V. THE EFFICIENCY RATIOS
According to the second law of thermodynamics "no process involving an energy transformation will spontaneously occur unless there is a degradation of energy from a concentrated form into a dispersed form". As "some energy is always dispersed into unavailable heat energy, no spontaneous transformation of energy is 100% efficient" (Odum 1953).

The light energy is transformed into potential energy during photosynthesis. Part of the potential energy stored by plants in the form of organic matter is transformed into the mechanical energy to do their internal work. The rest of the stored energy (potential) forms the basic food of all the organisms of the community. When the herbivores consume a portion of the food to do their internal and external work, the rest of it is being stored in the form of growth. Again when the carnivore feeds on a herbivore the same process of transformation takes place.

So at all stages of transformation there is a degree of conversion of food into the organic matter of their own bodies as well as a degree of utilisation of energy which have been designated as efficiencies with respect to growth. These efficiencies and their calculation are of considerable interest in the modern studies of community metabolism.
These have been calculated for those organisms whose rate of growth could be determined taking individual species populations into consideration by such authors who have studied community metabolism taking the individual species populations. (Ivlev 1939, 1945; Teal 1957; Odum, E.P. & Smalley 1959; S. Richman 1959). Others who have studied the community metabolism taking into consideration a trophic level as a sub-unit, rather than the individual, have determined efficiency ratios for total populations of trophic levels rather than for the individual species populations. (Lindeman and Hutchinson 1948; Clarke 1946; Dineen 1953; Odum H.T. 1957). The latter types of efficiency ratios could not be calculated in the present study because the animals of the pond under study were not so far studied for their food and feeding habits quantitatively and not divided into various food groups or trophic levels. Secondly the amount of incident light and absorbed light of the community and the amount of food ingested by the various types of food groups for a unit period of time were not determined because of the limitations of time. The efficiencies of a trophic level as followed by various authors are given below. (Lindeman and Hutchinson 1942) have defined the efficiency of a trophic level with respect to lower level as
\[
\frac{n}{100} \quad \text{or} \quad \frac{\frac{n}{n-1}}{100}. \quad (\text{Clarke 1946})
\]
describes four types of efficiency ratios for each trophic level.

1. **Plants:**

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Absorption</td>
<td>Absorbed light</td>
</tr>
<tr>
<td></td>
<td>Incident light</td>
</tr>
<tr>
<td>2. Assimilation</td>
<td>[ \frac{C_6H_{12}O_6 \text{ formed}}{\text{Absorbed light}} ]</td>
</tr>
<tr>
<td>3. Growth</td>
<td>Plant growth ( P_2 )</td>
</tr>
<tr>
<td></td>
<td>[ \frac{C_6H_{12}O_6 \text{ } P_1^*}{\text{Plant growth } P_2} ]</td>
</tr>
<tr>
<td>4. Increase</td>
<td>Net increase of plants ( P_3 )</td>
</tr>
</tbody>
</table>

II. **Herbivore:**

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Consumption</td>
<td>Plants consumed ( C + U )</td>
</tr>
<tr>
<td></td>
<td>Plants growth ( P_2 )</td>
</tr>
<tr>
<td>2. Assimilation</td>
<td>Plants assimilated</td>
</tr>
<tr>
<td></td>
<td>Excluding ( U )</td>
</tr>
<tr>
<td></td>
<td>Plants consumed ( C + U )</td>
</tr>
<tr>
<td>3. Growth</td>
<td>Herbivore growth ( P_2 )</td>
</tr>
<tr>
<td></td>
<td>Herbivore assimilation ( P_1 )</td>
</tr>
<tr>
<td>4. Increase</td>
<td>Net increase of herbivores ( P_3 )</td>
</tr>
<tr>
<td></td>
<td>Herbivore growth ( P_2 )</td>
</tr>
</tbody>
</table>
III. Carnivore:-

1. Consumption

   Herbivore consumption C + U
   Herbivore growth P2

2. Assimilation

   Herbivore assimilation C excluding U
   Herbivore consumption C + U
   Carnivore growth P2
   Carnivore assimilation P1

3. Growth

4. Increase

   Net increase of carnivore P3
   Carnivore growth P2

$P_1, P_2, P_3$ are the different trophic levels. $C =$ consumed.
$U =$ Unassimilated).

