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Studying streams as a biological unit

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Abstract

The case for viewing and studying streams from the standpoint of processors of materials and energy instead of exporters from the forest is elaborated. The unique opportunity for stream and terrestrial biogeochemical investigators to cooperate and be coinvestigators on the same stream systems is explored and specific programs are identified.

The shift in emphasis from standing crop sampling and instantaneous ingestion and growth information to process studies utilizing radioisotope material balance experiments and carbon flux experiments is explained. Short term experiments using radioisotopes as food markers are described and discussed as to their usefulness in determining the effect of food quality on ingestion rates and assimilation efficiencies.

The Stream as a Biological Unit

The primary aquatic interface with the terrestrial component occurs in small watershed streams. There is a general consensus that the stream itself probably contributes little to the conservation of nutrients (compared to the total terrestrial system of which they are a part) since relative biomass levels are low and export is a pervasive feature of streams, particularly during freshets. Such ideas, although partially correct, have helped to perpetuate out-moded views advanced by terrestrial ecologists around the turn of the century concerning streams. The opening paragraph of a paper by Shelford and Eddy (1929)[1] is sadly appropriate in 1972:

> Modern ecologists . . . have considered that the development of communities gives the clue to their dynamics and relations to each other. Most plant ecologists have usually assumed that there are no permanent fresh water communities. This assumption is based upon negative evidence. Streams change their locations, and it is essentially their abandoned positions that become ponds and develop into land communities. Streams are permanent as long as the existing climate endures, and this is the condition under which land communities reach a climax.

The state of the art of stream ecology has clearly upheld Shelford and Eddy's hypotheses that permanent stream communities exist, undergo successional development, reach and maintain a relatively stable condition, and manifest seasonal and annual differences, i.e., streams are bona fide biological units. To continue further, streams are highly evolved biological units. As Hynes (1970) has pointed out, almost every taxonomic group of invertebrates is represented in, on or near the substratum of lotic environments. In contrast to lakes and ponds there are several groups which occur only in lotic systems and more which reach their maximum development and diversity there. This is quite probably a consequence of the permanence of streams as compared with lakes and ponds. Rivers rarely disappear so they are not evolutionary traps (Hynes 1970).

The attitudes of terrestrial ecologists toward streams have not basically changed since the paper of Shelford and Eddy (see footnote 1). A recent symposium at Oregon State University on forest land uses and

[1] V. E. Shelford and S. Eddy. Methods for the study of stream communities. Ecology 10: 382-392, 1929.

stream environments (Krygier and Hall 1971) indicates that attitudes toward streams by policymakers and foresters may be changing. However, with the notable exceptions of Chapman (1966) and Lantz and Hall (personal communication), the analysis of the effects of logging on streams seldom considers the stream directly from a biological point of view.

In perhaps the most complete study on a watershed to date, the Hubbard Brook Experimental Forest in New Hampshire (Likens et al. 1970, Bormann et al. 1969), the capacity for streams to alter and process the various kinds and forms of chemicals was not considered. The various forms in which nitrogen enters a stream (organic, both dissolved and particulate, and inorganic) and their fates have not been carefully explored for either undisturbed or clearcut watersheds. One might expect that more nitrogen is lost to the terrestrial portion but retained in the stream portion of the forest ecosystem than Likens and Bormann have shown. Indeed, Fisher (1970), working on the same watershed, has shown that 80 percent or more of the particulate fraction that enters a small stream is processed in the stream. Kaushik and Hynes (1971) and Triska (1969), in studies on the fate and residence times for leaves in streams, also indicate that processing and not export is the dominant process.

Objectives of the Research on Andrews Watershed Streams

The inclusion of streams in the Coniferous Biome Study represents a unique opportunity for stream biologists and terrestrial biogeochemical investigators to cooperate on and investigate the same stream systems, thus exploring together long neglected problems. We have taken advantage of this opportunity on the Andrews forest streams by emphasizing major terrestrial-aquatic couplings in our stream investigations such as: (1) obtaining estimates of allochthonous inputs and exports both particulate and dissolved; (2) documentation of successional changes in microflora and the identification of specific metabolic activities carried out during leaf decomposition; (3) determining the significance of root return of nutrients via riparian vegetation with the aid of radioactive isotopes and mass balance experiments; and (4) estimating the importance of fish and amphibians as the top carnivores in some of the small watershed streams.

