How-To-Do-It

Using Stream Fish to Demonstrate Predator-Prey Relationships and Food Selection

Paul M. Kotila

Much current ecological research is zeroing in on predators and their prey, because they are key components in many ecosystems. The impracticalities of observing and/or collecting and dissecting large numbers of predators, however, can make it difficult to demonstrate this ecological relationship between predator and prey. Therefore, I developed this exercise to minimize such problems and yet provide students with data from a natural system. The exercise involves a nonlethal technique for collecting consumed prey from stream fish, at the same time gathering samples of invertebrates near the fish collection site. This allows students to compare the fishes' available food with their actual consumption.

The objectives of this exercise are to: 1) introduce students to a technique for determining the diet of a natural population of predators; 2) demonstrate the variety of prey consumed and methods for quantifying such consumption; and 3) demonstrate the selective nature of predation and its quantification using an electivity index.

Equipment

1. 7.5 l pump sprayer (H.D. Hudson Manufacturing Co., 500 N. Michigan Ave., Chicago, IL 60611); 1.0 ml hypodermic syringe attached to sprayer nozzle using 0.8 mm ID Tygon tubing and ring clamp; 18 gauge needle with 4–6 cm of 1.4 mm ID plastic tubing (larger needle and tubing may be substituted for larger fish)
2. D-frame or triangular dip net with net mesh of 500 µm or less
3. Misc. field equipment: shallow white pans, forceps, 70% alcohol, squirt bottle, 100 ml sample jars with labels, bucket, hip boots, fish measuring board (optional)
4. Lab equipment: watch glasses, dissection microscopes, identification keys, data sheets

Methods

I have used sculpins (*Cottus* spp.) for this exercise because of their small size (generally <10 cm long), ease of collection and relative abundance. Other fish species may be equally suitable, and the following procedures can be modified easily to accommodate larger fish. A fishing license and collecting permit often are required for this type of work, and instructors should check with local fish and game authorities before beginning this exercise.

Sculpins are common benthic (bottom-dwelling) fish of shallow riffle areas of medium-sized streams where they are predators on benthic invertebrates, small fish and fish eggs. These fish can be collected by placing a flat-edged dip net on the bottom just downstream of any large loose stone. The stone is then kicked over and any sculpin present will be swept by the current into the net. The fish then can be transferred to a holding bucket. I have collected 10-20 sculpins in an hour using this technique.

You collect benthic invertebrates near the fish collection site. The dip net is placed firmly on the bottom and the substrate immediately upstream of the net opening is agitated with your foot. Dislodged organisms will drift into the net. This technique will collect most benthic invertebrates of fast water that are accessible to fish (Hynes 1970). Three bottom samples are usually sufficient to collect a hundred or more invertebrates. More samples may be necessary if benthic populations are sparse. A net with a mesh of >500 µm should not be used because you will not retain many of the smaller invertebrates likely to be consumed by sculpins.

Invertebrates are separated from debris by dumping the collected sample into a white pan containing stream water and picking out the organisms (photo developing trays work well). Alternatively, samples can be preserved in 70 percent alcohol for later sorting in the lab.

Gut contents of collected fish are obtained using a stomach washing (gastric lavage) technique (Light, Adler & Arnold 1983). The pump sprayer with an attached hypodermic syringe is used to wash food items from fish stomachs (Figure 1). A damp cloth or cotton glove is used to hold each fish firmly against the bottom of a white pan. The plastic tubing attached to the syringe needle is inserted through the fish's mouth into the stomach until resistance is encountered. This should be done carefully to avoid puncturing the stomach or passing the tube out through the gills. The sprayer valve is depressed for 3-5 seconds to wash any gut contents into the pan. This technique causes little mortality (Meehan & Miller 1978) and avoids the regurgitation that can occur when fish are killed in formaldehyde or alcohol for later dissection.