Dineen (1953) in his studies on Minnesota pond has calculated the following ratios, which could not be actually treated as efficiency ratios but ratios of organisms of a trophic level to another level, one of them being the predator group and another the prey group. These ratios cannot easily be calculated without a clear study of the prey predator relationships. The ratios of Dineen (1953) are given below.

1. Zooplankton
   Phytoplankton

2. Benthic predators
   Browsers.

3. Plankton predators
   Zooplankters

4. Browsers
   Producers

5. Benthic predators
   Producers

6. Swimming predators
   Producers
7. **Primary consumers**
   producers

8. **Secondary consumers**
   Producers

9. **Secondary consumers**
   Primary consumers

Odum H.T. (1957) has calculated the following efficiency ratios for various trophic levels.

1. Utilisation efficiency $Eu = \frac{\text{Rate of Ingestion}}{\text{Rate of net organic synthesis}}$

   $\frac{1_3}{P_1} = \frac{1_3}{P_2} = \frac{1_4}{P_3} = \frac{1_5}{P_4}$

2. Assimilation efficiency $Eq = \frac{\text{Rate of assimilation}}{\text{Rate of ingestion}}$

   $Eu = \frac{A_2/A_3 = A_4/A_5}{I_2 = I_3 = I_4 = I_5}$

3. Tissue growth efficiency: $Et = \frac{\text{Rate of net organic synthesis}}{\text{Rate of Assimilation}}$

   $Et = \frac{P_2/P_3 = P_5/P_5}{A_2/A_3 = A_4/A_5}$

4. Ecological growth efficiency:

   $Ec = \frac{P}{1_2} = (Et.) (Ea)$

5. Lindeman efficiency: Ratios of intakes of trophic levels

   $E_1 = \frac{I_2}{I_1} = (Ec) (Ea)$
6. Trophic level production ratios.

\[ E_p = \frac{P_2}{P_1} = (E_n)(E_c) = (E_u)(E_t)(E_a) \]

The second group of biologists who have taken the individual species population as a sub-unit for calculations have determined the physiological efficiency ratios of populations of individuals species. These physiological efficiency ratios of several types of species with the same food habit, when summed up, will give an ecological efficiency ratio of a trophic level. The efficiency ratios for the individual species were calculated as early as Needham (quoted by Ivlev, 1939). Later Ivlev (1939) calculated the efficiency ratios of _Tubifex tubifex_ (both respiration efficiency and growth efficiency) as

\[
\frac{\text{Respiration}}{\text{growth}} \quad \text{and} \quad \frac{\text{growth}}{\text{Assimilation}}
\]

respectively. Ivlev (1939a, 1945) after Terreine used a generalised equation

\[ Q = Q_1 + Q_R + QT + QV + QW -- (1) \]

Ricker (1946) grouped Q1 + QV + QW as respiration loss. From this Input = growth + Egestion + Respiration. The egestion may be the loss of energy in the form of undigested food in the fecal matter and the amount of food initially lost due to inefficient feeding mechanism.

\[ Q = \text{input}; \ Q_1 = \text{growth}; \ Q_R = \text{Fecal matter}. \]

\[ QT = \text{primary heat}; \ QV = \text{energy of external work}. \]

\[ QW = \text{energy of internal work}. \]
Teal 1957 calculated efficiency ratios for cold temperate
ature spring animals after the method of Ivlev (1939 - '45).
He calculated \( \frac{\text{Respiration}}{\text{Assimilation}} : \frac{\text{Net production}}{\text{Assimilation}} \)
\[ \text{Energy passed on to other populations} = \text{ratios} \]
\[ \text{Energy assimilated from outside sources} \]
Richman (1959) calculated, for populations of Daphnia pulex,
the gross efficiency ratio and net efficiency ratio. Gross
efficiency ratio of Richman and "assimilation efficiency"
of Odum H.T. are one and the same and the "net efficiency"
of Richman is nothing but the "growth efficiency" of Odum
but the difference is in their application to an individual
species population b. the former and a trophic level by the
latter. Odum E.P.: Smalley (1959) have calculated the effi-
ciency ratios, very similar to that of Richman and Odum H.T.,
as mentioned above.

