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# STREAM ECOLOGY IN RELATION TO LAND USE *

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# STREAM ECOLOGY IN RELATION TO LAND USE

The primary aquatic interface with the terrestrial environment occurs in small watersheds and valley streams. The input of organic and inorganic materials to streams arises on the landscape. As a result, the events in the terrestrial environment largely determine what materials streams receive. These losses from the landscape are a relatively insignificant quantity of material so far as the terrestrial environment is concerned. However, these organic and inorganic materials represent both a tremendous resource to the aquatic environment and a potential for destruction of its living resources.

For example, after a watershed is clearcut, nutrient losses (specifically nitrogen and phosphorus) from forest ecosystems are relatively low where vegetative growth recovers rapidly. While the values may be low in relation to the total forest nutrient capital, concentrations of nitrate and phosphate in streams draining clearcuts may increase 20 to 100 fold for a period of 1 to 3 years after clearcutting. The microbial and algal communities of these streams live in an environment in which nutrient levels are extremely low, quite possibly limiting. The effect on these organisms of a sudden and sustained 20 to 100 fold increase in nitrogen and phosphorus is poorly understood, but of great significance in the breakdown of organic debris and growth of algae.

Likewise, increases in stream temperature have been shown to be significant following logging in both coniferous and deciduous forests. Coupled with nutrient increases, the impact on algal growth and the rates of decomposition of organic debris is quite significant.

Many excellent studies have been conducted on small streams for water export, water quality, suspended sediments, and nutrient runoff. Some of these studies were discussed by Dr. Reichle. All provide a very valuable beginning for the stream biologists. However, the approach to looking at the effects of logging, irrigation diversion, or fertilization on streams has yet to consider the stream as a living system.

That streams have not been looked at as living systems by land-use managers is not too surprising. To look at a stream's processing structure and capabilities is an enormous undertaking. The formulation of suitable management practices for streams has been greatly hampered by the lack of fundamental data on the functioning of stream systems. Since it is non-polluted streams that man wishes to maintain or restore, the data required necessarily involve the complex communities typical of healthy streams. Through the Analysis of Ecosystem program stream ecologists have begun to provide the conceptualization and basic data essential for the intelligent preservation, manipulation, and rehabilitation of our continental streams. The general strategy of the Analyses of Ecosystems stream groups has been to describe the structure and function of a "representative" stream for a geographical area. Emphasis has been placed on process and transfer rates.

The experimental approach has been directed at achieving predictive capability related to land manipulations that change these processing and transfer rates (e.g., clearcutting, irrigation diversion, nutrient inputs). The attempt is being made to set the permissable ranges of alterations of various biological parts of streams that result from a given manipulation of the light, temperature, current, and nutrient regimes or from particulate and dissolved organic inputs.

## IBP STREAM GROUPS

In North America there are presently 7 groups of investigators from different geographical locations that are involved with the conceptualization of stream systems and are actively engaged in the development of models of such systems. Four of these groups have been supported to some extent and are a part of the U. S. IBP effort.

The Coniferous Forest Biome has two sites, one on the west Cascade slopes and one in the Coast Range. This group is working closely with the State Game Commission, U. S. Forest Service, and has worked with the Environmental Protection Agency and the U. S. Geological Survey.

The Desert Biome has 2 major sites, Rattlesnake Springs in eastern Washington and Deep creek in northern Utah. This group is working closely with the Atomic

Energy Commission at Hanford, Washington, and has recently received a contract from the Bureau of Reclamation for the use of its stream model.

The Eastern Deciduous Forest Biome has two principle sites: 1) At the U. S. Forest Service's Coweeta Hydrologic Laboratory in western North Carolina, IBP personnel are studying four watersheds, three of which have been manipulated to establish white pine, weeds, and hardwoods; 2) the other site is Walker Branch at Oak Ridge, Tennessee, and is an integral part of the major watershed study and modeling effort in the Eastern Deciduous Forest Biome. This group, strongly supported by the Atomic Energy Commission, has acquired an extensive data base for their ecosystem analysis work.

At all Biome sites, many perturbations such as fertilization of watersheds, logging, irrigation diversion, nutrient runoff from agriculture and livestock, and effects of different vegetative treatments on watershed streams are being studied.

## CONCEPTUAL MODEL

Our ideas about stream ecosystem structure and function emphasize the heterotrophic nature of streams. That is, the focus is on the fate and role of terrestrially produced organic matter (detritus) once it enters the stream system. Like the terrestrial systems Dr. Reichle discussed, most streams are dependent on dead material from the land to drive them energetically. The producers appear to be primarily light limited, so that activities such as clearcutting, which increase the light income to streams, may make production by algae the dominant energy source as it appears to be in the desert streams.

A simplified view of the stream ecosystem according to processing functions is shown in Figure 1, with a few representative organisms indicated. The particulate organic matter input is symbolized by oak and fir, although many different leaf species enter any given stream together with a wide variety of other materials such as flowers, fruits, bud scales, terrestrial insects, their feces, etc. Dissolved organic matter is visualized as being derived from this litter material, either leached out in the terrestrial environment and introduced through runoff, or leached from the material once it has entered the stream. Microbes invade the leaves and needles and take up the dissolved organic matter. In-stream primary producers are symbolized by algae, many of which are highly shade adapted. The animal consumers have been partitioned on the basis of their primary feeding activity into "shredders" that feed on intact leaves; "collectors" that ingest fine particles; "grazers" which are algal feeders; and, "predators."

