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MATHEMATICAL MODELING OF THE FOOD ITEMS IN THE GUT AND THEIR AVAILABILITY IN THE ENVIRONMENT FOR THE HILL-STREAM FISH, *Barilius bendelisis* (HAMILTON) BASED ON STRAUSS SELECTIVITY INDEX

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Barilius bendelisis (Hamilton) is an ornamental fish. The feeding ethos of fish is of great concern for its culture and breeding. Strauss selectivity index is simply the unweighted difference in proportion ($L= r_i - p_i$) of the prey item in the gut and the environment. It ranges from -1 to + 1 with a positive value indicating preference and the negative value indicating avoidance or inaccessibility. Three length-groups (1 < 5cm, 5-10cm. and > 10cm.) were analyses in current study. *Barilius bendelisis* has been found to accompany a change of food habit with more emphasis on insect items in higher length groups. It had been noticed that in *Barilius bendelisis* feeding ethos showed dipterans larva as more available digestible food part in gut portion than ephemeroptera and trichoptera larvae in all different size groups.

Keywords: Barilius bendelisis; feeding behaviour; strauss selectivity index.

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1. INTRODUCTION

Barilius bendelisis (Hamilton) locally known as "Jabula" is an ornamental fish having food value [1]. It is found to inhabit the sandy and pebbly bottom of spring-fed stream Basti Damar Gad. *B. bendelisis* belonging to the order Cypriniformes and family Cyprinidae is an ornamental fish and in this local region of Uttarakhand is used as food [2]. Local folk use this to fulfill their daily protein needs. Observation on reproductive biology (GSI, fecundity, spawning period, sex ratio) and other biological aspects (eye abnormality and length-weight relationships) in different water bodies of Garhwal Himalayas have been reported by Badola and Singh [3], Dobriyal and Singh [4,5], Dobriyal [6], Bahuguna et al. [7-11].

The feeding behaviour of fish is of great concern for its culture and propagation. The stomach content analysis is an important parameter used for this purpose. Feeding biology investigation provides vital information regarding the main prey organisms and the preference on the dietary overlap between different species living in the same or comparable habitats. It helps in assessing the month-wise, season-wise and geographical variations in dietary composition to determine the diet rhythm in feeding ethos, estimate the energy resources and to help in energy flow in the hill-stream ecosystem. In addition, the quality and quantity of food are one of critical observations/determinants of the larval fish. Information on their diet is crucial for practices of aquatic management, especially agriculture, aquaculture and conservation.

The knowledge of benthic biota is another important ecological aspect in fish biology as these are the main food for fish in the hill-streams as mentioned by various workers [12-19]. Dewam and Saha [20] suggested that the food and feeding behaviour of fish is an important biological factor for selecting a group of fish for culture. Differences in behaviour, habitat and time of feeding, as well as kind and size of prey, may reduce dietary overlap in fishes [12,13,21,22,23].

In the study of the feeding biology of fish, it is very important aspects to know how the fish selects its food from the environment. On the one hand, it depends on its feeding nature being herbivore, omnivore or carnivore but on the other side, it also depends on which food item is more preferred by the fish. To solve this issue Ivlev [24] for the first time suggested a food selectivity index and forage ratio which has been widely used by various fish biologists in their studies ($E = r_i - p_i / r_i + p_i$). According to Strauss [25], the Ivlev's indices are biased when the size of the prey sample is different in gut and the habitat. Hence he proposed a new Linear index of food selection which avoids most of the mathematical inadequacies raised out of Ivlev's indices. The proposed Strauss index [25] is simply the unweighted difference in proportion ($L= r_i - p_i$) of the prey item in the gut and in the environment. It ranges from -1 to + 1 with a positive value indicating preference and a negative value indicating avoidance or inaccessibility.

2. MATERIALS AND METHODS

The fish *Barilius bendelisis* (Hamilton) was caught by local fishermen using different traditional fishing gears [26-32]. The sample was immediately preserved with 8-10% formalin solution upon arrival to the laboratory. A total of 55 fish specimens were collected from the spring-fed stream Basti Damar Gad, Garhwal Himalaya, from June 2019 to May 2021. The total length was measured to the nearest 1mm. Bodyweight was measured on a digital balance with 0.001 mg precision.

