Chapter 9

Feeding Ecological Studies

9.1 What is Feeding Ecology

Food and feeding habit of any heterotrophs in and around its habitat is an important parameter for assessing its functional role in the ecosystem. It also influences as well as co-relates all other aspects of habitat ecology for that particular organism. The functions of community dynamics for organism can be best studied on the basis of food and feeding habits. Therefore, to generate information on available feed in and around its dwelling environment, the study of feeding ecology of an organism is must. However, there still exists confusion towards the extent of using most appropriate approaches for obtaining complete information on feeding ecology of an organism. Lack of such approach is mainly due to appropriate feeding ecology parameter to be considered to draw up conclusions on food habit of studied organism. The following is a description of some feeding ecology indices used to obtain information on feeding ecology of fish.

9.2 Simple Indices for Gut Analysis

9.2.1 Fullness and Fullness of Gut

Fullness of gut predicts the foraging pattern, feeding intensity and environmental effect on feeding rate of fish for a given time. There is a controversy regarding appropriate fullness index. However, commonly used method is visual scale method. In this method following scale is used for organisms with considerable length of gut.

Empty stomach = 0

$1/4^{th}$ full stomach = 0.25

$1/2^{nd}$ full stomach = 0.50

$3/4^{th}$ full stomach = 0.75

Completely full stomach = 1.0

In visual methods, the results may be biased due to inappropriate or unequal length of the gut. Partial fullness of the gut may not fall within the specified scale. Presence of trace amount of food in the gut is generally ignored. Fullness index is studied only to support some other food studies result.

However, Herbold (1986) proposed an alternative method where he calculated the fullness index as percentage of observed gut content mass to expected maximum gut content mass.

$$\%\ \text{Fullness Index} = \frac{\text{Observed gut content mass}}{\text{Expected maximum gut content mass}} \times 100$$

Fullness index is also expressed as Percent Fullness of gut.

$$\%\ \text{Fullness of gut} = \frac{\text{Number of guts with food}}{\text{Total guts examined}} \times 100$$

Higher value of Percent fullness of gut indicates more intensive feeding while lower values indicate less intensive feeding. Higher value with less number of fish indicates higher activity and lower value with more number of fish indicates low feeding activity.

9.2.2 Stomach Content Index

Stomach content is the difference of the wet weight of the stomach before and after emptying it. It is expressed as

Stomach Content = Gut weight before emptying – Weight of empty gut

For this gut of organism is preserved immediately to avoid losing any food content from the stomach. The excess water from the gut is removed with a blotting paper and weight of full gut is taken. The stomach is then cut to open it and gut contents are collected carefully with a brush. All stomach contents are removed till it looks empty to naked eyes. The weight of the empty gut is taken to measure Stomach content.

Stomach content can also be expressed as Percent Stomach content weight to body weight. This is expressed as

$$\% \text{ Stomach Content} = \frac{\text{Stomach content}}{\text{Total weight o the fish}} \times 100$$

9.2.3 Stomach Index

Stomach Index is expressed as the percentage of the ratio of weight of the full stomach to fish body weight when the fish lacks a sizable stomach to store a considerable amount of feed.

$$\text{Stomach Index} = \frac{\text{Stomach Weight}}{\text{Fish body weight}} \times 100$$

9.2.4 Percent Composition of Food Items in the Gut

The percentage composition of food item is the total value of a food item observed in all stomach (Tf_p) divided by the total number of all food item (Tf) for a particular length-group of fish or time.

$$\% \text{ Composition of food} = \frac{Tf_P}{Tf} \times 100$$

9.3 Dietary Breadth

Study of dietary breadth determines the way the fish utilize the resource (or food) from its environment. The most common indices to measure diet breadth in ecology were niche breadth of Levins (1968), Hulbert (1978) and Smith (1982). These metrics use observed food category in the gut of studied organism as the basis of calculation.

9.3.1 Levin's Diet Breadth

Levin's diet breadth is the modification of Simpson's diversity index. It is calculated as:

$$B = 1/\sum(p^2_j)$$

where, B is Levin's Diet Breadth, p_j is fraction of items in the diet that are of food category j.