The fish can be measured at this time, if you desire, before returning the fish to the stream or placing them in a holding bucket. The food items are rinsed into a labeled collection jar using a squirt bottle filled with water. Each fish's gut contents must be placed in a separate jar. Later, transfer these samples to 70 percent alcohol, but do not use alcohol as a pan rinse because this could harm the fish.

Invertebrates should be identified at least to the order level (Edmondson 1959; Needham & Needham 1962; Pennak 1978), and family determinations of common groups may be useful (Table 1). Identification usually requires use of a dissection microscope. Organisms in the benthic samples should be identified first. This will enable students to associate body parts in the guts with whole organisms. The number of prey consumed by each fish is then determined from the identification of these parts.

Paul M. Kotila is currently a visiting assistant professor of environmental studies in the Environmental Studies Program at St. Lawrence University, Canton, NY, 13617, where he teaches courses in environmental studies, water quality, and ecological toxicology. Over the past eight years he has taught a variety of courses in ecology, including his specialty in stream ecology. His research concentrates on the ecological and environmental relationships of stream invertebrates.

Do not count duplicated parts (e.g., 6 legs/insect) as more than one individual. While more rapid digestion of soft-bodied prey can bias these data (Hyslop 1980), there is no way to correct for this effect without conducting studies of digestion rates.

A labeled display of invertebrates collected from the stream will speed identification of specimens and body parts by students. As instructor, you should check identifications before students record them. My experience indicates that a class of 15 students can complete gut washing (using one sprayer), invertebrate identification and enumeration, and discuss data analysis within a three-hour lab period if fish and benthos are collected ahead of time and brought to the lab. An additional 2-3 hours will be necessary if the whole class participates in the collecting.

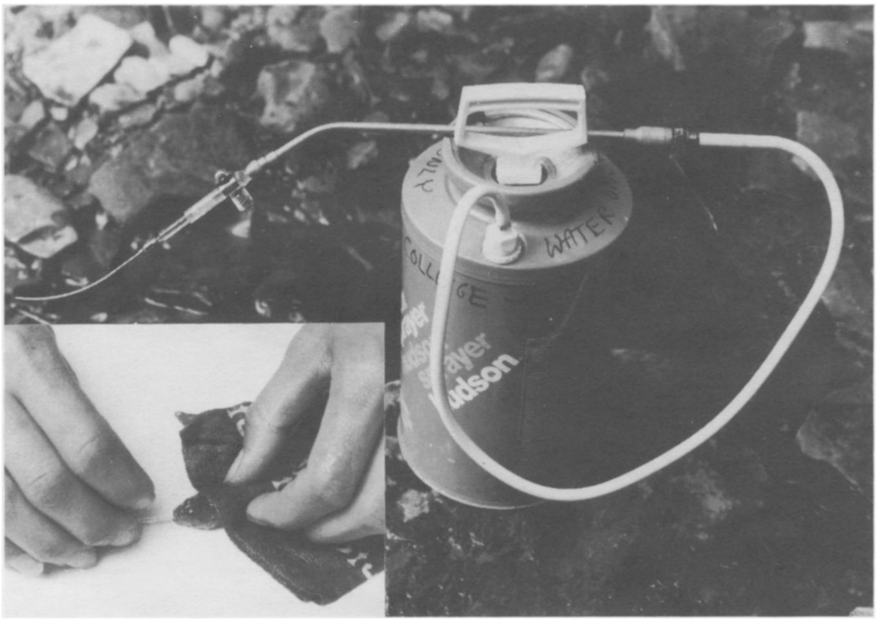

Figure 1. Pump sprayer apparatus for washing stomachs of sculpins. Insert: Sculpin with hypodermic tubing inserted.

Data Analysis and Interpretation

Students should examine the tabular data before they begin the calculations outlined below, noting the variety of food items, the number of fish with empty guts and the presence of unconsumed "foods." The absence of a gut item from the benthic samples may indicate that sampling was inadequate.

