1728

| Verh. Internat. Verein. Limnol. | 22 | 1842—1846 | Stuttgart, Dezember 1984 |
|---|---|---|---|

# Uptake of dissolved organic carbon in mountain streams

CLIFFORD N. DAHM

With 2 figures and 1 table in the text

## Introduction

The vast majority of organic carbon in streams consists of either dissolved organic carbon (DOC) or detrital particulate carbon, ultimately of terrestrial or aquatic autochthonous origin (CUMMINS 1974; WETZEL 1983). Instantaneous measurements of these components are biased towards recalcitrant fractions which resist microbial or invertebrate utilization. It is the more biologically active fractions, however, which provide most of the energy upon which the stream ecosystem depends.

To study the rates and mechanisms for conversion or transfer within the labile subfractions of organic matter in streams, it is often necessary to devise experimental procedures which focus upon processes affecting known labile components of this material (e.g. NYKVIST 1963; KAUSHIK & HYNES 1971; LOCK & HYNES 1975, 1976; DAHM 1981; ROUNICK & WINTERBOURN 1983). The processing of DOC to either particulate carbon or carbon dioxide is one example where this approach is especially germane, since an active labile fraction and a recalcitrant portion of the DOC are present in most sources of DOC (CUMMINS et al. 1972; WETZEL & MANNY 1972; LOCK & HYNES 1975, 1976; DAHM 1981). Therefore, the differentiation of the labile and recalcitrant fractions of DOC plus problems associated with downstream transport and analytical sensitivity often require the use of either recirculating chambers or experimental streams which confine the stream water and sediment. Using techniques of this type, three factors potentially affecting the rate and efficiency of uptake of DOC in mountain streams are examined in this paper. They include the source of the DOC, the order of stream, and the vegetational structure of the riparian zone.

## Site descriptions

The study streams are located in forested watersheds of the Coast and Cascade Ranges of western Oregon (U. S. A.). Oak Creek is a third order (STRAHLER 1957) stream of low gradient and elevation in the eastern foothills of the Coast Range. A biological research station on Oak Creek was used for experiments with $DO^{14}C$ to determine the effect of different sources on the rates and efficiency of DOC uptake. Sediments and water from both Oak Creek and Ennis Creek, a clearcut first order high gradient stream in the Cascade mountains, were tested.

Three streams in old growth forests of the Cascade mountains were used to test whether stream order affects the rate of DOC uptake. Devil's Club is a first order stream, Mack Creek is a third order stream, and Lookout Creek is a fifth order stream. Characteristics of these streams and their watersheds are summarized in NAIMAN & SEDELL (1979 a, b).

Mack Creek, within an old growth forest dominated by Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Thuja heterophylla*), was also used in the comparison of DOC uptake from streams with distinctly different riparian zones. Quartz Creek, a third order stream in a 30- to 40-year old alder (*Alnus rubra*) stand, and Grasshopper Creek, a third order stream with a clearcut completed in 1977, provided streams with a deciduous canopy and an open sunlit channel, respectively.

## Methods

Enclosed chambers with a recirculating pump (BOTT et al. 1978) were used to measure the rate of uptake of DOC. Approximately 2 kg of stream sediment and 10 l of water were placed into the

0368-0770/84/0022-1842 $ 1.25

chamber. The chamber was then allowed to run for 12—24 h before the addition of DOC. Preparation of the DOC for use in the experiments followed the method of Dahm (1981). Samples were drawn periodically throughout the incubation and then analysed for either DOC (Menzel & Vaccaro 1964) or $DO^{14}C$ (Dahm 1981). Samples were analysed in triplicate and filtration and sample preparation carried out on site within 30 min of collection.

The $DO^{14}C$ was obtained by leaching algae, leaves, and needles grown in $^{14}CO_2$-enriched air or water. The leaves and needles were grown through one full growing season and then dried and frozen until later use. The algae was grown for 72 h in a recirculating chamber with $NaH^{14}CO_3$ added. The algae were removed, dried, and frozen until use.

## Results and discussion

Three sources of $DO^{14}C$ were tested for the rate and efficiency of uptake using first and third order stream sediment and water (Table 1). The three sources included an algal lysate (*Nostoc parmelioides*), alder (*Alnus rubra*) leaf leachate, and Douglas fir (*Pseudotsuga menziesii*) needle leachate. The disappearance of $DO^{14}C$ from solution was then followed for 48 h.

