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Reports on Global Health Research

Cummins KW Rep Glob Health Res 4: 129.
DOI: 10.29011/2690-9480.100129

Review Article

The Use of Macroinvertebrate Functional Feeding Group Analysis to Evaluate, Monitor and Restore Stream Ecosystem Condition

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Citation: Cummins KW (2021) The Use of Macroinvertebrate Functional Feeding Group Analysis to Evaluate, Monitor and Restore Stream Ecosystem Condition. Rep Glob Health Res 4: 129. DOI: 10.29011/2690-9480.100129

Received Date: 15 February, 2021; **Accepted Date**: 27 February, 2021; **Published Date:** 04 March, 2021

Abstract

The case is made that macroinvertebrates provide the most useful tool for analyzing the condition of running water ecosystems. They are ubiquitous, readily collected, and easily observed with the unaided eye or simple 3X hand lens. Semi-quantitative (30 second) D-Frame dip can be used to collect stream samples for analysis. Macroinvertebrates in the samples can be sorted into Taxonomic-Functional Feeding Group (FFG) categories using easily recognized morphological and behavioral characters. The taxonomic separations are usually only at the higher order or family level. Worldwide studies have shown that a limited number of stream macroinvertebrate FFGs are matched to a limited number of their food resources. This reliable linkage between FFGs and their food is the underlying basis for predicting the ecological condition of stream ecosystems. A step by step procedure for sorting and enumerating FFG macroinvertebrates in a stream sample is outlined. Ratios of the relative numbers of the macroinvertebrate FFGs can be used as surrogates for stream ecological conditions that are much more difficult to measure directly. The macroinvertebrates integrate the stream environmental conditions over the space and time scales of their growth cycles (weeks to years) difficult to match with direct measures.

Keywords: Functional feeding groups; FFG; Stream ecology; Stream environmental monitoring; Stream macroinvertebrates; Stream water quality

Introduction

The purpose of this paper is twofold. The first goal is to review and support the utility of macroinvertebrate Functional Food Group (FFG) analysis as an important tool for evaluating the ecological condition of running water (lotic) ecosystems. The second goal is to describe and discuss how ratios of the relative abundance of FFGs can be used as surrogates for lotic ecosystem attributes if they are measured directly. The basis for this is that Stream and river (lotic) macroinvertebrate communities worldwide can be partitioned into six FFGs defined by their adaptations for acquiring six matching food resource categories. A step by step procedure for FFG analysis is summarized that easily can be performed by individuals with little or no expertise in macroinvertebrate taxonomy.

Suitability of Macroinvertebrates as Monitors of Stream Ecosystem Condition

For over 100 years, benthic macroinvertebrates have been a pillar in the analysis of stream ecosystem conditions [1]. The taxonomic diversity of macroinvertebrate communities in streams has been widely employed to rank the level of degradation of a stream ecosystem relative to a comparable one of similar geomorphology which is judged to be the most pristine stream available in the same region [2,3]. These comparisons have always been hampered by the level of taxonomic resolution used in the evaluations. The methodology referred to as species diversity, has rarely utilized taxonomic identifications at the species level [4]. For example, the Diptera family Chironomidae, often the most abundant taxon in any stream, is given the value of 1 in determining species diversity index, even though the number of species present would likely be 20 or more [5].

Taxonomic resolution issues aside, macroinvertebrates can serve as outstanding monitors of stream ecosystem condition. Their distribution and abundance is word wide, they are large enough to be observed with the unaided eye or a simple 3X hand lens, and they live and grow in streams over the majority of their life cycles of weeks to a year or more [4]. Also, their populations are more abundant and less mobile than stream fishes which simply migrate away from degraded environmental conditions [6].

By contrast, chemical and physical water measurements are severely limited in space and time. Even if recording devices

are used, very significant variations in space (lateral and vertical) remain [7]. The lesser mobility and greater population densities of stream macroinvertebrates often provide better monitors of stream contamination than the highly mobile fish populations [7].