The shredders are depicted by a stonefly, cranefly, and caddis fly. The collectors ingest either by moving about and scraping and/or vacuuming fine detrital particles from surfaces or crevices (the example shown is a mayfly), or by remaining in a relatively fixed position and filtering fine particles from passing water (exemplified by the blackfly). From this perspective I would like to discuss some of the approaches taken and results obtained by IBP.

One basic experimental approach used by all groups is an accounting of the various inputs, standing crops and outputs.

That woodland streams are indeed processing systems is nicely illustrated by these particulate organic matter budgets, which to date have been constructed for two very different stream systems. One stream system is in the Eastern Deciduous Forest and is a relatively low gradient stream (14 percent streambed slope), receives the bulk of its litter input in the fall and has a fairly evenly distributed precipitation pattern of about 123 cm/yr. The other stream in the western Cascades coniferous forest, is a high gradient stream (45 percent slope), receives the bulk of its litter input over the summer and fall, and receives 240 cm/yr. precipitation, 90 percent of which falls in a 6-month period between October and March. For both systems, 99 percent of the particulate organic input is detritus or litter, 1 percent or less is contributed by the primary producers. For both streams, 62-63 percent of the detrital inputs are processed by organisms in the stream. Only about one-third of the detrital input is exported out of these small streams (Fig. 3).

In order to determine how this detrital input is processed, a bioassay for detrital consumer activity in streams has been developed and is being used in all three biomes. The basic premise is that forest streams and some desert streams are processors of terrestrial litter. Therefore, measuring how fast leaf material disappears in a given stream under a given set of conditions, provides a sensitive community monitoring strategy. The bioassay consists of attaching packs of leaves or needles to bricks and placing them in the stream to simulate natural leaf accumulations.

This leaf pac method has been used in field experiments on many different species of leaves (Fig. 4). The result is a heirarchy of leaf species along a processing continuum. Leaves of dogwood and alder are 90 percent consumed within 7-8 months. That is, a leaf of these two species entering the stream in September would not be found in a recognizable form or in a leaf pac after April or May. The slow species, such as oak and aspen, take more than 15 months for 90 percent of their material to be processed.

One result of this continuum is the stepwise addition of new sources of food as slower leaf species become functionally available to the stream system. This results in a continuous source of energy to the stream community, even though most leaves enter during a relatively short period in the fall. Additional experiments are being performed with other species of leaves from different forest associations to determine the generality of this continuum.

The leaf pac bioassay provides an easy yet sensitive procedure for evaluating both qualitative and quantitative aspects of the streams' function. Studies of lignin and cellulose content, carbon:nitrogen ratios, nutrient cycling, and respiration have been completed or are underway at the present time. Such refinements have provided a more sensitive indicator of decomposition processes. The technique also allows a comparison of rates of leaf or needle processing and biotic activity in natural benchmark systems and in systems affected by land-use practices.

This concentration of effort on the fate of terrestrial litter has application for stream managementproblems as illustrated by the following two examples. One major problem in stream management today is the protection of streams from excess inputs of organic debris during logging operations, and the removal of such debris that does reach the stream. Adverse effects of excess debris on fish populations have been documented for one clearcut watershed in western Oregon. It is equally obvious from a biological viewpoint that removal of all organic matter from a stream with a bulldozer during a cleanup following logging is not beneficial to the stream community either. Part of the confusion over stream cleanup specifications stems from a lack of understanding of the biological role of detritus in streams. Our research is designed to investigate the appropriate level of organic debris in streams subject to logging, answering the question of how much debris should be left in the stream.

The second example involves the maintenance of intact strips of streamside vegetation during logging operations, which has long been advocated as a measure to preserve fish habitat. Such measures have been recommended for several purposes and their value established. Among the bases for streamside protection have been temperature control, prevention of debris accumulation, and reduction of sedimentation by maintaining an intact streambank. It is clear that streamside vegetation has a significant influence on another important component of fish habitat - the food supply. However, this aspect of fish habitat has received little attention in research on effects of logging.

Much of the previous research on fish habitat in relation to logging has been approached from the physical point of view, i.e., temperature, sediment, dissolved oxygen. Present Biome research is studying related biological aspects of the habitat, specifically the availability of food organisms and the primary energy source, leaf detritus. Our work will provide a basis for evaluating the efficacy of present guidelines for streamside management from the standpoint of an additional component of fish habitat, the detritus-based food chain.

The other energy source in streams is the periphyton or algae. Periphyton as an energy source is very important in desert streams and clearcut watersheds.

A model of periphyton dynamics has been developed which is based on the results of research with periphyton assemblages in laboratory streams and actual field data from streams. Periphyton consists of the various kinds of algae, and their associated fungi, bacteria, and protozoans. The model is designed to provide an insight into the dynamics of an important functional component of the biota in streams, at a level of resolution appropriate to both ecologists concerned with the production of consumer organisms, and land-use managers.

In this model (Fig. 5), there are four state variables: periphyton biomass, terrestrial organic input or litterfall, snail biomass, and biomass of snail fences. The food available to the snail biomass at any time, is the summation of the periphyton biomass and litterfall biomass. These components are coupled with 12 rate variables.

In general, the biomass of periphyton in most small forest streams is relatively low as compared to streams in the deserts. The results of the simulation sequence that includes the physical and chemical parameters of a small stream in Oregon, support the concept that a combination of low light intensity, silt load, and snail grazing can account for the low levels of periphyton biomass that are observed in a woodland stream, Berry Creek (Fig. 6).