The rate of $DO^{14}C$ uptake was clearly dependent upon the source of the soluble material. The $DO^{14}C$ from the algal material was taken up very rapidly with 60 and 83 % removal within 6 h in the first order and third order stream, respectively. The rate of uptake then slowed and approximately 10 % remained in both stream samples after 24 h. The alder leachate was initially removed at a slower rate than the algal material, but in the third order stream 98 % of the alder $DO^{14}C$ had been taken up over 48 h. A slower rate of uptake occurred in the first order stream with approximately half of the leachate in solution after 48 h. The uptake of $DO^{14}C$ from leachate derived from conifer needles was the slowest. Less than 10 % loss from solution occurred in the first 6 h and at the end of 48 h there remained 65 and 40 % of the $DO^{14}C$ in solutions in the first and third order stream experiments, respectively.

The overall rate of $DO^{14}C$ uptake in Oak Creek was higher than in Ennis Creek for the alder and Douglas fir leachates, although nearly equal temperatures occurred. Numerous factors such as geological setting, sediment characteristics, gradient, elevation, stream order, and the quantity and characteristics of allochthonous inputs from the ri-

Table 1. Uptake of $DO^{14}C$ from the leachate of algae, deciduous leaves, and conifer needles. The values are expressed as per cent taken up of the added $DO^{14}C$.

| Stream | Time (h) | Algae (*Nostoc parmelioides*) | Alder (*Alnus rubra*) | Douglas fir (*Pseudotsuga menziesii*) |
|---|---|---|---|---|
| Ennis Creek[1] | 6 | 60 | 24 | 9 |
| Ennis Creek | 12 | 77 | 28 | 15 |
| Ennis Creek | 24 | 89 | 36 | 21 |
| Ennis Creek | 48 | – | 49 | 35 |
| Oak Creek[2] | 6 | 83 | 25 | 6 |
| Oak Creek | 12 | 85 | 44 | 38 |
| Oak Creek | 24 | 90 | 76 | 53 |
| Oak Creek | 48 | 94 | 98 | 60 |

[1] Stream order 1; 900 m elevation; temperature ranged from 11.5 to 13.5 °C; 2 kg sediment and 10 l water in recirculating chambers.

[2] Stream order 3; 100 m elevation; temperature ranged from 12 to 13 °C; 2 kg sediment and 10 l water in recirculating chambers.

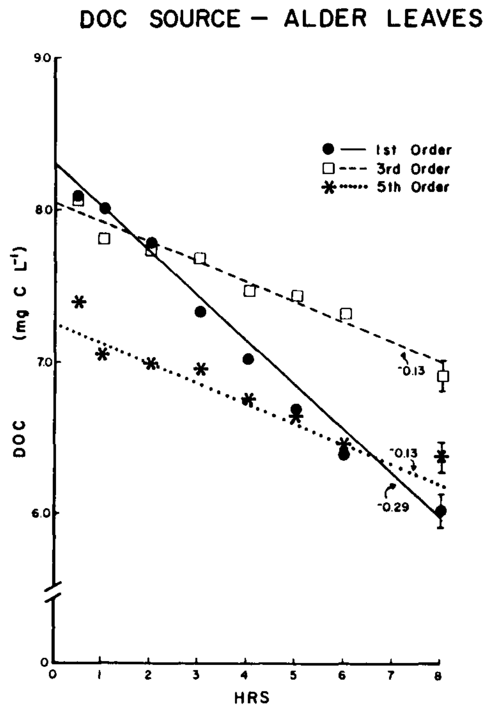


Fig. 1. Uptake of DOC through time in a first, third, and fifth order mountain stream.