B value ranges from 1.0, when the population under study uses one resource state exclusively and equal to R (i.e. the number of taxonomic identity or size category or anything categorizing resource or food) when the population uses all resource states. B can be normalized by R as follows:

$$B = 1/(R\sum p^2_j)$$

The normalized B ranges from 1/R when the population uses one resource state to 1.0 when the population uses all resource state in equal proportions. Hulbert suggested the following standardized measure of niche breadth:

$$B_A = \frac{\left(1/\sum P_j^2\right) - 1}{n - 1} \times 100$$

BOX 6

Calculation of Levin's Diet Breadth

Sl no.	Name of organism	individual count in he gut	p_j	p^2_j
1	*Scenedesmus sp.*	22	0.0503	0.0025
2	*Pediastrum sp.*	56	0.1281	0.0164
3	*Oedogonium sp.*	36	0.0824	0.0068
4	*Spirogyra sp.*	10	0.0229	0.0005
5	*Bulbochaete sp.*	4	0.0092	0.0000
6	*Closterium sp.*	26	0.0595	0.0035
7	*Chlorella sp.*	18	0.0412	0.0017
8	*Pleurotaenium sp.*	60	0.1373	0.0189
9	*Triplocera sp.*	20	0.0458	0.0021
10	*Xanthidium sp.*	14	0.0320	0.0010
11	*Cosmarium sp.*	10	0.0229	0.0005
12	*Staurastrum sp.*	8	0.0183	0.0003
13	*Gonatozygon sp.*	30	0.0686	0.0047
14	*Mesotaenium sp.*	25	0.0572	0.0033
15	*Euastrum sp.*	98	0.2243	0.0503
		N = 437		$\sum$ 0.1127

Levin's measure or $B = (1/\sum p^2_j)$. Here $\sum p^2_j = 0.1127$. Therefore, $B = 1/0.1127 = 8.8731$.

Normalized B using R i.e. $B = 1/R(\sum p^2_j) = 1/15(0.1127) = 1/0.1127 = 0.5915$.

Normalized B using n i.e. $B_A = [(1/\sum p^2_j)-1]/n-1 = 8.8731-1 / 14 = 0.5624$.

9.3.2 Hulbert's Diet Breadth

However, Hulbert (1978) proposed an index that accounts resources available in the environment. It is calculated as:

$$B' = 1/(\sum p_j^2/a_j)$$

Where B ´is Hulbert's standardized diet breadth, p_j is fraction of items in the diet that are of food category j (∑(p =1.0), a_j is proportion of total available resources consisting of resource j ($\sum a_j$ =1.0). B ´ranges from 1/n to 1.0.

Hulbert's diet breadth can be standardized as:

$$B'_A = \frac{[1/\sum(p_j^2/a_j)] - a_{min}}{1 - a_{min}}$$

Where B'_A is Hulbert's standardized diet breadth, p_j and a_j are as described in B ´. The a_{min} is smallest observed proportion of all the resources or minimum a. B'_A ranges from 0 to 1.0.

The variance of Hulbert's diet breadth can be estimated by delta method (Smith, 1982). It is

$$Var(B') = \frac{4B'^4[\sum(p_j^2/a_j)] - (1/B')^2}{Y}$$

Where,

Var (B ´) = Variance of Hulbert's measure of diet breadth (B ´);

p_j and a_j = As described in B ´;

Y = Total number of individuals studied = ∑N.