The highest rates of primary production, and the greatest accumulation of biomass, occur during early spring after the heavy rains and before the canopy is reestablished. This simulation is supported by field experiments which also found the highest rates of primary production for this stream occurred during March, April, and May.

The model is useful for determining the effects of complete changes in the stream's energy base as a result of clearcutting, when the stream switches from a detrital to an algal energy base. When light is at high levels, such as would occur following clearcutting, or in most desert streams, the periphyton can assimilate large amounts of energy, even though present at low biomass (Fig. 7). The fact that a periphyton biomass ranging from 5-20 $g/m^2$ can support a consumer biomass ranging from 105-130 $g/m^2$ in a heavily shaded stream, is not intuitively obvious. Turnover ratios of periphyton (annual production/mean biomass) may range from 10-70. Thus, a very little periphyton can support a large consumer biomass.

This model, and one developed by the desert biome, are of use in analyzing another management problem, that of stream diversion for irrigation. When the water is removed and stream level lowered, the algae are stranded on the banks where they decompose. The water movement is reduced and the stream stagnates. Fish and invertebrates are killed by the reduction in flow, or forced to leave the area. The problem is one where farmers take water out for irrigation and then, when not using it, let it flow back down the stream. The water flow first decreases very rapidly and remains low for a period of a week or two and then increases very rapidly and stays at a high velocity for a short while. It is the rapid water level fluctuation, especially increases, that disrupt the community and cause large numbers of organisms to be washed away.

The desert biome group has studied the effects of these variations and the magnitude of the problem created. From the study, insight has been gained into how stream and irrigation processes could be better managed so as to be less detrimental to the stream biota. Timing and frequency of fluctuations is important. For instance, when fish are spawning it is detrimental to drop the water level. A stream model developed by the desert biome suggests how often fluctuations can occur. It can tell not only how much water can be removed before causing damage to the biota, but, also, how fast one can raise and lower the water level without causing severe problems. The model can also suggest alternatives ranging from leaving the stream in its natural state, to total use and, therefore, destruction of the stream as a living system. The desert biome stream group has recently been awarded a contract by the Bureau of Reclamation for use and development of this model to help land and water managers in central Utah determine the effects of various management options. Another problem common to desert streams is stream bank erosion by cattle, which results in extreme turbidity several miles downstream. The model can consider this aspect of land use, also.

Both of these models, and the one being developed in the eastern deciduous biome, are consistent with the concept of multiple hypotheses. That is, they are not fully committed to any particular contention about the system of interest but, instead, can be adapted to a particular case in question. Therefore, these general models of flowing water ecosystems will provide structural components that account for the spectrum of conditions that may be encountered in natural streams.

In conclusion, it should be stated that any useful model of a stream ecosystem must be coupled to a model of the surrounding terrestrial environment, as the dynamics of stream communities are intimately associated with the chemical, physical, and biological events taking place on the adjacent watershed. All of the IBP stream models have been designed to couple with watershed or hydrological models. Indeed, a major strength of the biome programs is the interaction between terrestrial and aquatic biologists.

Each of the biome stream programs are looking at different problems in different ways, with different resources. Similarities and differences between the functioning of stream systems are beginning to emerge. Sustained integrated team research is necessary if we are to provide the conceptualization and basic data essential for the intelligent management of our stream systems.

This paper is a result of the ideas and data provided by the various stream groups in the Analysis of Ecosystems Programs. Inquiries about stream biology or problems in a geographical area should be addressed to one or more of the following stream group chairmen:

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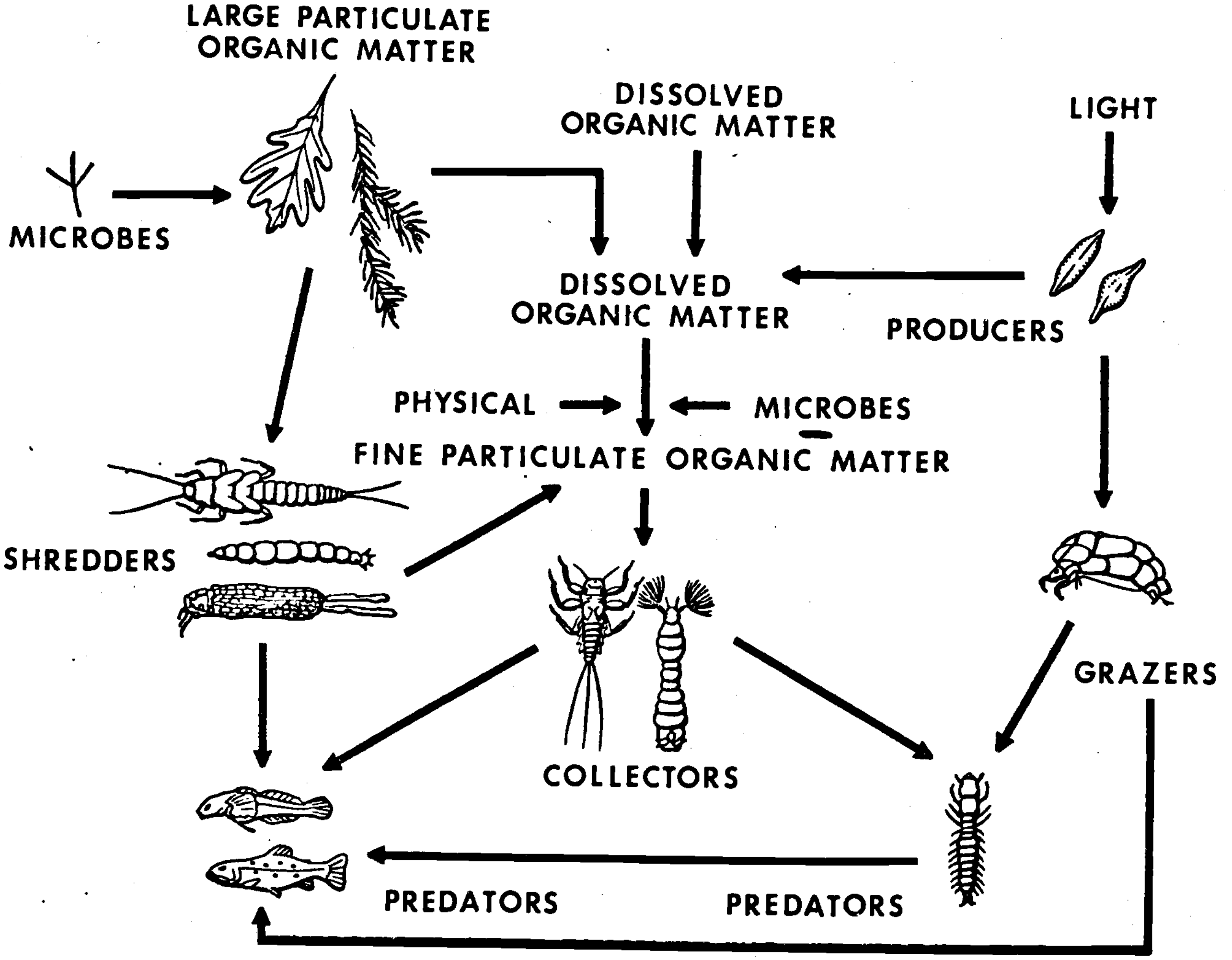

Figure 1. A simplified view of trophic relationships in a woodland stream community. Deciduous leaves, coniferous needles, and photosynthesis by diatoms are utilized, together with soil runoff, as representative of energy inputs to the system. *Pteronarcys*, *Tipula*, and *Pycnopsyche* are shown as typical shredders, *Stenonema* and *Simulium* as collectors, *Glossosoma* as a grazer, and *Nigronia* and the fish *Cottus* and *Salmo* as predators. Litter microbes are characterized by fungi (such as aquatic hyphomycetes) and fine particle microbes by bacteria.