2.1 Strauss Selectivity Index

Prey availability and predation by hill stream fishes were examined in spring-fed stream Basti Damar Gad. The Strauss selectivity index [25] of each $p_i : r_i$ length-ratio size class was calculated on each of the 3-sampling dates. This linear index was used because it mitigates statistical and mathematical biases resulting from absolute and relative sample sizes, and was derived separately for each prey species using the relationship:

$$L_i = r_i - p_i$$

Where L_i is the selectivity index for size class i, r_i is the proportion of size class i in the fish stomachs, and p_i is the mean proportion of size class i in the spring-fed stream. Indices will be also calculated to compare overall selection between prey species using r_i as the proportion of prey species i in the fish stomach and p_i as the proportion of prey species i in the spring-fed stream. Possible values for the index range from - 1 to + 1, with positive values indicating preference for prey type i and negative values indicating avoidance or inaccessibility.

According to Strauss selectivity index [25], Linear food selection Index (L**)** properties include the following. (1) Linear food selection Index ranges from -1 and +1, with positive value indicating preference and negative values indicating avoidance or inaccessibility. (2) the expected value of the index for random feeding is zero under all conditions. (3) the measure takes on extreme values only when the prey item is rare but consumed almost exclusively, or is very abundant but is rarely consumed. (4) it is defined for all values of r_i and p_i. (5) it is linear in term of r_i and p_i . (6) the index is distributed approximately normally. (7) the sampling variance is defined so as to allow statistical comparison of two calculated values or of a calculated values and a null-hypothesis value (such as zero).

3. RESULTS AND DISCUSSION

Strauss food selectivity index is calculated for *Barilius bendelisis*, a Carni-omnivore fish species present in Basti Damar Gad during winter, summer and autumn seasons. The average mean value of Season wise data estimated the quantitative analysis (food item 'pi' in the environment) of gut contents of *Barilius bendelisis* (Table 1).

Tabel (1) shows that the different types of insect food (Range for Ephemeroptera = 10 to 16%, for Trichoptera = 17 to 35% and Diptera = 10 to 15%) contribute a major portion of its food along with green algae (05 to 10%) and diatoms (30 to 40%). The highest percentage of insect matter (60.0%) was found in the summer season. the lowest percentage of insect parts was observed in the autumn season (48.0%).

For Barilius bendelisis, different fish length-wise gut food analysis r_i (food item 'i' in the gut) for winter, summer and autumn seasons are expressed in Tables 2 to 4. Three length-groups (1 < 5cm, 5-10cm. and > 10cm.) were analyses in these studies. *Barilius bendelisis* has been found to accompany a change of food habit with more emphasis on insect's items in higher length groups.

A Linear food selection Index (L**)** for *B. bendelisis* during winter, summer and autumn seasons were presented in Table 5 to 7. For fish size < 5cm, Value of food selective index for *Barilius bendelisis* during winter is positive for diptera (+0.33) and Trichoptera (+0.08) and negative for ephemeroptera (-0.03), diatom (-0.31) and green algae (-0.07) (Table 5). For fish size 5-10 cm., value of food selective index during winter is positive for diptera (+0.17), Trichoptera (+0.10) and ephemeroptera (+0.01) and negative for diatom (-0.28) and green algae (-0.06) (Table 5). For fish size more than 10 cm., value of food selective index for *B. bendelisis* during winter is positive for Trichoptera (+0.10) and negative for diptera (-0.10), ephemeroptera (-0.05), diatom (-0.23) and green algae (-0.02) (Table 5).

For fish size less than 5cm., value of food selective index during summer is positive for diptera (+0.38) and ephemeroptera (+0.16) and negative for Trichoptera (-0.18), diatom (-0.26) and green algae (-0.10) (Table 6). For fish size 5-10cm., value of food selective index during summer is positive for diptera (+0.30) and ephemeroptera (+0.14) and negative for Trichoptera (-0.10), diatom (-0.25) and green algae (-0.09) (Table 6). For fish size more than 10cm., value of food selective index during summer is positive for diptera (+0.22) and ephemeroptera (+0.22) and negative for Trichoptera (-0.06), diatom (-0.28) and green algae (-0.10) (Table 6).

For fish size < 5, value of food selective index during autumn is positive for diptera (+0.22), ephemeroptera (+0.20), Trichoptera (+0.04) and negative for diatom (-0.39) and green algae (-0.07) (Table 7). For fish size 5-10, value of food selective index during autumn is positive for ephemeroptera (+0.19), diptera (+0.15) and Trichoptera (+0.07) and negative for diatom (-0.37) and green algae (-0.04) (Table 7). For fish size more then 10, value of food selective index during autumn is positive for ephemeroptera (+0.26) and Trichoptera (+0.14) and negative for diatom (-0.42), diptera (-0.09), and green algae (-0.07) (Table 7).

