THE EFFECT OF FOREST CLEARCUTTING IN

NEW ENGLAND ON STREAM-WATER CHEMISTRY

AND BIOLOGY

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ABSTRACT

Changes in stream chemistry following clearcutting were sought in 56 streams at 15 locations throughout New England. Streams draining clearcut areas were compared with nearby streams in uncut watersheds over periods of up to 2 years. In general, concentrations of all elements studied (inorganic N, SO_4 - S, Cl, Ca, Mg, K, Na), as well as pH and specific conductivity, varied as much among uncut streams at a location as between uncut and cutover streams. However, at most locations, at least one of these variables differed between uncut and cutover streams. The greatest differences occurred with nitrogen in northern hardwood forests in the White Mountains of New Hampshire. At 4 of the locations the effect of cutting on algae and invertebrates in the streams were also examined. Both algal and invertebrate densities were greater in cutover streams by factors of 2 to 4, probably because of increased light and temperature. The taxonomic composition of both algal and invertebrate populations was also changed by cutting. Partial cuts and sufficiently wide buffer strips can minimize both chemical and biological changes.

Keywords: *Forest hydrology, logging, nutrient cycling, water pollution, *watershed management

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Buffer strips -
>   Trees left along both sides of a stream within a clearcutting

Central hardwood forest -
>   Primarily composed of several species of oaks, hickories, and red maple.

Clearcutting -
>   Harvesting of most trees larger than 5 cm DBH.

Coniferous forest -
>   Primarily composed of red, white or black spruce and balsam fir with inclusions of white pine and northern wide cedar.

Detritus -
>   Dead particulate organic matter and associated fungi, bacteria, protozoa, and other microscopic invertebrates.

Diatoms -
>   Algae with cell walls made of silica.

Macroinvertebrates -
>   The invertebrates which live in, on, or near the bottom of the stream. They include insects, crustaceans, clams, snails, oligochaete worms, and leeches.

Nitrogen -
>   Nitrate nitrogen ($NO_3 - N$) plus ammonium nitrogen ($NH_4 - N$).

Northern hardwood forest -
>   Primarily sugar maple, yellow birch and beech.

pH -
>   A logarithmic measure of hydrogen ion activity.

Reference watershed -
>   Watersheds that have had no timber harvesting on them during the past 35 years.

Specific conductance -
>   A measure of a solution's ability to conduct electricity because of the substances dissolved in it, expressed in μmhos/cm.

Stem-only harvesting -
>   Clearcutting with the removal of only the trunks of the trees from the woods. The limbs, tops, and leaves remain in the woods.

Whole-tree havesting -
>   Clearcutting with most above-ground parts of the trees removed from the woods.

ACKNOWLEDGEMENTS

INTRODUCTION

Forest management is classified as one of several non-point sources of water pollution in Section 208 of Public Law 92-500. Forest practices may influence stream-water quality by causing changes in temperature, sedimentation, eutrophication, and pesticide contamination. Pesticide effects were beyond the scope of this study. The effects of increased sedimentation on stream-water quality and stream biology have been documented (Bjornn et al. 1977; Cordone and Kelly 1961; Patric 1976; Tebo 1955). Methods are available for controlling temperature changes (Burton and Likens 1973) and for controlling sedimentation and erosion (Conners and Born 1978; Hartung and Kress 1977; EPA 1973; Winkelaar 1971; Kochenderfer 1970; Haussman 1960; Trimble and Sartz 1957). The nutrient status of forest streams is a more recently recognized problem, and the impact of pollutants on stream biota is not fully understood.

Although most forest practices have some impact on nutrients in streams, timber harvesting is the most widespread practice and is likely to be of greatest consequence in the near future. Timber harvesting reduces nutrient uptake, accelerates mineralization and nitrification and organic matter breakdown, and increases soil moisture and water yield. All these factors can lead to greater nutrient leaching and increased ion concentration in streams.

Assessing the impacts of clearcutting is particularly important because this practice is widely applied and has greatest potential for changing water quality. Also, clearcutting in New England is likely to become more widespread because of (1) greater demand for wood fiber and ways to obtain it more cheaply, (2) use of wood for energy and organic derivatives, and (3) increased mechanization of timber-harvesting operations.

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Cutting the forest can interrupt the nutrient-regulating ability of the system and bring about increased leaching of ions into streams (Bormann and Likens 1967). An extreme example was the forest clearing study at Hubbard Brook. Complete devegetation for 3 years resulted in higher nutrient levels in the stream due to acceleration of the nitrification process and more rapid decomposition of organic matter (Likens et al. 1970). Nitrate concentration in stream water rose 50 times on the average and reached a maximum concentration of 80 mg/l. Major cations rose 3- to 20- fold (Pierce et al. 1970).

The Hubbard Brook study stimulated research concerning nutrient outputs in streams from commercially cut forests at many locations in the eastern United States (Corbett et al. 1978). These studies indicated that forest cutting, and especially clearcutting, will usually change stream chemistry, although the amount of the change is highly variable. Stone (1973) and Reinhart (1973) have suggested that the consistently greater changes obtained in New Hampshire than at other locations in the East may be caused by such factors as: natural soil fertility; mineral soil depth, depth and type of organic accumulations, soil acidity; precipitation; and species, timing, and distribution of plant regrowth. Cole et al. (1975) have shown that the leaching of ions after clearcutting is dependent on whether chemical reactions in the soil favor the formation of mobil anions and thus facilitate the transport of cations. Whatever the causal factors, the studies point to a need for further quantifying changes in stream chemistry based on both geographical location and environmental parameters.