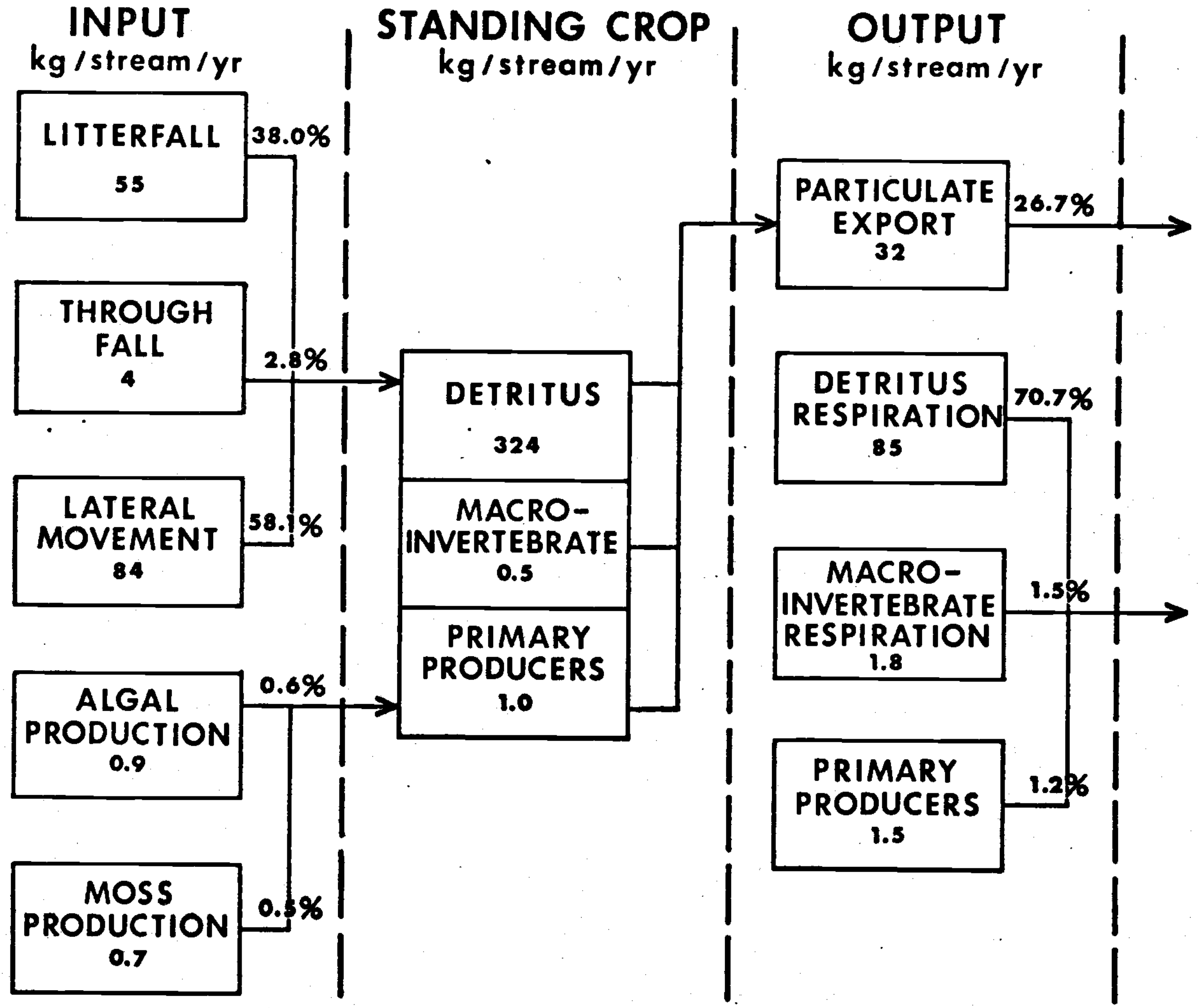

Figure 2. Annual flux of particulate organic material biomass (kg) in a small Cascade stream in Oregon. The percentage value associated with each vector indicates the proportion of total input or output represented.

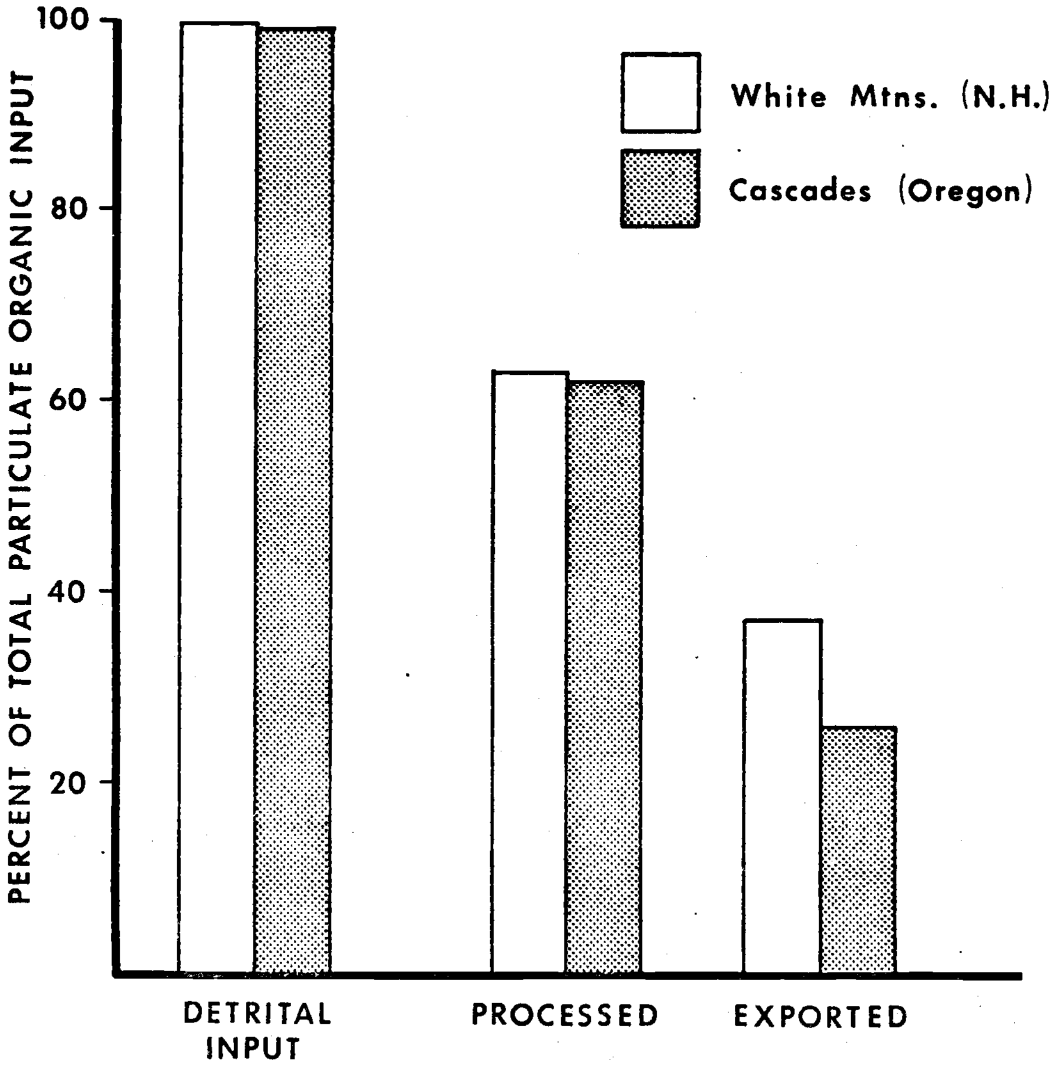

Figure 3. Comparison of particulate organic material input, processing, and export for two small mountain streams, Bear Brook in the White Mtns. of New Hampshire, and Watershed 10 in the Andrews Experimental Forest in the Oregon Cascades.