Stream Macroinvertebrate Functional Feeding Groups (FFG)

Two insights initiated the development of the Functional Feeding Group (FFG) procedure for analyzing stream macroinvertebrate communities. First in 1964, Bob Pennak, a preeminent North American freshwater invertebrate biologist, maintained that suitable ecological questions using stream macroinvertebrates could only be adequately addressed by species level identifications. This was not possible then, and is largely not possible today. For example, the most recent edition of the Aquatic Insects of North America provides keys to essentially all the North American genera. However, keys to species can be found only in monographs of selected genera [4]. Second, the original iteration of the FFG method resulted from comments made in 1970 by Noel Hynes, arguably the greatest stream ecologist of our time. He observed that whenever he examined a rock in any stream, Europe, North America, Australia, or the tropics, the macroinvertebrates all looked very familiar. But they were all classified as different Taxa. This suggested that there are a limited number of universal general adaptations of stream macroinvertebrates to the stream environment. The result of this realization was the Functional Feeding Group (FFG) concept for evaluation of macroinvertebrate communities in stream ecosystems [8-10]. An example of this phenomenon is seen in the same morphology of the North American mayfly family Heptageniidae and the Brazilian family Leptophlebiidae [11].

The FFG method employs only general levels of taxonomic identification (usually order, family and in some cases genus). The focus is on morphological and behavioral adaptations of the macroinvertebrates to their stream environment that allows acquisition of their required food resources. The FFG method, that was proposed 0ver 40 years ago, is recommended in this article as a tool for stream ecosystem evaluation (Table 1) [8-11].

In the greater than 40 years since the FFG procedure was proposed [8,9], an extensive literature on use of the method has developed. The FFG method has been expanded, modified, and adapted for analyzing wide range of stream ecosystems (e.g. 8,11-14). In particular, the River Continuum Concept that relates stream drainage geomorphology to predictable biological attributes relied heavily on FFG analysis [7]. Also, the volume edited by Cushing et al. [15] on stream and rivers of the world contains chapters by authors solicited to compare their North American, European, Australian, and tropical streams to the River Continuum Concept, including the FFG component.

The FFGs, their food resource categories, and North American taxonomic examples are summarized in Table 1.

Acronym	Functional Feeding Group	Food Rresource Categories	Common North American Taxa in each FFG
SC	Scrapers	Attached single cells and non-filamentous colonies of algae (filamentous algae excludes scrapers)	Mollusca: Gastropoda Ephemeroptera: Heptageniidae, some Ephemerellidae, *Drunella* Trichoptera: Glossosomatidae, Helicopsychidae, Turemmatidae (=Uenoidae), Limnephilidae (stone cases) Coleoptera: Psephenidae (larvae), Elmidae (adults)
HSH	Herbivore Shredders	Rooted aquatic vascular plants	Trichoptera: some Phryganeidae Lepidoptera: Crambidae Coleoptera: some Chrysomelidae
DSH	Detrital Shredders	Deciduous leaf and evergreen leaf or needle plant litter or in wood (CPOM). All are derived from the streamside riparian zone. Must conditioned by Hyphomycete fungi to be palatable for DSH	Crustacea: Amphipoda Plecoptera: Nemouridae, Capniidae Trichoptera: Lepidostomatidae, Limnephilidae: (organic cases) Diptera: Tipulidae, only *Tipula* (found in in leaf litter)
FC	Filtering Collectors	FPOM in transport the stream current (TFPOM)	Mollusca: Bivalvia (=Pelecypoda) Ephemeroptera: Isonychidae Trichoptera: Hydropsychidae, Philopotamidae, Polycentropidae Diptera: Simuliidae, Chironomidae, Tanytarsini
GC	Gathering Collectors	Benthic FPOM on or in the sediments (BFPOM)	Oligochaeta Ephemeroptera: Baetidae, Leptophlebiiidae, Caenidae Coleoptera: Elmidae (larvae) Diptera: Chironomidae, Chironominae, Chironomini, Orthocladiinae

P	Predators	Live Invertebrate prey	Plecoptera: Perlidae Odonata, Anisoptera, Zygoptera Megaloptera, Corydalidae, Sialidae Coleoptera: Dytiscidae (larvae), Hydrophilidae (larvae) Diptera: Tipulidae (except *Tipula*), Chironomidae, Tanypodinae

CPOM = Coarse Particulate Organic Matter; FPOM = Fine Particulate Organic Matter.