Table 1. For *Barilius bendelisis* fish, p_i (food item 'i' in the environment) food items in different environment season

S. No.	Food Item	Winter season % Composition benthic form	Total % Values	Summer season % Composition benthic form	Total % Values	Autumn season % Composition benthic form	Total % Values
1	Diatoms	40	45	30	40	45	47
2	Green algae	05		10		07	
3	Ephemeroptera	10	55	15	60	16	48
4	Trichoptera	30		35		17	
5	Diptera	15		10		15	

Table 2. ***Barilius bendelisis*** **different fish lengthwise food item r_i (food item 'i' in the gut) analysis for winter season**

S.No.	Fish Length	Food Items
1	1< 5cm.	Trichoptera - 10; Ephemeroptera - 25; Diptera - 60; Diatom – 5; Green algae - Nil
2	5-10cm.	Trichoptera - 19; Ephemeroptera -19; Diptera - 51; Diatom – 7; Green algae -04
3	>10cm.	Trichoptera - 40; Ephemeroptera - 05; Diptera - 45; Diatom – 10; Green algae - nil

Table 3. ***Barilius bendelisis*** **different fish lengthwise food item r_i (food item 'i' in the gut) analysis for summer season**

S.No.	Fish Length	Food Items
1	1< 5cm.	Trichoptera - 17; Ephemeroptera - 31; Diptera - 48; Diatom – 4; Green algae - Nil
2	5-10cm.	Trichoptera - 25; Ephemeroptera -29; Diptera - 40; Diatom – 5; Green algae -01
3	>10cm.	Trichoptera - 29; Ephemeroptera - 37; Diptera - 32; Diatom – 2; Green algae - nil

Table 4. ***Barilius bendelisis*** **different fish lengthwise food item r_i (food item 'i' in the gut) analysis for autumn season**

S.No.	Fish Length	food items
1	1< 5cm.	Trichoptera - 21; Ephemeroptera - 36; Diptera - 37; Diatom – 6; Green algae - Nil
2	5-10cm.	Trichoptera - 24; Ephemeroptera -35; Diptera - 30; Diatom – 8; Green algae -03
3	>10cm.	Trichoptera - 31; Ephemeroptera - 42; Diptera - 24; Diatom – 3; Green algae - nil

Table 5. L for *B. bendelisis* during winter

S.No.	Li (< 5)	Food items in % value $r_i - p_i$	A Linear food selection index (L)
1	L_{Diatom}	0.05 - 0.40	-0.35
2	$L_{Green\ algae}$	0.00 - 0.05	-0.05
3	$L_{Ephe.}$	0.25 – 0.10	+0.15
4	$L_{Tric.}$	0.10 – 0.30	-0.20
5	$L_{Dipt.}$	0.60 - 0.15	+0.45
S.No.	**Li (5-10)**	**Food items in % value $r_i - p_i$**	**A Linear food selection index (L)**
1	L_{Diatom}	0.07 – 0.40	-0.33
2	$L_{Green\ algae}$	0.04 – 0.05	-0.01
3	$L_{Ephe.}$	0.19 – 0.01	+0.18
4	$L_{Tric.}$	0.19 – 0.30	-0.11
5	$L_{Dipt.}$	0.51 – 0.15	+0.36
S.No.	**Li (>10)**	**Food items in % value $r_i - p_i$**	**A Linear food selection index (L)**
1	L_{Diatom}	0.10 - 0.40	-0.30
2	$L_{Green\ algae}$	0.0 0 - 0.05	-0.05
3	$L_{Ephe.}$	0.50 – 0.10	+0.40
4	$L_{Tric.}$	0.40 – 0.30	+0.10
5	$L_{Dipt.}$	0.45 - 0.15	+0.30

Table 6. L for *B. bendelisis* during Summer

S.No.	Li (< 5)	Food items in % value $r_i - p_i$	A Linear food selection index (L)
1	L_{Diatom}	0.04 - 0.30	-0.26
2	$L_{Green\ algae}$	0.00 - 0.10	-0.10
3	$L_{Ephe.}$	0.31 – 0.15	+0.16
4	$L_{Tric.}$	0.17 – 0.35	-0.18
5	$L_{Dipt.}$	0.48 - 0.10	+0.38