The numbers of food items in the stomachs can be standardized to fractions or percentage values in two ways (Table 2). The Frequency of Occurrence (FO) is the fraction of those guts with food in them which contained a particular item. (Note that fish #2 is not included in this calculation.) This indicates how widespread a particular food is in the guts of all fish collected and how variable diet is from fish to fish. Mayflies, for example, occurred in 5 of 11 fish collected (Table 1), giving a FO of 0.45 (Table 2).

The Fractional Composition (or Percent Composition) by numbers indicates the fraction of all food items belonging to a particular category. These values can be calculated for gut contents (r_i) and benthos (n_i). Gut fractional composition values (r_i) indicate the relative importance of the various food types to the group of fish examined while n_i values indicate the relative abundances of foods in the environment. Eight mayflies, for example, occurred in both the guts and benthos, giving r_i and n_i values of 0.032 (8/248) and 0.066 (8/122), respectively.

Spearman's rank correlation test (Siegel 1956) can be used to compare relative abundances of foods in the guts and the benthos. Consumed prey and benthic organisms are separately ranked in decreasing order of abundance with the most common type receiving the highest rank of one. Less abundant prey receive progressively higher ranks (2, 3, etc.), and tied categories are assigned the average of their ranks. The differences in the ranks of each prey type (guts vs. benthos) are used to calculate a correlation coefficient (r_s) (Siegel 1956). The prey in Table 2, for example, exhibit significant rank correlations between abundances in the guts and abundances in the benthos ($r_s = 0.85$, $p < 0.05$), as well as between frequency of occurrence in guts and benthic abundance ($r_s = 0.80$, $p < 0.05$). It therefore appears that sculpins consume prey in relative order of their abundances in the environment.

The food preferences of sculpins also can be examined using any of a number of selectivity or electivity indices (Lechowicz 1982). Ivlev's (1961) Electivity (E) is one such index that compares the fractional composition of a particular food item (i) in the guts (r_i) to its fractional composition in the available food supply (p_i):

$$E_i = (r_i - p_i)/(r_i + p_i)$$

Values of E can range from -1 to 1. A value of less than zero indicates possible avoidance of a food type, while a value greater than zero indicates an apparent preference. A value of zero indicates that a prey is being consumed in the same proportion as it is found in the environment. While high electivity implies that a fish "looks for" this particular food, such a value could also indicate a particularly accessible or easily found prey. Low E values might indicate active avoidance, poor visibility or good defense by the prey (Ringler 1979). Further study would be necessary to determine why a predator selects certain foods.*

Note that the same E value can occur for very different composition values (e.g., $E = 0.33$ for $r_i = 0.8$, $p_i = 0.4$ or $r_i = 0.1$, $p_i = 0.05$). Thus, E indicates selection for or against a prey but not its importance in the diet. While other indices have been proposed to incorporate an importance component (e.g., Strauss 1982), the use of such indices does not result in any apparent improvement in measures of relative prey preference (Lechowicz 1982).

Once students realize that E is not a measure of feeding intensity, they should understand intuitively the meaning of relatively high or low E values. The ranking of foods based on E values can be compared to a ranking based on availability using Spearman's test. This correlation is not statistically significant for my example (Table 2) ($r_s = 0.38$, $p > 0.05$),

---

* A printed copy of a BASIC computer program for calculating E and six other electivity indices is available free from the author. A copy on computer disk for the IBM-PC is also available for $5. Make checks payable to the author.

Table 1. Invertebrates collected from sculpin guts and benthos.

Taxon (common name)	Fish													Benthos			
	1	2	3	4	5	6	7	8	9	10	11	12	Tot.	1	2	3	Tot.
Chironomidae (midge larvae)	9		7	1	3	10	2	2	11	2	9	2	58	58	106	26	190
Simuliidae (black fly larvae)	6		1					13	1	13	2	3	39	20	5	4	29
Other Diptera (true fly larvae)			2	1	1						1		5	9			9
Trichoptera (caddisfly larvae)	1		3		2	1	1	1			3		12	2	4	1	7
Coleoptera (beetles)													0	1			1
Ephemeroptera (mayfly nymphs)			3	1		1	1					2	8		2	6	8
Plecoptera (stonefly nymphs)													0	1	1	2	4
Total	16	0	16	3	6	12	4	16	12	15	15	7	122	91	118	39	248

thus indicating that food preferences are not merely a reflection of abundance.