Statistically, this Var (B ´) can be used to measure 95% confidence limit for B ´ using following expression:

$$B' \pm 1.96\sqrt{var(B')}$$

BOX 7

Calculation of Hulbert's diet breadth

From the p_j and a_j values, Smith's diet breadth can be calculated as follows:

Sl no.	Name of organism in the gut	Individual count from resource	Individual count from gut	a_j	p_j	$(p_j)^2$	p^2_j/a_j
1	*Scenedesmus sp.*	22	0	0.0503	0	0	0
2	*Pediastrum sp.*	56	25	0.1281	0.1269	0.0161	0.1257
3	*Oedogonium sp.*	36	18	0.0824	0.0914	0.0083	0.1007
4	*Spirogyra sp.*	10	0	0.0229	0	0	0
5	*Bulbochaete sp.*	4	0	0.0092	0	0	0
6	*Closterium sp.*	26	20	0.0595	0.1015	0.0103	0.1731
7	*Chlorella sp.*	18	5	0.0412	0.0254	0.0006	0.0146
8	*Pleurotaenium sp.*	60	24	0.1373	0.1218	0.0148	0.1078
9	*Triplocera sp.*	20	8	0.0458	0.0406	0.0016	0.0349
10	*Xanthidium sp.*	14	6	0.0320	0.0305	0.0009	0.0281
11	*Cosmarium sp.*	10	0	0.0229	0	0	0
12	*Staurastrum sp.*	8	0	0.0183	0	0	0
13	*Gonatozygon sp.*	30	10	0.0686	0.0508	0.0026	0.0379
14	*Mesotaenium sp.*	25	15	0.0572	0.0761	0.0058	0.1014
15	*Euastrum sp.*	98	66	0.2243	0.3350	0.1122	0.5002
	N = 437				∑1.2244		

Hulbert's B ́= $1/(\sum p^2_j/a_j)$. Here, B ́ = 0.8167. The diet breadth is closure to 1.0. Hence, the gut has wider diet breadth. The a_{min} is 0.0092. Hence B'_A is 0.8150.

9.3.3 Smith's Diet Breadth

Smith (1982) diet measure is calculated as:

$$FT = \Sigma \sqrt{(p_j a_j)}$$

Where,

FT is Smith's diet breadth, p_j and a_j are as described in B_A and B'_A.

BOX 8

Calculation of Smith's diet breadth

From the p_j and a_j values, Smith's diet breadth can be calculated as follows:

Sl no.	Organism in the gut	Individual count from resource	Individual count from gut	a_j	p_j	$\sqrt{(p_j a_j)}$
1	*Scenedesmus sp.*	22	1	0.0503	0	0
2	*Pediastrum sp.*	56	25	0.1281	0.1269	0.1275
3	*Oedogonium sp.*	36	18	0.0824	0.0914	0.0868
4	*Spirogyra sp.*	10	1	0.0229	0	0
5	*Bulbochaete sp.*	4	1	0.0092	0	0
6	*Closterium sp.*	26	20	0.0595	0.1015	0.0777
7	*Chlorella sp.*	18	5	0.0412	0.0254	0.0323
8	*Pleurotaenium sp.*	60	24	0.1373	0.1218	0.1293
9	*Triplocera sp.*	20	8	0.0458	0.0406	0.0431
10	*Xanthidium sp.*	14	6	0.0320	0.0305	0.0312
11	*Cosmarium sp.*	10	1	0.0229	0	0
12	*Staurastrum sp.*	8	1	0.0183	0	0
13	*Gonatozygon sp.*	30	10	0.0686	0.0508	0.0590
14	*Mesotaenium sp.*	25	15	0.0572	0.0761	0.0660
15	*Euastrum sp.*	98	66	0.2243	0.3350	0.2741
	N = 437		0.0	$\sum\sqrt{(p_j a_j)}=0.9270$		

Smiths FT = $\sum\sqrt{(p_j a_j)}$. Here, FT ´= 0.9270. The diet breadth is closure to 1.0. Hence, the gut has wider diet breadth.

9.3.4 Saikia's Diet Breadth or DB (χ^2) (Saikia, 2012)

The recent method of measurement of diet breadth is Saikia's diet breadth (Saikia, 2012) which follows χ^2 (Chi square) statistics. The χ^2 expression for diet breadth is computed as follows:

$$DB(\chi^2) = \sum_{i}^{n} \frac{(\log O_i - \log E_i)^2}{\log E_i}$$

Here, the DB(χ^2) is diet breadth, logO_i and logE_i are the log value of observed and expected food abundances of ith category. DB(χ^2) considers that log$O_i \neq 0$ for log$E_i > 0$. Rather, in such cases where logO_i for logE_i is 0, a minimum representation '1' is considered in gut. This will not affect the result since log(1)=0. The expected food abundance in DB(χ^2) is constituted of available food resources in the environment.