The long-range objective of the Andrews stream program is to elucidate the role of a stream in the functioning of the watershed ecosystem. The inclusion of fish, which are certainly quantitatively significant in some of the streams, makes it apparent that the other components and their relationships will be defined as well. The determination of how the relationships between productivity and structure at the various trophic levels are altered by various degrees of land use—in this instance, logging—will be a prime objective. Because of the relatively short-term nature of the research, logged vs. unlogged comparisons will be based primarily upon simultaneous observations over a range of conditions rather than on the conventional before-and-after approach. The Andrews forest provides a wide range of conditions from which to sample; including virgin watersheds, watersheds where streamsides have been recently logged, and watersheds where streamside vegetation has grown after past logging. There are obvious problems in this comparative approach. We will have to look at a number of "undisturbed" streams to establish a sort of natural variance in order to distinguish between natural vs. imposed variation.

The Andrews Approach to Stream Studies

At present the emphasis is focused on the role of the biota in the small streams in the Andrews forest. We are presently determining the structure of the stream, its energy sources, and its energy processing components. This descriptive work is both necessary and tedious and will continue into year 3. The methods and approaches being used are standard for this type of stream work with some modifications to cover the peculiarities of our specific streams.

A significant problem not being dealt with in year 2 is the dimension of the dissolved organic fraction (DOM) and the utilization of that fraction. The DOM from leaf leachate, algal excretion, and soil solution represents a significant organic pool which turns over quite rapidly, even though a large amount of rather refractory matter may be expected. K. W. Cummins (personal communication),[2] attempting to model woodland streams in a deciduous forest, estimated that about 50 percent of the total DOM input was reflocculated into fine particulate organic matter (FPOM). This occurred by flocculation around air bubbles, colloidal settling, and chemical precipitation. The other half was metabolized by microbes of which he estimated 50 percent passed off as respiratory CO_2 and 50 percent went into production of microbial FPOM. The DOM compartment is a vital coupling between the dynamics of the stream biota and such biome investigations as stream hydrology and biogeochemistry.

Little is known concerning the many changes in quantity and quality of DOM that are produced by the biological processes in and near streams. The functional role of DOM in stream metabolism is also understood poorly and that information which is available is essentially circumstantial. Inferences have been drawn from physiological studies of bacterial and algal cultures under laboratory conditions. Technological difficulties have delayed the transition from laboratory to field investigations.

The approaches planned, to tackle the dynamics of DOM in forest streams, involve an investigation of the processes of microbial decomposition of allochthonous material, measuring the quantity and quality of DOM involved, and examining the fluxing between physical and biotic compartments in and along the streams.