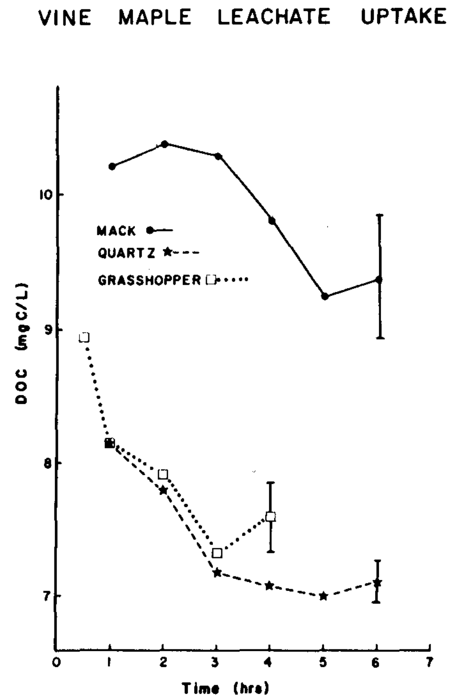


Fig. 2. Uptake of DOC leached from vine maple leaves through time in an old growth conifer, alder, and clearcut mountain stream.

parian zones are possible contributing factors in the rate of uptake of DOC. Two factors, stream order and varying riparian structure, were examined in streams in geologically similar regions with comparable gradients and elevations for a possible effect on DOC removal.

The rate of removal of DOC from alder leachate in a first, third, and fifth order stream is shown in Fig. 1. The rate of uptake in the first order stream was approximately double that measured in the third and fifth order streams. Over an 8 h period, approximately 45 % of the additional DOC (5 mg $C \cdot l^{-1}$) was removed from solution while only 21 % disappeared in the third and fifth order streams. Uptake was linear and amounted to 6 % $\cdot h^{-1}$ in the first order and 3 % $\cdot h^{-1}$ in the third and fifth order systems.

A conclusion that DOC uptake is more rapid in smaller order streams must be made cautiously. It is possible that the more direct linkage between the watershed and small streams results in a microbial population better able to utilize allochthonous sources of DOC such as alder leaves; however, differences in sediment characteristics used in the experiment may also explain these trends. Sediment from the main channel of the first order stream was mainly fine sand and gravel, while larger gravel and cobble were present in the third and fifth order streams. A response due to increased surface area with the same weight of sediment could also explain the data. Also, the larger streams have complex channel structure with backwaters, side channels, and debris dams where more active uptake may occur. Direct addition of DOC in association with a conservative tracer followed by measurement of DOC disappearance over equidistant reaches of stream will better resolve the role of stream order in DOC uptake.

The effect of the structure of the riparian zone on DOC uptake was tested using leachate from vine maple (*Acer circinatum*), a species present in all the test watersheds. The background concentration was increased by 6 mg $C \cdot l^{-1}$ in recirculating chambers containing sediment and water from three third order streams. The initial response in both the open clearcut stream (Grasshopper Creek) and in the alder dominated watershed (Quartz Creek) was a steady decrease in DOC (Fig. 2). The stream in an old growth forest (Mack Creek) showed little decrease in DOC over the first three hours with a gradual decrease thereafter. The uptake amounted to a 34, 32, and 7% loss of the added leachate in the clearcut, alder, and old growth watersheds over the first 4 h of incubation.

Two potential mechanisms to explain the slower uptake of DOC in the old growth forest are a more limited supply of labile DOC or a greater concentration of inhibitory compounds such as polyphenols and terpenes in the stream. A more active microbial population might be present in the stream within a clearcut, where increased algal production occurs, and in the stream within a deciduous forest, where throughfall and litter quality provide a labile allochthonous source of DOC. Conversely, the throughfall and leachate from the old growth coniferous forest may well be enriched in inhibitory secondary plant metabolites and suppress microbial activity. The data does not allow differentiation between these possible mechanisms for explaining the different rates of DOC uptake in the streams.

The organic rich films which adhere to sediment surfaces in streams have been shown to be an important nutritional resource for aquatic insects (Madsen 1972, 1974; Calow 1975; Karlström 1978; Rounick & Winterbourn 1983). These organic layers are complex layered structures containing algae, bacteria, fungi, adsorbed and trapped organic detritus, and extracellular material of algal and bacterial origin. These structures also can form in the dark without the presence of algae when adequate concentrations of DOC exist (Rounick & Winterbourn 1983). In addition, Rounick & Winterbourn (1983) showed that the surface organic layers on stones are efficiently assimilated by several common stream invertebrates. The source and concentration of the DOC within the stream water affects the rate of formation and the structure of these organic rich zones which occur at the interface between the streambed and stream water. The uptake of DOC at such surfaces also provides a mechanism whereby DOC is retained within the stream and potentially made available to consumer organisms. The overall importance of these processes to stream ecosystems remains to be addressed.