When food categories in the diet show equal representation as in the resource, DB(χ^2) is 0, and greater variation of result from 0 indicates avoidance of the resource food categories by the organism.

BOX 9

Calculation of Saikia's diet breadth

From the p_j and a_j values of Box 7, Smith's niche breadth can be calculated as follows:

Sl no.	Organism in the gut	Individual count from resource	Individual count from gut	(logO- logE)^2	(logO- logE)^2/logE
1	*Scenedesmus sp.*	22	1	1.802	1.3424
2	*Pediastrum sp.*	56	25	0.1227	0.0702
3	*Oedogonium sp.*	36	18	0.0906	0.0582
4	*Spirogyra sp.*	10	1	1.000	1.000
5	*Bulbochaete sp.*	4	1	0.3625	0.6021
6	*Closterium sp.*	26	20	0.1298	0.0092
7	*Chlorella sp.*	18	5	0.3095	0.2464
8	*Pleurotaenium sp.*	60	24	0.1584	0.0891
9	*Triplocera sp.*	20	8	0.1584	0.1217
10	*Xanthidium sp.*	14	6	0.1354	0.1181
11	*Cosmarium sp.*	10	1	1.000	1.000
12	*Staurastrum sp.*	8	1	0.8156	0.9031
13	*Gonatozygon sp.*	30	10	0.2276	0.1541
14	*Mesotaenium sp.*	25	15	0.0492	0.0352
15	*Euastrum sp.*	98	66	0.0295	0.0148
	N = 437		202	$\sum$(logO- logE)^2/logE=5.7647	

DB(χ2)= 5.7647. Since 5.7647>>0.0, the diet breadth of the organism is narrow. It does not feed wholly on the resources considered.

9.3.5 Czekanowski's Proportion of Similarity Index

Feinsinger et. al. (1981) advocated Czekanowski's Proportion of Similarity Index for diet breadth analysis of a species. It takes into account the resource items availability in the environment for the species studied. It is calculated as:

$$Ps_x = 1 - 0.5\Sigma\left|Px_i - q_i\right|$$

Where, Ps_x is the Czekanowski's Proportion of Similarity Index, Px_i is the proportion of resource items in category i out of all items used by species x and q_i is the proportion of i^{th} items available in the resource base for the population of the species studied. A Czekanowski's index closure to 1.0 indicates wider diet breadth of organisms. An explanatory example is shown in BOX 10.

BOX 10

Calculation of Czekanowski's Proportion of Similarity Index

From the p_j and a_j values of BOX 7, Smith's diet breadth can be calculated as follows:

Sl no.	Organism in the gut	Individual count from resource	Individual count from gut	a_j	p_j	$\lvert p_j-a_j \rvert$
1	*Scenedesmus sp.*	22	0	0.0503	0	0.0503
2	*Pediastrum sp.*	56	25	0.1281	0.1269	0.0012
3	*Oedogonium sp.*	36	18	0.0824	0.0914	0.0090
4	*Spirogyra sp.*	10	0	0.0229	0	0.2290
5	*Bulbochaete sp.*	4	0	0.0092	0	0.0092
6	*Closterium sp.*	26	20	0.0595	0.1015	0.0420
7	*Chlorella sp.*	18	5	0.0412	0.0254	0.0158
8	*Pleurotaenium sp.*	60	24	0.1373	0.1218	0.0155
9	*Triplocera sp.*	20	8	0.0458	0.0406	0.0051
10	*Xanthidium sp.*	14	6	0.0320	0.0305	0.0015
11	*Cosmarium sp.*	10	0	0.0229	0	0.0229
12	*Staurastrum sp.*	8	0	0.0183	0	0.0183
13	*Gonatozygon sp.*	30	10	0.0686	0.0508	0.0173
14	*Mesotaenium sp.*	25	15	0.0572	0.0761	0.0192
15	*Euastrum sp.*	98	66	0.2243	0.3350	0.1107
	N = 437				$\sum \lvert p_j-a_j \rvert = 0.3615$	

Czekanowski's Proportion of Similarity Index is $Psx = 1-0.5 \sum \lvert Pxi - qi \rvert = 1-0.5\ (0.3615) = 1-0.18075 = 0.81925$.