Table 1: Stream macroinvertebrate Functional Feeding Groups (FFG) and their associated food resources. The taxonomic examples are from North America. Adapted from [8-11].

Equipment, Materials and Methods

FFG analysis involves separation of the macroinvertebrates collected in a sample of stream benthos into easily recognized FFG categories. The recommended step by step procedure is summarized in Table 2. The directions are intended for use stream side, in the field, by at least three people. The procedure should be accomplished in the field because separation of the macroinvertebrates into taxonomic and FFGs is measurably easier when live animals are sorted. Before sampling, a data sheet should be prepared with date, time, stream name and description for recording the information obtained.

Semi- quantitative benthic samples are sufficient. A set of 30 second, habitat specific, collections with a Frame 0.5 mm mesh Dip Net [Bioquip™, 4]. Three dip net samples are taken in each major habitat: gravel-cobble riffles, depositional pools and/or back waters, leaf litter accumulations, and rooted vascular plant beds (when present). Each sample should be sorted and tabulated separately. Compositing of sample habitat data can be performed later if desired.

Before heading to the stream bank with a sample in the dip net, pre-treat it. By swishing the net up and down and side to side in the current to remove silt. By hand, remove macroinvertebrates from the surface of cobbles, pebbles, and large pieces of wood, drop them into the net, and discard the substrates back onto the stream.

Analysis of each Dip Net sample begins by emptying the contents of the net into a shallow, white 8 x 10 inch (20.5 x 25.4 cm) plastic or metal tray. Then, the macroinvertebrates are separated into taxa and FFGs as described step by step in Table 2. The picture key in [12] is a very useful aid in following the procedure. The important point in sorting the macroinvertebrates into FFGs is that only a general level of taxonomic resolution necessary to place them in a FFG is required. For example, only insect order is needed to categorize Odonata (dragonflies and damselflies) and Megaloptera (dobsonflies and alderflies) as predators.

A muffin tin with 8 large wells can be used to hold the sorted FFGs. The designation of each FFG can written on the bottom of each well with a white sharpie. That is, SC = Scrapers, DHS = Detrital Shredders, GC = Gathering Collectors, FC = Filtering Collectors, P = Predators, and HSH = Herbivore Shredders. Two wells should be marked for DSH and P because the specimens are larger. Information about the stream reach where the samples are taken should be recorded on the data sheet along with results of the FFG sorting. During sorting, numerical abundance of the macroinvertebrates by taxa and FFG is recorded. Also, an estimate should be made and recorded of the percent stream bottom covered by each habitat type sampled allowing the macroinvertebrate data to be weighted by the percent stream bottom covered by each habitat type in the stream reach. If the numerical data are to be converted to dry biomass, a separate procedure can be found in [16].

The supplies required for sorting the macroinvertebrate samples are long fine point forceps, magnifying glass (3X with a 5X bubble), and a bug scoop™. The bug scoop consists of a 1.5 cm square of plastic screen with a ridge around the edge made with a hot glue gun. A bead of hot glue in the middle of one edge receives a dissecting needle that serves as a handle. This scoop greatly facilitated the capture of rapidly swimming macroinvertebrates such as the usually very abundant mayfly nymphs in the family Baetidae (Table 1).

Step by step directions for field sorting of FFGs are given below in Table 2.