The microbial uptake of DOC provides one pathway by which this potential source of energy is utilized within the stream. The efficiency of this process is strongly a function of the source of the DOC. The structure and vegetational composition of the riparian zone also affects the rate of DOC uptake both directly through the types of organic inputs and indirectly by controlling the amount of sunlight reaching the stream. The order of the stream may also influence the rate and efficiency of DOC uptake; however, sediment size and type, and the structural complexity of the stream may ultimately be more important than size.

## Acknowledgements

I thank Amelia K. Ward and Ken W. Cummins for helpful discussions and constructive criticism. Richard J. Kepler, Susie Philipp, Marcy Liljeberg, and Rhea L. Graham provided excellent technical support. Research was supported by the U.S. National Science Foundation grants DEB 7923444 and DEB 8112455. This is Riparian contribution no. 5.

## References

Bott, T. L., Brock, J. T., Cushing, C. E., Gregory, S. V., King, D. & Petersen, R. C., 1978: A comparison of methods for measuring primary productivity and community respiration in streams. — *Hydrobiologia* **60:** 3—12.

Calow, P., 1975: On the nature and possible utility of epilithic detritus. — *Hydrobiologia* **46:** 181—189.

Cummins, K. W., 1974: Structure and function of stream ecosystems. — *BioScience* **24:** 631—640.

Cummins, K. W., Klug, M. J., Wetzel, R. G., Petersen, R. C., Suberkropp, K. F., Manny, B. A., Wuycheck, J. C. & Howard, F. O., 1972: Organic enrichment with leaf leachate in experimental lotic ecosystems. — *BioScience* **22:** 719—722.

Dahm, C. N., 1981: Pathways and mechanisms for removal of dissolved organic carbon from leaf leachate in streams. — *Can. J. Fish. Aq. Sci.* **38:** 68—76.

Karlström, U., 1978: Role of the organic layer on stones in detrital metabolism in streams. — *Verh. Internat. Verein. Limnol.* **20:** 1463—1470.

Kaushik, N. K. & Hynes, H. B. N., 1971: The fate of dead leaves that fall into streams. — *Arch. Hydrobiol.* **68:** 465—515.

Lock, M. A. & Hynes, H. B. N., 1975: The disappearance of four leaf leachates in a hard and soft water stream in South Western Ontario, Canada. — *Int. Rev. ges. Hydrobiol.* **60:** 847—855.

— — 1976: The fate of "dissolved" organic carbon derived from autumn-shed maple leaves (*Acer saccharum*) in a temperate hard-water stream. — *Limnol. Oceanogr.* **21:** 436—443.

Madsen, B. L., 1972: Detritus on stones in small streams. — *Mem. Ist. Ital. Idrobiol. Suppl.* **29:** 385—403.

— 1974: A note on the food of *Amphinemura sulcicollis* (Plecoptera). — *Hydrobiologia* **45:** 169—175.

Menzel, D. W. & Vaccaro, R. F., 1964: The measurement of dissolved organic and particulate carbon in seawater. — *Limnol. Oceanogr.* **9:** 138—142.

Naiman, R. J. & Sedell, J. R., 1979 a: Characterization of particulate organic matter transported by some Cascade Mountain streams. — *J. Fish. Res. Bd. Can.* **36:** 17—31.

— — 1979 b: Benthic organic matter as a function of stream order in Oregon. — *Arch. Hydrobiol.* **87:** 404—422.

Nykvist, N., 1963: Leaching and decomposition of water-soluble organic substances from different types of leaf and needle litter. — *Studia Forestalia Suecica* **3:** 1—31.

Rounick, J. S. & Winterbourn, M. J., 1983: The formation, structure and utilization of stone surface organic layers in two New Zealand streams. — *Freshwater Biol.* **13:** 57—72.

Strahler, A. N., 1957: Quantitative analysis of watershed geomorphology. — *Trans. Amer. Geophys. Union* **38:** 913—920.

Wetzel, R. G., 1983: *Limnology.* — Saunders College Publ., Philadelphia, 767 pp.

Wetzel, R. G. & Manny, B. A., 1972: Decomposition of dissolved organic carbon and nitrogen compounds from leaves in an experimental hard-water stream. — *Limnol. Oceanogr.* **6:** 927—931.

Author's address:

C. N. Dahm, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon 97331, U.S.A.