9.4 Dietary Overlap

Diet overlap among species or size classes of a single species helps to explain the community structure or to clarify competitive relationship (Fig 6). This is an ecological measure through which competition between two organisms for similar diets can be assessed. Hence, diet overlap simply means food organisms from natural environment shared by both competitors in an ecosystem. Narrow is the diet breadth, less is the competition between the two.

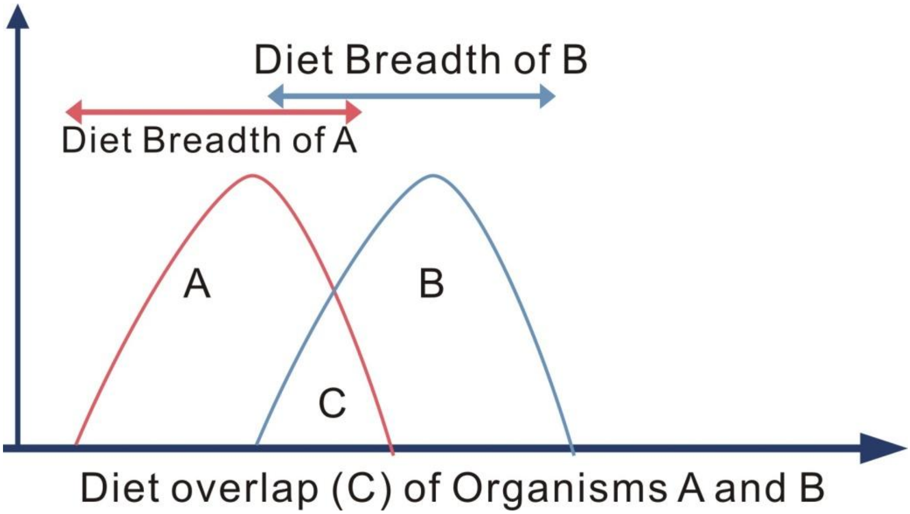

Fig. 6. *Diet overlap of two organisms (A and B) in an environment. The overlap (C) is moderate. Hence, both the organisms are not good competitor.*

9.4.1 Schoener's (α) Index

The most satisfactory method in absence of any estimate of food available is Schoener's (α) index. It is calculated as

$$\alpha = 1 - 0.5\left|Px_i - Py_i\right|$$

Where α is Schoener's index, Px_i is the proportion out of all resource items in category i used by species x, Py_i is propotion out of all resource items in category i used by the species y.

Schoener's (α) index ranges from 0.0 (representing no overlap) to 1.0 (complete overlap).

BOX 11

Calculation of is Schoener's (α) index

Sl no.	Organism in the gut	Individual count from gut of X	Individual count from gut if Y	Px_j	Py_j	$\lvert Px_j\text{-}Py_j \rvert$
1	*Scenedesmus sp.*	10	40	0.0265	0.0946	0.0681
2	*Pediastrum sp.*	20	22	0.0529	0.0520	0.0009
3	*Oedogonium sp.*	14	10	0.0370	0.0236	0.0134
4	*Spirogyra sp.*	6	20	0.0159	0.0473	0.0314
5	*Bulbochaete sp.*	22	8	0.0582	0.0189	0.0393
6	*Closterium sp.*	40	40	0.1058	0.0946	0.0113
7	*Chlorella sp.*	60	50	0.1587	0.1182	0.0405
8	*Pleurotaenium sp.*	38	32	0.1005	0.0757	0.0249
9	*Triplocera sp.*	10	70	0.0265	0.1655	0.1390
10	*Xanthidium sp.*	8	85	0.0212	0.2009	0.1798
11	*Cosmarium sp.*	50	10	0.1323	0.0236	0.1086
12	*Staurastrum sp.*	5	15	0.0132	0.0355	0.0222
13	*Gonatozygon sp.*	15	7	0.0397	0.0165	0.0231
14	*Mesotaenium sp.*	35	6	0.0926	0.0142	0.0784
15	*Euastrum sp.*	45	8	0.1190	0.0189	0.1001