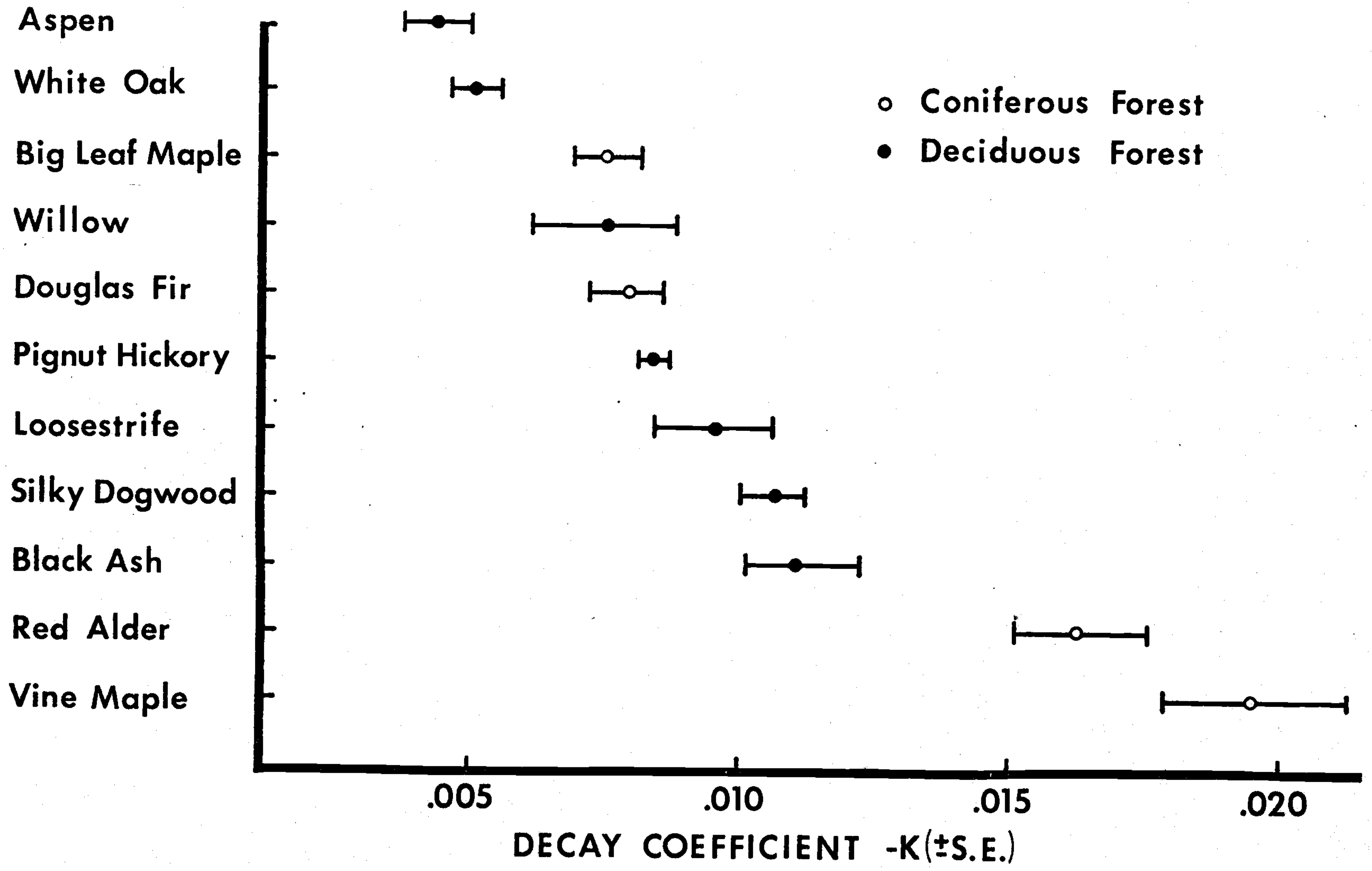

Figure 4. Daily exponential rate of loss of leaf material in streams for two forest sites.