A close examination of the data frequently turns up some interesting "contradictions," such as a commonly consumed prey (high r_i) that exhibits a low E (e.g., Chironomidae). Such data can be used as a basis for a discussion of how r_i, FO, and E measures differ, what they can and cannot tell us, and how they can be used together to determine the importance of various prey and how fish feed.

It should be possible to see significant size differences among individuals in some taxa. The mass of various species of dipterans, for example, may differ by two orders of magnitude or more. Such differences introduce students to concepts of biomass, nutrients and energy content. It also indicates a potential problem when only higher taxonomic categories are used in food selection studies or numbers of individuals are used to quantify trophic relationships.

Once students realize that predators are both selective and flexible in their feeding habits, they can begin to understand why many questions in predator-prey relationships remain unresolved. The effects of predators on prey numbers, distribution, genetic composition and evolution are vigorously debated issues that have important implications for the management of endangered species, game animals and pests. This laboratory will introduce students to techniques used in predator-prey studies and some approaches for data analysis.

References

Edmondson, W.T. (Ed.). (1959). *Freshwater biology*. (2nd ed.). New York: Wiley.

Hynes, H.B.N. (1970). *Ecology of running waters*. Toronto: University of Toronto Press.

Hyslop, E.J. (1980). Stomach contents analysis—a review of methods and their application. *Journal of Fish Biology, 17*, 411-429.

Ivlev, V.S. (1961). *Experimental ecology of the feeding of fishes*. New Haven: Yale University Press.

Lechowicz, M.J. (1982). The sampling characteristics of electivity indices. *Oecologia (Berl), 52*, 22-30.

Light, R.W., Adler, P.H., & Arnold, D.E. (1983). Evaluation of gastric lavage for stomach analysis. *North American Journal of Fishery Management, 3*, 81-85.

Meehan, W.R. & Miller, R.A. (1978). Stomach flushing: effectiveness and influence on survival and condition of juvenile salmonids. *Journal of the Fisheries Research Board of Canada, 35*, 1359-1363.

Needham, J.G. & Needham, P.R. (1962). *A guide to the study of fresh-water biology*. (5th ed.). San Francisco: Holden-Day.

Ringler, N.H. (1979). Prey selection by benthic feeders. In R.H. Stroud & L.H. Clepper, (Eds.). *Predator-prey systems in fisheries management*. Washington, D.C.: Sport Fishing Institute.

Pennak, R.W. (1978). *Fresh-water invertebrates of the United States*. (2nd ed.). New York: Wiley.

Siegel, S. (1956). *Nonparametric statistics*. New York: McGraw-Hill.

Strauss, R.E. (1979). Reliability estimates for Ivlev's electivity index, the forage ratio, and a proposed linear index of food selection. *Transactions American Fisheries Society, 108*, 344-352.

Taylor, R.J. (1984). *Predation*. New York: Chapman & Hall.

Table 2. Electivity (E) values and relative composition of invertebrates found in sculpin guts and benthos.

	Gut Contents		Benthos	
Taxon	Freq. of Occurrence (FO)	Fraction of Total (r_i)	Fraction of Total (p_i)	Electivity (E)
Chironomidae	1.00	0.475	0.766	−0.23
Simuliidae	0.64	0.320	0.117	0.46
Other Diptera	0.36	0.041	0.036	0.06
Trichoptera	0.64	0.098	0.028	0.56
Coleoptera	0.00	0.000	0.004	−1.00
Ephemeroptera	0.45	0.066	0.032	0.35
Plecoptera	0.00	0.000	0.016	−1.00