$N = \sum\lvert Px_j\text{-}Py_j\rvert = 0.8811$

Schoener's (α) index is $\alpha = 1 - 0.5 \lvert Px_i - Py_i \rvert = 1\text{-}0.5\ (0.8811) = 1\text{-}0.4406 = 0.5595$. The species X and Y has moderate overlap of diets in the environment studied.

9.4.2 Clumping of Gut and Possible Diet Overlap

DB(χ^2) can give guts with possible diet overlap through clumping of gut (Fig 7). Clumping of guts means grouping of DB(χ^2) values of organisms on foods available in same resource environment. It helps in understanding magnitude of competition among different organisms assessed on similar food resource in an ecosystem.

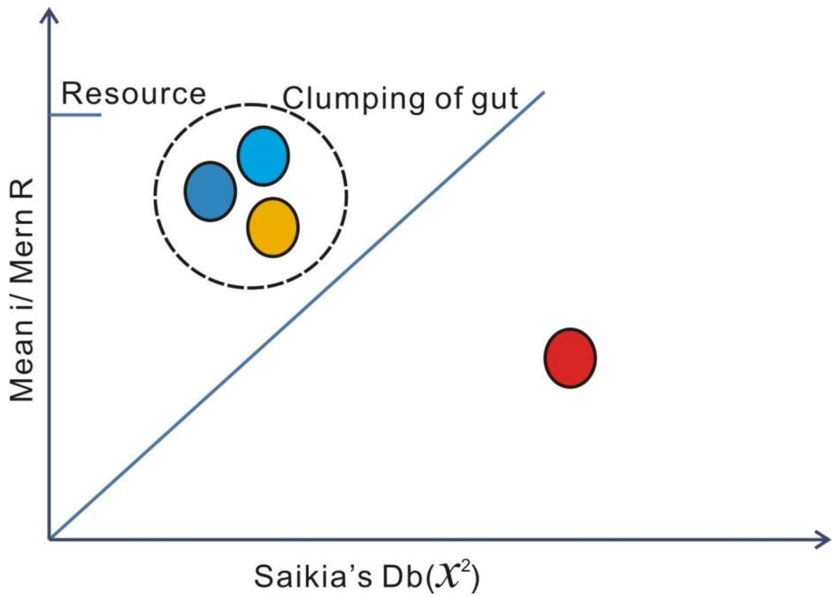

Fig. 7. *Clumping of guts (dashed circle) shows these organisms are competitive for food resources (on y axis). However, the gut represented by single circle (red) shows it does not feed on the food resources studied for.*