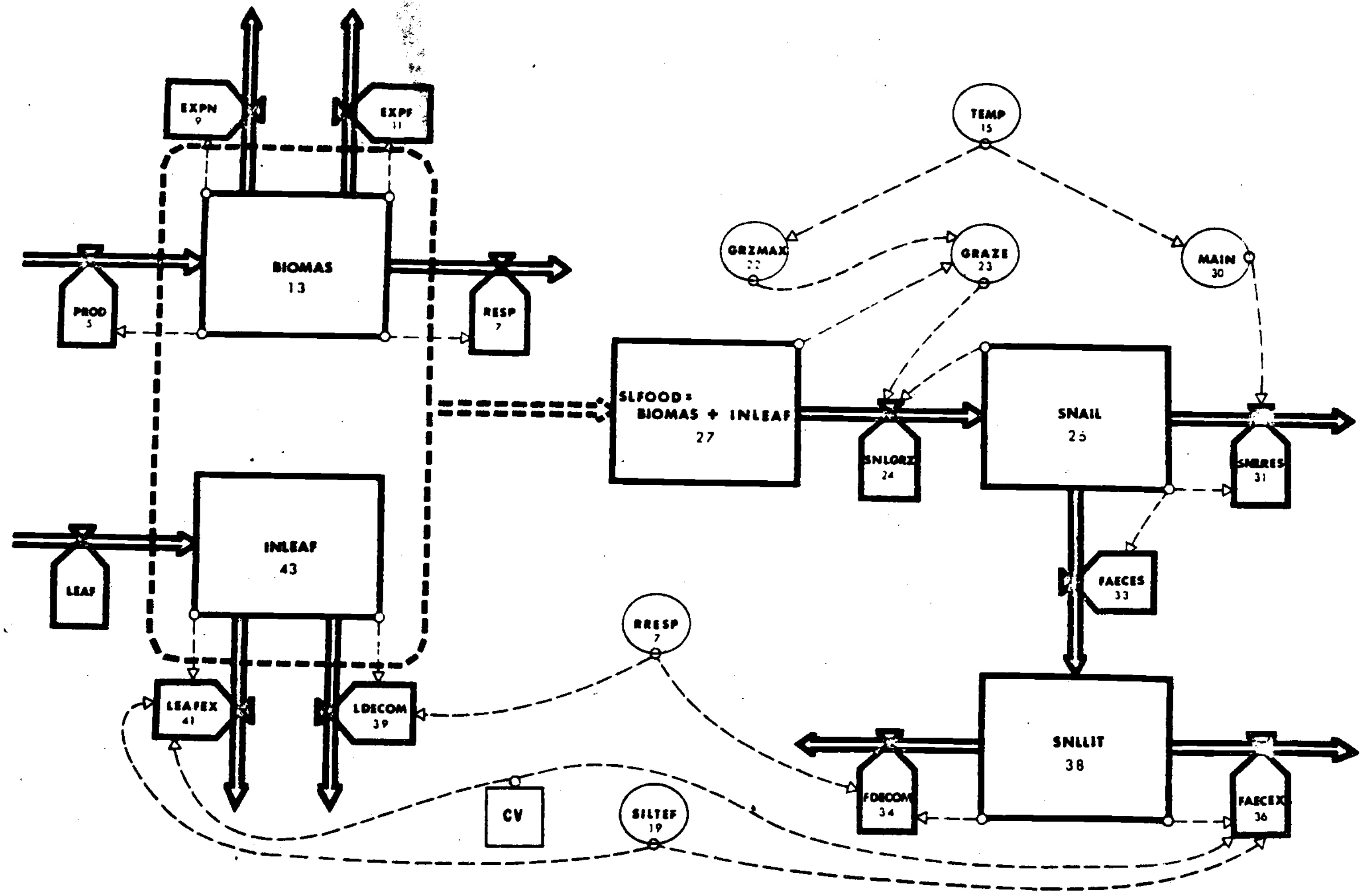

Figure 6.

Figure 5. A systems diagram of a model of periphyton dynamics.

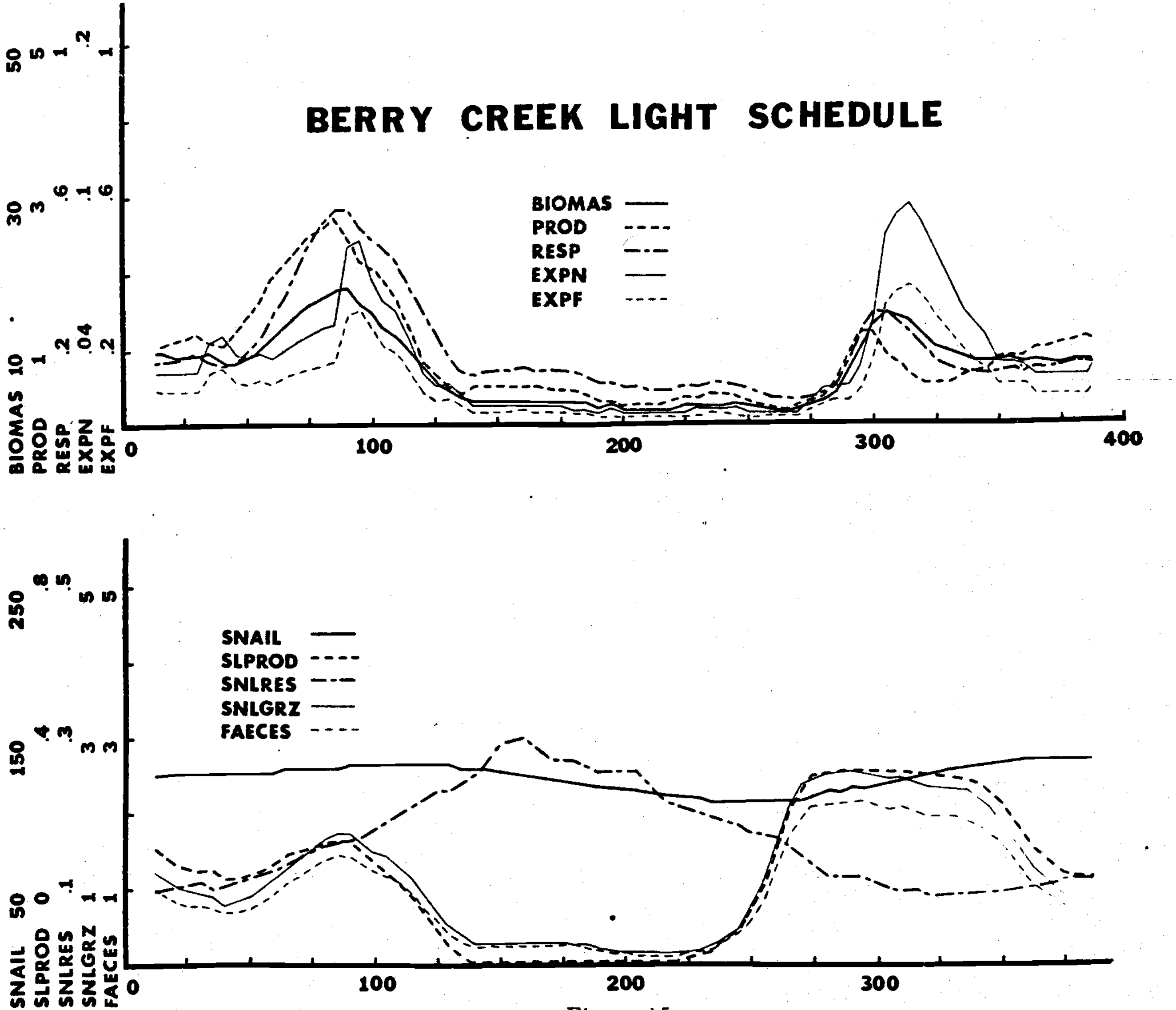

Figure 15.