Step	Sorting Procedure	Taxa	Characteristics	FFG
1	If rooted aquatic plants are present , with forceps remove larvae with forceps	Coleoptera , Chrysomelidae	No abdominal prolegs	HSH
		Lepidoptera, Crambidae	Abdominal pro legs with circle of small hooks at ends	
2	By hand, or with forceps, remove all non-insect macroinvertebrates (size 1-2 cm)	Mollusca, Gastropoda	hard spiral shell	SC
		Mollusca, Bivalvia	two hard bivalve shells	FC
		Crustacea. Amphipoda	more than 6 jointed legs, flat side to side	DSH
		Crustacea. Isopoda	more than 6 jointed legs, flat top to bottom	DSH
		Crustacea. Decapoda	More than 6 jointed legs, first appendage is a large claw	DSH, GC
		Oligochaeta	No legs, multi-segmented worms with a pair of setae on the side of each segment	GC
3	Wit forceps remove all large insects; they all have 6 jointed legs (size 1.5 -4 cm)	Odonata	long extendible lower lip (labium) with terminal grasping claws	P
		Hemiptera	Under side of head with long, sharp pointed, body piercing beak, very long narrow body with long legs or brad flat body	P
		Plecoptera	active nymphs with large eyes. most with yellow color pattern	P
			very large sluggish nymphs, small eyes. uniform brown or black color	DSH
		Megaloptera	large mandibles, lateral abdominal filaments	P
		Trichoptera	case baring larvae, greater than 2/3 front of case constructed of organic material	DSH
		Trichoptera	case baring larvae, greater than 2/3 front of case constructed of mineral material	SC
	With forceps remove large worm like non segmented larvae, no jointed legs, retractile head capsule, lobed disc at end of body (size 2.5 – 5 cm)	Diptera, Tipulidae	Very large rotund larvae found in leaf litter accumulations; *Tipula*	DSH
			Medium size larvae terminal abdominal segment swollen	P
4	With the bug scoop remove nymphs with 3 (middle one may be very short) or 2 long terminal filaments (most 1-2 cm size)	Ephemeroptera	3 (middle one may be very short) terminal filaments, lateral abdominal gills,1 tarsal claw on end of each leg	SC, GC
		Plecoptera	2 terminal filaments, no lateral abdominal gills,2 tarsal claw on end of each leg	DSH, P

5	With bug scoop separate nymphs with 3 (middle one may be very short) terminal filaments (size 1-2 cm)	Ephemeroptera	nymphs flat upper to under side, eyes and antennae dorsal	SC
			nymphs round or oval upper to under side, eyes and antennae lateral	GC
6	With bug scoop separate nymphs with 2 terminal filaments (size 1-2 cm)	Plecoptera	active nymphs, large eyes little color pattern	P
			sluggish nymphs, small eyes. uniform brown or black color	DSH
7	With forceps add small case baring larvae to Trichoptera (size 0.5 -2 cm)	Trichoptera	organic case	DSH
			Mineral case	SC
8	With forceps remove larvae that have 2 prolegs at end of abdomen with 2 strong hooks (size 1.5 -2.5 cm)	Trichoptera	short terminal prolegs, larva in fixed retreat with filtering net	FC
			long terminal prolegs, small mandibles, in a fixed retreat with a filtering net	FC
			Free ranging Rhyacophilidae have large mandibles)	P
9	With forceps remove beetle adults; front wings modified as hard shell covers (1-2.5 cm)	Coleoptera	large mandibles, hind legs modified for swimming or crawling, labial palps short	P
			Small mandibles, hind legs modified for swimming, labial palps long and appear to be the antennae	GC
			Six long jointed legs, not modified for swimming	SC
10	With forceps remove beetle larvae; only remaining larvae, short jointed front legs (size 1.5-2.5 cm)	Coleoptera	disc shaped, body entirely concealed beneath dorsal plates	SC
			Body not concealed, large mandibles, lateral abdominal filaments, posterior abdominal hooks	P
11	With insect scoop remove only remaining larvae,, no jointed legs (size 1.5-2.5 cm)	Diptera: Simuliidae	Bowling pin shape, filtering head fans end of abdomen with circle of small hooks	FC
		Diptera: Tanypodinae	Long round body shape, larger larvae with large quadrate head	P
		Diptera: Tanytarsini	Long round body shape, very small larvae with round head and long antennae, in vertical tube with prongs at tip strung with silk	FC
		Diptera: Chironomini	Long round body shape, round head, small to medium size, posterior pro lrgs, some are bright red	GC
		Diptera: Orthocladiinae	Long round body shape, medium size larvae with oblong head	GC