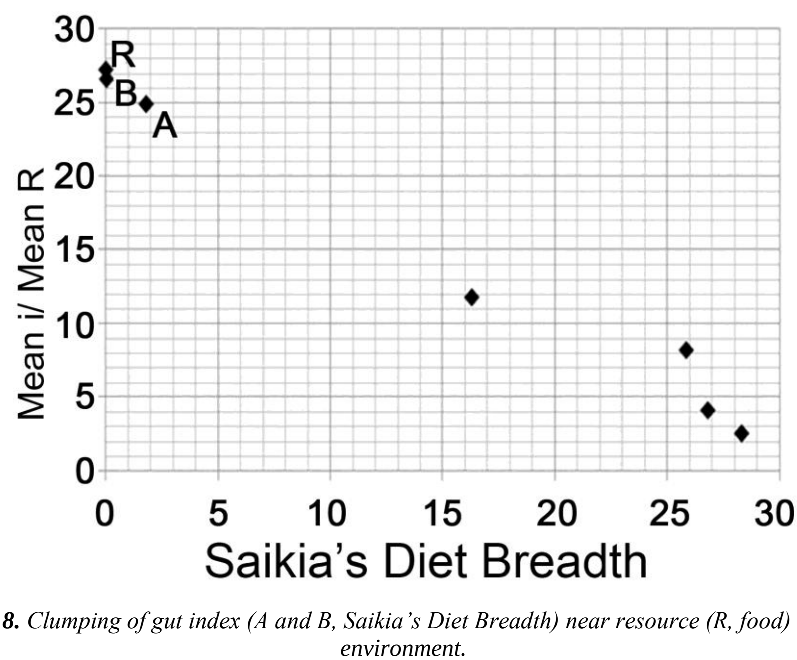

Fig. 8. *Clumping of gut index (A and B, Saikia's Diet Breadth) near resource (R, food) in the environment.*

In Fig 8, clumping of gut has been explained for six fishes of which A and B showed strong competition for food resource R. This is shown by plotting DB(χ^2) values on a graph against mean i/meanR where mean i represents mean value of abundances of gut category i and mean R represents mean value of abundances in R or resource. Co-ordinates for R on the graph is (0,1.0) which means complete preference of food from the environment by the organisms (DB(χ^2) =0) and mean i (mean value of abundances of gut category i) = mean R (mean value of abundances in R).

9.5 Feeding Strategy Study

(1) Ivlev's Electivity Index

Ivlev's (1961) electivity index is used to measure the selection of available food organisms by fish.

$$Ei = St_i - P_i / St_i + P_i$$

Where

E_i = Ivlev's electivity index for species i;

St_i = Relative proportion of species i in the diet;

P_i = Relative proportion of species i in the environment;

E value varies from 0 to 1. E value around to 0 indicates random ingestion, +1.0 or around to +1.0 indicates strong ingestion and 0 to -1.0 indicates weak to strong avoidance.

Since Ivlev's electivity (E) values are sensitive to the relative densities of the food types (Jacob, 1974), feeding strategy is analyzed by plotting E values against relative proportion of resource available in the environment studied (Fig 9).