Three types of efficiency ratios for each species popu-
lation were calculated in the present study, following the
procedures of Ivlev, Odum, Teal and Richman.

1. Net efficiency = \( \frac{\text{net production or growth (new pro-}}{\text{toplam)}}}{\text{Assimilation}} \)
2. Respiration efficiency = \( \frac{\text{Respiration}}{\text{Assimilation}} \)
3. Growth efficiency = \( \frac{\text{Growth}}{\text{Respiration}} \)
4. Respiration efficiency with respect to growth = Respiration growth

Plants:

Najas species:—

This is the most dominant producer plant of the community. The average of two respiration measurements of this plant gave a value of 0.31744 c.c. / gm. wet wt./day. The net production per gram was measured for both overcast and bright sky. The average of four experiments gave a value of 57.87 calories/gram wet wt. per day. The assimilation of Najas spp. per day is 61.817 calories/gram wet wt. per day. From the oxycalorific coefficient of Ivlev (1934), the respiration of Najas in terms of calories is 3.947 cal/gram wet wt./day.

1. The respiration efficiency with respect to growth = \[
\frac{3.947 \times 100}{57.87} = 6.8\%
\]

2. Respiration efficiency = \[
\frac{3.947 \times 100}{61.817} = 6.386\%
\]

3. Net efficiency = \[
\frac{57.87 \times 100}{61.317} = 93.61\%
\]

Decapoda:—

2. Palaemon Lamarrie:—

24 respiratory measurements covering 4 seasons comprising winters and summers were made. The average calories of energy utilised for the respiration in a day is 444.2 calories per gram wet wt. The rate of growth con-
verted into calories 31.418 calories per day per gram wet wt.

1. Net efficiency \( = \frac{31.418}{475.618} \times 100 = 6.607\% \)

2. Respiration efficiency \( = \frac{444.2}{475.618} \times 100 = 93.42\% \)

3. Growth efficiency \( = \frac{31.418}{444.2} \times 100 = 7.073\% \)

Gastropods:

3. *Melanoides tuberculatus*:

11 respiratory measurements were performed which extended for three seasons. The average calories of energy burnt by the organism per gram wet wt./day is 91.87 calories. The rate of growth of the organism is 6.497 calories per gram wet wt. per day.

1. Net efficiency \( = \frac{6.497 \times 100}{98.367} = 6.674\% \)

2. Respiration efficiency: \( = \frac{91.87 \times 100}{98.367} = 93.37\% \)

3. Growth efficiency \( = \frac{6.497 \times 100}{91.87} = 7.073\% \)

4. *Viviparous dissimili*s:

Twenty one respiratory measurements covering four different seasons were made. The average calories of
of energy utilized for the respiration of the organism are 23.79 calories per day per gram wet wt. The rate of growth per day per gram wet wt. is 2.3244 calories.

1. Net efficiency = \( \frac{2.3244 \times 100}{26.1144} = 8.9\% \)

2. Respiration efficiency = \( \frac{23.79 \times 100}{26.1144} = 91.11\% \)

3. Growth efficiency = \( \frac{2.3244 \times 100}{23.79} = 9.768\% \)

5. *Amnicola stenothyroides*:

Ten respiratory rate measurements covering 5 different seasons of winter and summer were made. The average calories of energy lost during respiration per day per gram wet wt. of organism is 24.56 calories. The energy contained in the amount of new protoplasm of growth per day is 0.24908 calories.

1. Net efficiency = \( \frac{0.24908 \times 100}{24.80908} = 1.0\% \)

2. Respiration efficiency = \( \frac{24.56 \times 100}{24.80908} = 98.53\% \)

3. Growth efficiency = \( \frac{0.24908 \times 100}{24.56} = 1.014\% \)

6. *Planorbis Species*:

9 respiratory measurements covering 3 different sea-
sons were made. The average calories burnt by this
gastropod is 24.2\textsuperscript{c} cal. per gram wet wt. per day. The
rate of growth is 5.01 cal. per day per gram wet wt.