Groups (FFG). BMI = Benthic Macroinvertebrates; SC = Scrapers; FC = Filtering Collectors; DSH = Detrital Shredders; HSH = Herbivore Shredders; GC= Gathering Collectors; P = Predators; see text for description of insect scoop. The use of the picture key to FFG in [12] along with this table is recommended. Taxonomy follows [4,17].

Table 2: Stepwise procedure for sorting live stream benthic macroinvertebrate samples in the field into Functional Feeding.

Use of FFG Ratios as Surrogates for Selected Stream Ecosystem Attributes

The relative abundance of a FFG predicts the availability of their required food resources. By extension, this predicts the status of the environmental conditions that produced these food resources. For example, light and nutrient levels regulate the primary production by attached algal food for scrapers and light, nutrients and sediment type limit abundance of vascular plant beds that are the food for herbivore shredders [18].

Because the FFG procedure has been used widely used and validated, the intent of this paper is to provide a step by step guide for collecting and using FFG data to evaluate stream ecosystem condition. The guide in Table 2 is suitable for use by people with limited knowledge of stream macroinvertebrates. The case is made that the FFG data collected in the field can be used to calculate ratios of FFG. These ratios can serve as surrogates for direct measures of the condition of a stream from which the samples were taken. The step by step procedure to facilitate this, is provided in Table 2.

Comparing the abundances of FFGs indicates the relative availability of their required food resources. By extension, this predicts the status of the environmental conditions that produce the food resource. For example, light and nutrient levels regulates stream l primary production [19,20].

Because a Limited number of feeding adaptations linked to a limited number of food resource categories, the relative abundance of a FFG indicates the relative availability of the required food resource. By extension, this predicts the status of the environmental conditions that produce the field; for example, light and nutrient levels that regulate primary production; attached algae and rooted vascular plants.

Because the FFG procedure has been used widely and validated, the intent of this paper is to provide a blueprint for collecting and using FFG data to evaluate stream ecosystem condition that can be used by people with limited knowledge of stream macroinvertebrates. The case is made that the FFG data collected in the field can be used to calculate ratios of FFGs to evaluate the condition of a stream from which the samples were taken. A step by step procedure is provided for collecting the FFG data needed (Table 2). The FFG ratios serve as surrogates for directly measured stream ecosystem environmental conditions. The ratios are dimensionless numbers and therefore are relatively independent of sample size. That is, the ratio calculated from collections of one sample are very similar to the ratios calculated by the average of three sample (Cummins, unpublished).

FFG ratios and predicted stream ecosystem conditions are summarized in Table 3.

Acronym Or Descriptor	Index	Direct Stream Measurement	FFG Surrogate Ratio	Proposed Threshold	Prediction of Stream Ecological Condition if FFG Ratio is Above Threshold Level
P/R	Gross Primary Production	Total Primary Production / Community Respiration	SC + HSH to DSH + GC + FC	0.75	Stream is autotrophic, dominated by primary producers (attached single cell and small colony non-filamentous algae) and/or vascular aquatic plants
PLANTS/ ALGAE	Rooted vascular plants	Density of Vascular Plants	HSH To SC	0.50	Rooted vascular aquatic plant beds have shaded or crowded out non-filamentous algae
CPOM/ FPOM	Shredder abundance	DSH per g Leaf litter	DSH to GC + FC	Fall-winter 0.50	Fall-winter: expected shredder abundance dependent on deciduous leaf litter conditioned by hyphomycete fungi
				Spring-summer 0.25	Spring-summer: expected shredder abundance dependent on resistant deciduous and evergreen litter conditioned by hyphomycete fungi
FPOM/ CPOM	Filtering Collector	g per liter of FPOM in suspension	FC to GC	0.50	Unusually high concentration of FPOM being transported in the stream current (abnormal turbidity)