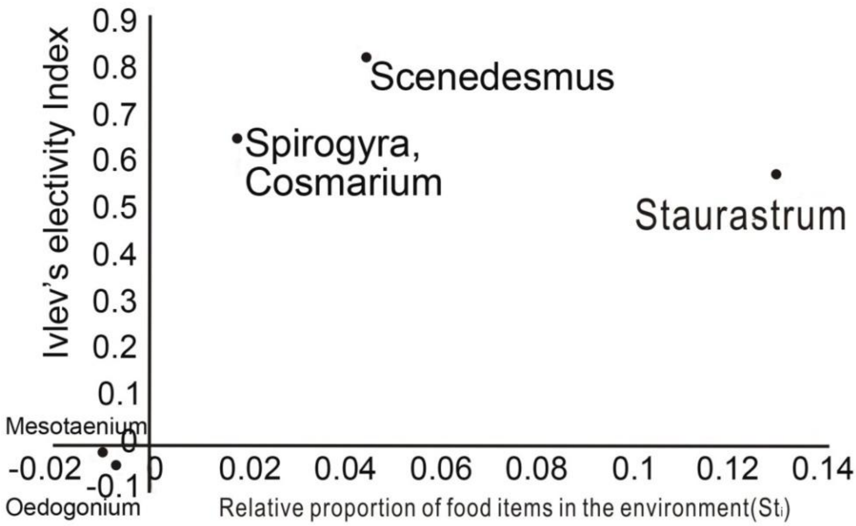

Fig. 9. *Ivlev's electivity index on a graph.*

BOX 12

Calculation of Ivlev's electivity Index

	Name of organism	Individual count from environment	St_i	Individual count from gut	P_i	$St_i + P_i$	$St_i - P_i$	$St - P_i/St_i - +P_i$
1	*Scenedesmus sp.*	22	0.05	1	0.005	0.055	+0.045	+0.81
2	*Pediastrum sp.*	56	0.128	25	0.124	0.252	+0.004	+0.016
3	*Oedogonium sp.*	36	0.082	18	0.089	0.171	-0.007	-0.041
4	*Spirogyra sp.*	10	0.023	1	0.005	0.028	+0.018	+0.64
5	*Bulbochaete sp.*	4	0.009	1	0.005	0.014	+0.004	+0.285
6	*Closterium sp.*	26	0.059	20	0.099	0.158	-0.04	-0.253
7	*Chlorella sp.*	18	0.041	5	0.025	0.066	+0.016	+0.242
8	*Pleurotaenium sp.*	60	0.137	24	0.119	0.256	+0.018	+0.070
9	*Triplocera sp.*	20	0.046	8	0.039	0.085	+0.007	+0.082
10	*Xanthidium sp.*	14	0.032	6	0.029	0.061	0.003	+0.049
11	*Cosmarium sp.*	10	0.023	1	0.005	0.028	+0.018	+0.64
12	*Staurastrum sp.*	8	0.018	1	0.005	0.023	+0.013	+0.565
13	*Gonatozygon sp.*	30	0.068	10	0.049	0.117	+0.019	+0.162
14	*Mesotaenium sp.*	25	0.057	15	0.074	0.131	-0.01	-0.017
15	*Euastrum sp.*	98	0.224	66	0.326	0.55	-0.102	-0.185
	N =	437	0.997	202	0.998			

The graphical presentation of Ivlev's electivity index is shown in Fig 9. *Scenedesmus* were preferred over *Spirogyra* and *Cosmarium*. Though abundant, *Staurastrum* were preferred moderately. *Mesotaenium* and *Oedogonium* were avoided.

The above results can be presented in a more meaningful way using following graphical analysis (Fig 10). The E value beyond a level of +0.4 and –0.4 represents a biologically significant selection and avoidance. While between -0.4 and +0.4 indicates generalization (Amundsen et al. 1996).

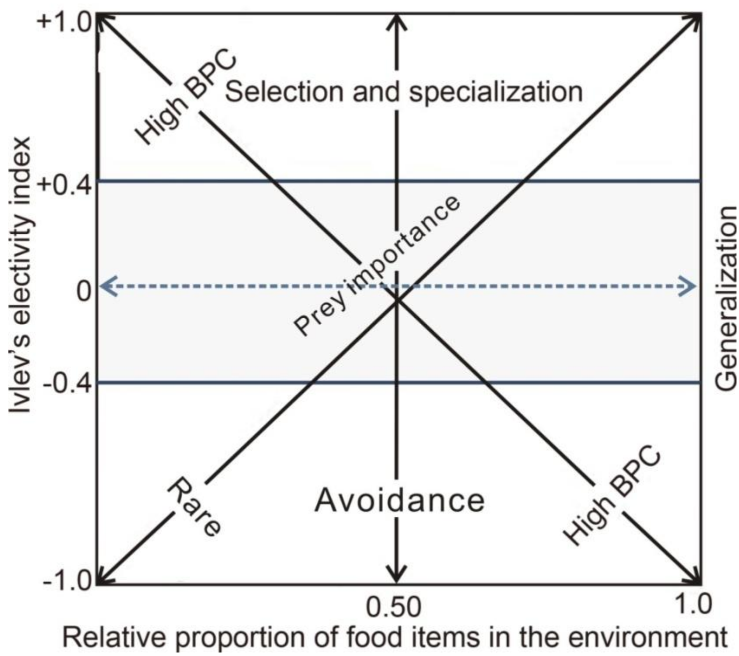

Fig. 10. *Explanatory diagram of feeding strategy and prey selectivity and avoidance (Amundsen et al. 1996). BPC, between phenotype component; WPC, within phenotype component.*

On the basis of graphical explanation in Fig 10, the results from the BOX 12 can be interpreted as follows:

- The organism highly prefers *Cosmarium* sp, *Spirogyra* sp, *Scenedesmus* sp and *Staurastrum* sp.
- It specially prefers *Staurastrum* sp. This reference is proportionate to the availability of prey item in the environment.
- *Cosmarium* sp and *Spirogyra* sp, though not available in the environment, preferred over other food items.