1. Net efficiency $\frac{5.018 \times 100}{29.268} = 13.6\%$

2. Respiration efficiency $\frac{24.25 \times 100}{29.268} = 82.85\%$

3. Growth efficiency $\frac{5.018 \times 100}{24.25} = 20.66\%$

Amphibia:

7. Tadpole Larvae:

Thirteen respiratory measurements covering four
different seasons were made. The average respiratory
rate in terms of calories is 85.49. The rate of growth
measurements were made separately for the tadpole
larvae of Rana hexadactyla and Rana tigrina and the ave-
rage of the two were taken here because the respira-
tory rate measurements were performed for both types
together. The rate of growth is 193.149 calories.

1. Net efficiency $= \frac{193.149 \times 100}{277.639} = 69.56\%$

2. Respiration efficiency $= \frac{85.49 \times 100}{277.639} = 30.8\%$

3. Respiration efficiency with respect to growth $= \frac{85.49}{193.149} \times 100 = 44.28\%$
Fishes:


Five respiratory measurements extending two seasons were made. The average respiratory rate in terms of calories is 50.44 per day per gram wet wt. The rate of growth is 13.24 calories per gram wet wt. per day.

1. Net efficiency = \( \frac{13.24}{63.68} \times 100 = 20.73\% \)

2. Respiration efficiency = \( \frac{50.44}{63.68} \times 100 = 78.96\% \)

3. Growth efficiency = \( \frac{13.24}{50.44} \times 100 = 26.25\% \)


Fifteen respiratory measurements covering 4 seasons were made. The average respiratory loss of energy is 68.0 calories per gram wet wt. per day. The rate of growth in terms of calories per day per gram is 0.055257.

1. Net efficiency = \( \frac{0.055257}{68.055257} \times 100 = 0.08121\% \)

2. Respiration efficiency = \( \frac{68.0}{68.055257} \times 100 = 99.93\% \)

3. Growth efficiency = \( \frac{0.055257}{68.0} \times 100 = 0.08127\% \)

Annelida:

10. Megascolex mauritii.

2 respiratory measurements were made in one
season. The average respiration rate per day in terms of calories is 2.161. The rate of growth is 17.362 cal. per gram wet wt. per day.

1. Net efficiency = \[
\frac{17.362}{25.542} \times 100 = 67.74%\
\]

2. Respiration efficiency = \[
\frac{2.161}{25.542} \times 100 = 8.44%\
\]

3. Respiration efficiency with respect to growth = \[
\frac{2.161}{17.362} \times 100 = 12.5%\
\]

Branchiodrillus semperi and B. mononi.

Seven measurements covering 2 seasons were made. The average calories burned per day per gram wet wt. is 86.66 cal. The rate of growth of the organism is 66.307 cal.

1. Net efficiency = \[
\frac{66.307}{153.467} \times 100 = 43.44%\
\]

2. Respiration efficiency = \[
\frac{86.66}{153.467} \times 100 = 56.44%\
\]

3. Growth efficiency = \[
\frac{66.307}{36.82} \times 100 = 181.11%\
\]

19. Leroc limosa

Thirteen measurements were made covering three seasons. The average oxygen consumption per day per gram wet wt. in terms of calories is 71.96. The rate of growth per day per gram wet wt. is 17.50/cal.
1. Net efficiency $= \frac{17.501}{82.581} \times 100 = 19.75\%$

2. Respiration efficiency $= \frac{71.02}{82.581} \times 100 = 86.26\%$

3. Growth efficiency $= \frac{17.501}{71.00} \times 100 = 24.61\%$

The organisms of the community were grouped together into three categories namely producers, herbivores and carnivores and the following efficiency ratios were calculated.

1. Efficiency ratio for herbivores $= \frac{\text{assimilation of herbivores}}{\text{net production of plants}}$.

2. Efficiency ratio for carnivores $= \frac{\text{assimilation of carnivores}}{\text{net production of herbivores}}$.

Depending on their general feeding habits the animals of the community were grouped into herbivores and carnivores.

1. Efficiency for herbivores $= \frac{1323.73}{6399.52} \times 100 = 20.46\%$

2. Efficiency for carnivores $= \frac{557.55}{1963.6} \times 100 = 28\%$