S.No.	**Li (5-10)**	**Food items in % value r_i - p_i**	**A Linear food selection index (L)**
1	L_{Diatom}	0.05 – 0.30	-0.25
2	$L_{Green\ algae}$	0.01 – 0.10	-0.09
3	$L_{Ephe.}$	0.29 – 0.15	+0.14
4	$L_{Tric.}$	0.25 – 0.35	-0.10
5	$L_{Dipt.}$	0.40 – 0.10	+0.30
S.No.	**Li (>10)**	**Food items in % value r_i - p_i**	**A Linear food selection index (L)**
1	L_{Diatom}	0.02 - 0.30	-0.28
2	$L_{Green\ algae}$	0.00 - 0.10	-0.10
3	$L_{Ephe.}$	0.37 – 0.15	+0.22
4	$L_{Tric.}$	0.29 – 0.35	-0.06
5	$L_{Dipt.}$	0.32 - 0.10	+0.22

Table 7. L for *B. bendelisis* during Autumn

S.No.	**Li (< 5)**	**Food items in % value r_i - p_i**	**A Linear food selection index (L)**
1	L_{Diatom}	0.06 - 0.45	-0.39
2	$L_{Green\ algae}$	0.00 - 0.07	-0.07
3	$L_{Ephe.}$	0.36 - 0.16	+0.20
4	$L_{Tric.}$	0.21 - 0.17	+0.04
5	$L_{Dipt.}$	0.37 - 0.15	+0.22
S.No.	**Li (5-10)**	**Food items in % value r - p_i**	**A Linear food selection index (L)**
1	L_{Diatom}	0.08 – 0.45	-0.37
2	$L_{Green\ algae}$	0.03 – 0.07	-0.04
3	$L_{Ephe.}$	0.35 – 0.16	+0.19
4	$L_{Tric.}$	0.24- 0.17	+0.07
5	$L_{Dipt.}$	0.30 - 0.15	+0.15
S.No.	**Li (>10)**	**Food items in % value r_i - p_i**	**A Linear food selection index (L)**
1	L_{Diatom}	0.03 - 0.45	-0.42
2	$L_{Green\ algae}$	0.00 - 0.07	-0.07
3	$L_{Ephe.}$	0.42 - 0.16	+0.26
4	$L_{Tric.}$	0.31 - 0.17	+0.14
5	$L_{Dipt.}$	0.24 - 0.15	+0.09

It has been observed in current study that in *Barilius bendelisis* feeding behaviour showed dipterans larva as more available digestible food part in gut portion than ephemeroptera and trichoptera larvae in all different size groups. Hess and Rainwater [33] demonstrated in *Salvelinus fontinalis* (brook trout) that soft-bodied organisms such as dipteran larvae digest much more rapidly than heavily chitinized forms such as stonefly nymphs and caddisfly larvae. They noted that the differences in absolute digestion rates are temperature dependent. Relative value was experimentally assigned to each prey species to compensate for differential digestion. These value could be calculated as the reciprocal of the time required for half the individuals in a sample of predators to completely digest the prey type. These could be standardized in relation to some soft-bodied species. The standardized values multiplied by the actual number of organisms of each species found in the gut would then give the relative numbers eaten [33]. Rapid digestion of the Daphnia by alewife (*Alosa pseudoharengus*) led to their apparent avoidance [34].

According to Pert [35] diet preferences, as estimated by Strauss's (L) index, were variable of all salmonid species over time. Aquatic invertebrates were the primary food sources of sympatric steelhead and allopatric steelhead, the major food item frequently was ephemeroptera nymphs. Ephemeroptera nymphs were the only food item preferred by one or more fish species on eight out of nine sample data. Landingham et al. [36] examined patterns of prey selectivity by applying Strauss linear index of food selection to the same sets of predator-prey samples that had been analyzed for similarity. *Onchorynchus gorbuscha*

(Pink) and *O. nerk* (Sockeye) Salmon selected (L>0.10) neustonic prey more often than planktonic prey, and neustonic hyperiid amphipods were the most frequently selected organism. *O. keta* (Chum) and *O, kisutch* (Coho) Salmon selected neustonic and plantonic prey in nearly equal frequencies. All salmon species avoided (L<0.10) neustonic decapods larvae. Hussion et al. [37] reported that Strauss Linear index of selection showed that in fish, *Oreochromis niloticus* and *Sarotherodon galilaeus* were preferential to Bacillariophyceae and Chlorophyceae (positive values) and avoidant to Cyanophyceae and Dinophyceae (negative values) in their diet at all lake sectors.

4. CONCLUSION

The study of the food items in the gut and their availability in the hill stream environment is of great concern for the culture and breeding of an ornamental fish *Barilius bendelisis*. The findings of the present investigation revealed that, in larger length groups, *B. bendelisis* has been observed to be associated with a shift in feeding habits, with a greater proportion on insect items. Dipterans larvae were found to be more accessible digestible food components than ephemeroptera and trichoptera larvae in all size groups.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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