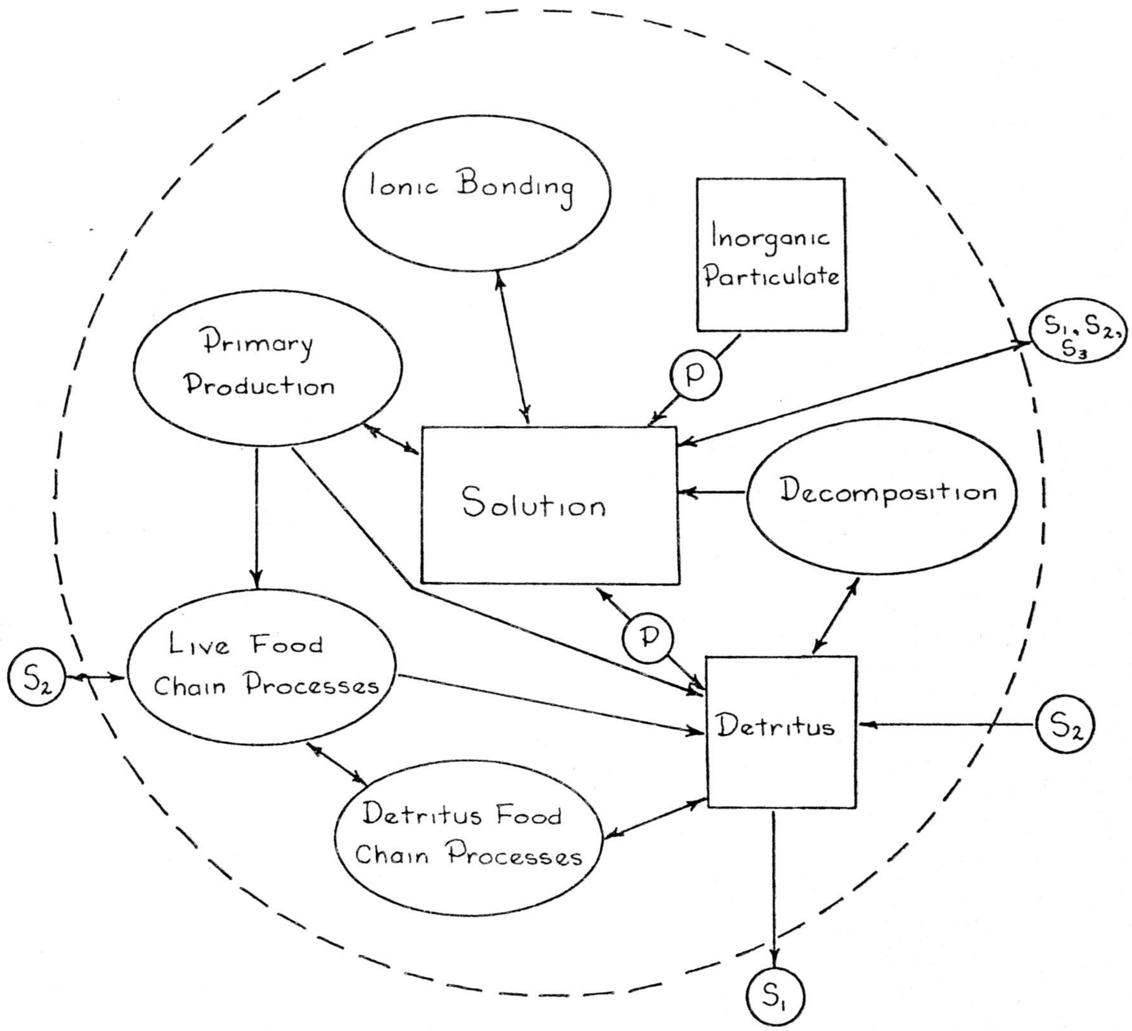
The variety of stream conditions in the Andrews watersheds provide excellent situations in which to measure the types and amounts of DOM and hopefully develop a budget. Integral to the measurements will be a study of the functional microbial groups involved in the decomposition of the large organic material such as leaves, woody pieces, and fish carcasses. The expertise of an investigator with knowledge of the biochemistry of microbial decomposition will be required.

The necessary techniques for studying stream processes and conceptualizing streams in general have not as yet been adequately developed for coniferous systems. However, major components with the forest stream systems can be identified (fig. 1). Contrary to the opinion of others in the biome, the periphyton and decomposer units can be usefully approached as a "black-box." The complexity can be used advantageously to measure disappearance of substrate and release of products, and some understanding of how ecosystems work and respond to perturbations can be gained. Radioactive isotope experiments will allow us to look at coupled events and processes in the stream. The parameters will be determined by the kinetics of the isotope. We can refine the experiments to look at what features of the system determine these parameters and how. Carbon-14 and phosphorus-32 will be used in mass balance techniques developed by Saunders (1969) and Saunders and Storch (1971) (closed chambers, short-term experiments with C^{14}) and in situ P^{32} techniques developed by Nelson et al. (1969) and Elwood and Nelson (personal communication).[3] Isotopes of selected elements will be incorporated into biogenic material such as salmon carcasses and the pathways and turnover rates of these elements following decomposition will be investigated.

In addition to the decomposition studies already mentioned, an estimate of the large woody pieces (greater than 1mm) above, in, and near the stream bed will be made. This will be done in cooperation with terrestrial biomass investigations on the Andrews forest.

[2] K. W. Cummins. Narrative for a stream energy budget model. Unpublished manuscript on file at Kellogg Biological Station, Michigan State University, Hickory Corners. 5 p., 1970.

[3] J. W. Elwood and D. J. Nelson. Measurement of periphyton production and grazing rates in a stream using a ^{32}P material balance method. Oikos (in press).



S_1 = Hydrologic
S_2 = Terrestrial
S_3 = Aquatic
P = Physical Processes

Figure 1. Stream system categories and relationships.

The primary production and energy sources estimations will utilize the aforementioned P^{32} material balance method. The technique consists of computing a material balance of P^{32} following a 30-60 min pulse release. Total standing crop and effective stream bottom area can be calculated by equating the quantities of P^{32} per unit area of substrate on the stream bottom and per unit weight of periphyton on these substrates to the total quantities of P^{32} retained in the study reach of the stream.