Channel Stability	Habitat Stability	% of stream bottom covered by coarse sediments, large wood, and rooted plants	SC + HSH + FC to DHS + GC	0.50	Low amounts of fine sediment on channel bottom low amounts of CPOM and FPOM transported during increased stream flows, Majority of stream bottom is bed rock, boulders or cobles, or large wood debris
Predators	Predator Top Down Control	Predators per meter square	P to SC + HSH + DSH + FC + GC	0.50	Large populations of small, rapid turnover macroinvertebrates in the macroinvertebrate community (e. g. Chironomidae midge larvae and *Baetis* Ephemeroptera nymphs)

P/R = gross primary production/total community respiration; CPOM = Coarse Particulate Organic Matter (> 1 mm size); FPOM = Fine Particulate Organic Matter (< 1 mm size); SC = Scrapers; HSH = Herbivore Shredders; DSH = Detritivore Shredders; FC = Filtering Collectors; GC = Gathering Collectors, P = Predators

Table 3: Ratios of the relative abundance of FFGs used to predict stream ecosystem condition. Stream condition interpretation is for at or above threshold value. Modified from [18].

These ratios and stream ecosystem attributes are based on North American studies. Modified or alternative ratios will undoubtedly be necessary to accommodate streams in other regions [18,20]. However, the general relationships outlined in Table 3 can serve as a general model of how such an analysis works and the evaluations of stream ecosystem conditions can be derived.

Proposed thresholds for the ratios are also given in Table 3 These thresholds are based on studies in Temperate [13,21-23] and tropical [24,25] running water ecosystems. In spite of the limited number of stream ecosystem studies on which the proposed ratios are based, they should serve as general examples for all streams. This implies that if data on the condition of a stream ecosystem are available or can be surmised (e. g. poor vs high water quality), collections for determining the relative abundances of the macroinvertebrate FFGs can be used, or developed to serve as surrogates for a more complete prediction of ecosystem condition of the stream. The development of ratio thresholds should provide a fertile avenue for further investigation. In addition, any published numerical or biomass data on the macroinvertebrates of a given stream can be assigned to FFGs (Table 1 and Table 2) and ratios calculated to predict the condition of the studied stream ecosystem (Table 3). The ultimate reason that such exercises can work is the universal nature of the six FFGs matched to six food resource groups worldwide documented in this article.

FFG analysis and resulting calculation of ratios should facilitate the process of evaluation of stream condition by workers of varying degrees of expertise in invertebrate taxonomy. The usefulness of this approach is based on the unique value of macroinvertebrates as monitors of the stream environment.

Conclusions

The stream macroinvertebrate FFG concept and the procedure for use in the analysis of stream ecosystem environmental condition has been reviewed. The method has worldwide application and can provide rapid analysis of stream condition by people with little or no expertise in stream macroinvertebrate taxonomy. Because stream macroinvertebrates spend the entirety of their growth period in the stream environment, t they are ideal monitors of stream condition. This level of complete monitoring of stream condition by month season or up to 2 years rapidly can provide better integrated data over time and space than most direct measurements of the stream ecosystem parameters. A final goal of this article is to encourage individuals to enlist the participation of their high school or college biology teachers to organize citizen groups to monitor legal streams. The as local stream ecosystem stewards of stream condition they can provide evaluation, monitoring, and restoration of regional streams to local officials.

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