupting emergence patterns as is suggested by Nebeker (1971) in *Pteronarcys dorsata* or to the susceptibility of low oxygen concentration in the medium in other aquatic insects (Nebeker 1972).

The quantitative nutritional approach consists of measuring the amount of food consumed, digested and assimilated, excreted, metabolised and converted into biomass (Woodring 1979). Analysis of these measurements in *D. indicus* and the impact of nutrition on oviposition strategy of *R. filiformis* reveal how organisms respond to different foods and which food component exerts the greatest effects on growth. Further investigations on mobilisation of biochemical components from...
haemolymph to various body parts may highlight the significance of food quality on reproductive biology of water bugs.

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