The retained P^{32} in the stream will be subsequently lost in both dissolved and particulate forms through three processes: (1) as P^{32} is replaced by stable phosphorus through metabolic turnover; (2) periphyton containing P^{32} may be sloughed from substrates and transported out of the study reach; and (3) particulate P^{32} released to the stream from primary and secondary consumers and drift of consumers.

Rates of change in the various compartments can be estimated by monitoring the P^{32} in the periphyton and stream water over time. The production rate of periphyton and the grazing rate of periphyton can then be estimated.

Nutrients could be lost from the stream to the riparian portion of the stream study research. The P^{32} technique allows one to measure this movement of nutrients from the aquatic to the terrestrial compartment.

The rationale for carbon flux experiments are discussed in another paper in this symposium by Lighthart and Tiegs (1972). We will not discuss this approach now, except to say that we think the technique can be adapted for use in stream research.

An additional study in the year 3 program will be the role of mosses in the stream bed in fixing energy and cycling nutrients. Their associated invertebrate fauna make them an important compartment in the streams trophic structure.

Studies on the production of benthic invertebrates will be completed. In the analysis of the data particular attention will have to be paid to "strategies of survival" used by the various functional groups of invertebrates. Population regulation must be expected to differ quite widely in response to the degree of stability of the environment. Freshets in the Andrews forest occur frequently but unpredictably. Food supplies may disappear almost entirely, and animals must be able to withstand and recover from very great fluctuations in numbers. They must be adapted to a great lack of constancy.

Special attention will be paid to the chironomid larvae, pupa and adults. This group which represents the greatest numbers, species and probably biomass of all of the aquatic insect groups, has been somewhat neglected in the first 2 years. Using a foam gathering method the associated exuvia, pupae, and emerging adult midges will be identified and quantified. W. P. Coffman (University of Pittsburgh) will be consulted on the identity of the midges. Feeding experiments with the major invertebrate species will determine ingestion and assimilation rates as affected by the quality and quantity of food.

Meaningful data concerning feeding habits of selected consumers and the relative nutritional values of different constituents of the periphyton are extremely rare. Gut analysis of insects are often misleading as to major source of nutrition due to differential digestion and assimilation rates. Sedell[4] has reported a technique which allows one to determine if the type of microflora on the natural substrates affect the rates of ingestion of stream invertebrates. Substrates from the stream are either differentially sterilized or are surface sterilized and then reinoculated with an algal, bacterial, or fungal community or any combination of the three treatments. The treated substrate is then soaked for 1 to 3 hours in a stream water solution of Co^{60}. The Co^{60} is adsorbed onto the aufwuchs and the specific activity of the food substance determined (mg/cpm). The Co^{60} is a gamma emitter and can be easily detected without killing the animal. This being the case sensitive experimental designs can be tried which use the individual as a block, thereby eliminating

[4] J. R. Sedell. Feeding rates and food utilization of stream caddisfly larvae of the genus *Neophylax* (Trichoptera: Limnephilidae) using ^{60}Co and ^{14}C. *In* D. J. Nelson (ed.), Symposium on radioecology: Proceedings of the Third National Symposium at Oak Ridge, Tenn. May 8-10, 1971. (In press.)

ingestion variation between individuals and ingestion variation between periods. By coupling this method with C^{14} labeling of different compartments of the aufwuchs one can determine assimilation, and the major source of nutrition or at least that food which is most easily assimilated.

Predator-prey experiments have been designed to examine the roles of macroinvertebrates, amphibians, and fish in the stream, and their influence on the community composition and numbers of aquatic insects. The higher consumer portion of the study will also relate the contribution of allochthonous and autochthonous production to the elaboration of fish flesh and to determine how the relationship may be altered by logging or other land management practices.

The role of amphibians in the consumer dynamics of the stream areas in which they are located is being investigated by a member of the terrestrial consumer group. This effort will strengthen the aquatic-terrestrial coupling studies.

The Andrews stream program for years 3 and 4 will be focused on aquatic-terrestrial couplings. Apart from viewing the stream as receiving the bulk of its energy from forest litter, the extent to which the stream delays the export of minerals and nutrients or may return them to the forest is not known. Stream research during years 3 and 4 will be geared to provide some of these answers.

Acknowledgments

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