Figure 6. Seasonal changes in PROD (Primary Production), BIOMAS (Periphyton Biomass), RESP (Periphyton Respiration), EXPN and EXPF (Periphyton Export), SNAIL (Snail Biomass), SLPROD (Snail Production), SNLRES (Snail Respiration), SNLGRZ (Consumption Rate), and FAECES (Deposition of Faecal Material) for a simulation sequence with the Berry Creek (Oregon) light schedule. PROD, RESP, EXPN, EXPF, SLPROD, SNLRES, SNLGRZ, and FAECES are expressed as g glucose $m^{-2}$ $day^{-1}$, and BIOMAS and SNAIL are expressed as g $m^{-2}$.

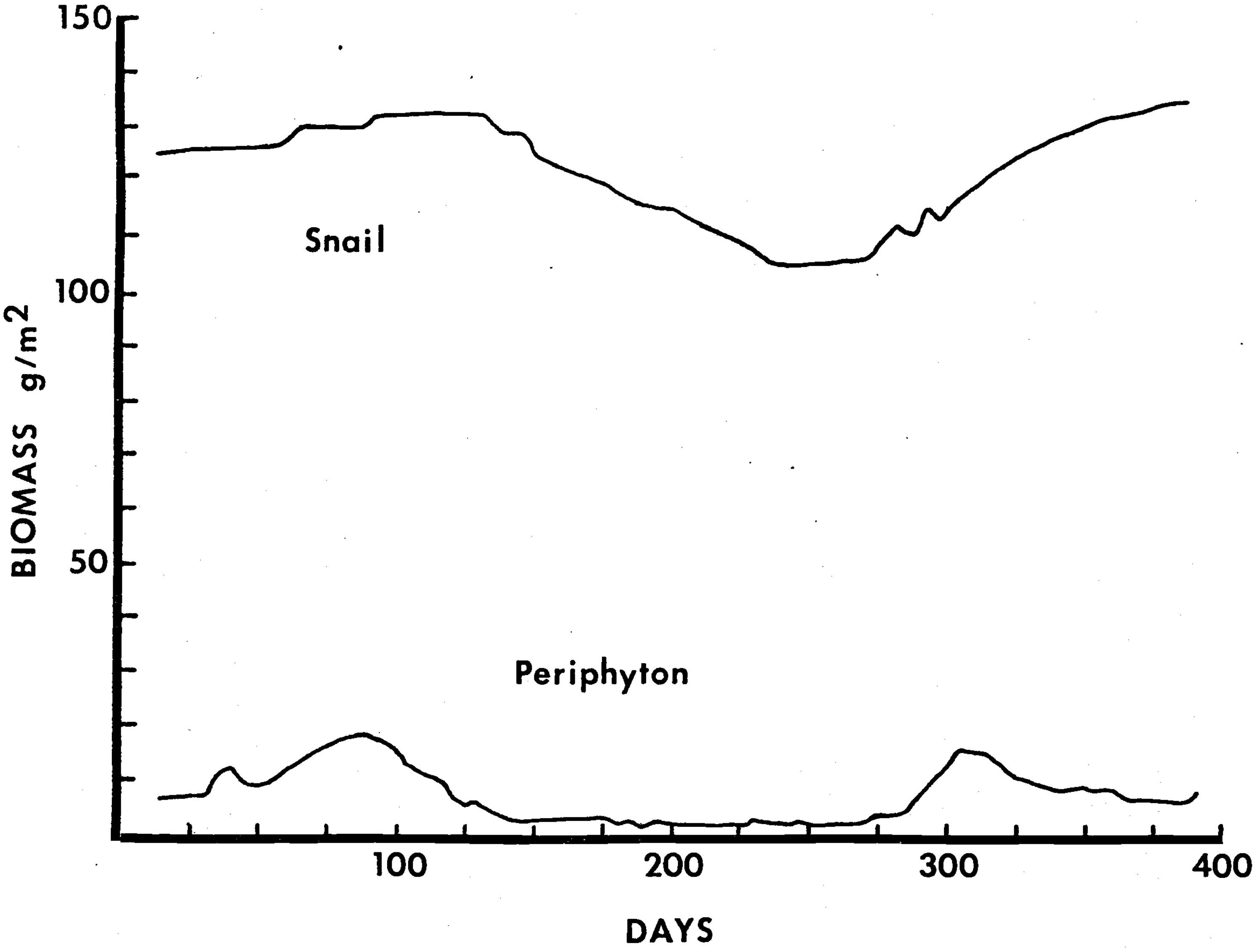

Figure 7. Snail and periphyton biomasses from a computer simulation sequence with the Berry Creek light schedule (from Figure 6).