Changes in light, temperature, chemistry, organic inputs, and sediment loads of streams following timber harvesting may alter the biology of streams. The effects of clearcutting on macroinvertebrates have been

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studied in northern California (Newbold 1977; Burns 1972), Oregon (Murphy 1979; Grafius 1976); Idaho (Edington 1969), the southern Appalachians (Tebo 1955) and New Hampshire (Thornton 1974). Generally, opening up the forest canopy by logging causes increases in macroinvertebrate density (Newbold 1977; Burns 1972), unless sedimentation is severe enough to cause reductions (Tebo 1955).

Effects of clearcutting of forests on stream algae have been studied in Oregon by Hansmann and Phinney (1973) and Lyford and Gregory (1975), and in less detail by several others (Murphy 1979; Newbold 1977). In these studies, clearcutting was followed by increases in periphyton standing crop and production, and by changes in the composition of the algae community.

OBJECTIVES

The objectives of this study were to:

(1) quantify the magnitude of the differences in stream chemistry between uncut and clearcut areas over a broad spectrum of vegetative cover, soil, geologic types, and harvesting practices throughout New England, and (2) to determine the effect of clearcutting, with major removal of streamside vegetation, on algal and macroinvertebrate populations in the streams involved.

We accomplished both of the objectives through the development of a regional survey of chemistry and biology in streams draining clearcut areas throughout New England. Stream chemistry was measured for a wide range of site, vegetation, and logging characteristics. Several of these streams were selected for the study of aquatic organisms. The goal of the study was not to determine whether clearcutting causes changes in stream chemistry; that has already been documented (Corbett et al. 1978). Our objective was to sample extensively as many different situations as possible to indicate the relative magnitude of change and particularly to look for those geologic, soil, and vegetation types where major changes occurred. A typical question that we wanted to answer was: Does clearcutting in the spruce-fir forest on poorly drained soils derived from sedimentary rock produce such a major change in stream chemistry as occurred in the White Mountains of New Hampshire, or does it produce minor changes such as have been reported elsewhere?

WATER CHEMISTRY STUDY

Methods

We selected groups of watersheds with similar forest cover, soils, geology, topography, and history with perennial streams in each. As a reference, at least one of each group had no recent cutting history. In the northern hardwood forest, stream chemistry should be similar to that for "virgin" forests by 35 years after cutting (Leak and Martin 1975). The other watersheds in the group had been partly or totally clearcut less than 2 years before the beginning of the study. Maximum changes in stream chemistry are known to occur in the first or second years (Martin and Pierce 1980).

We did not require that the entire watersheds be clearcut, because Martin and Pierce (1980) showed that valuable information can be gained from watersheds that were partially clearcut. Clearcutting was defined as a logging operation where most stems larger than 5 cm dbh were cut. Most logs and pulpwood greater than about 10 cm in diameter were removed from the site. Most limbs, tops, and trees less than 10 cm dbh were left on the ground. Whole tree harvesting is similar, except that most above-ground parts of trees 10 cm dbh and larger are entirely removed from the woods--trunk, limbs, leaves and needles.

We contacted Federal, State, and private land managers in all of the New England states. We were unable to locate suitable sites in Massachusetts and Rhode Island. Timber is harvested by other methods in those states, and most clearcutting is for urban development. We were able to locate sites in the central hardwood forest (oak-hickory-red maple) of Connecticut. Clearcutting is being practiced there to harvest forests

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that have been repeatedly defoliated by gypsy moths. In northern New England, clearcutting is practiced regularly on both public and private land. In all, we located 15 sites (Figure 1) and 56 watersheds (Appendix, Table 5) that generally satisfied our criteria.

The cuttings done in Connecticut, New Hampshire, and Vermont were stem-only harvests except at Victory, Vt. (V). The Victory site and all Maine sites except at TBR10 (□) were whole-tree harvests. Site TBR10 (□) was a stem-only commercial clearcut where only those trees 10 cm dbh and larger were cut. We accepted this site because it was the only intensively harvested northern hardwood site we could find in northern Maine.

We were able to find very few watersheds in New England that were entirely clearcut. Most sites had less than 50 percent of the area cut (Appendix, Table 5). Generally cuttings were confined to areas between streams. If cutting was done on both sides of a stream, a buffer strip of trees usually was left along the stream. Often the headwater sections of watersheds were not cut because they were either too swampy or too steep and rocky. Some were cut in strips.

We collected a single water sample from each of our stations in the months of February, April, June, August, October, and November during 1 or 2 years from 1978 to 1980. The number of samples collected varied among locations but not among streams within a location. February represented the midwinter low flow period under the snowpack; April represented the snowmelt period; June, the growing season while streams were still reasonably high; August, the midsummer low flow period; October, the soil moisture recharge period; and November, the high stream flow period before snowfall.
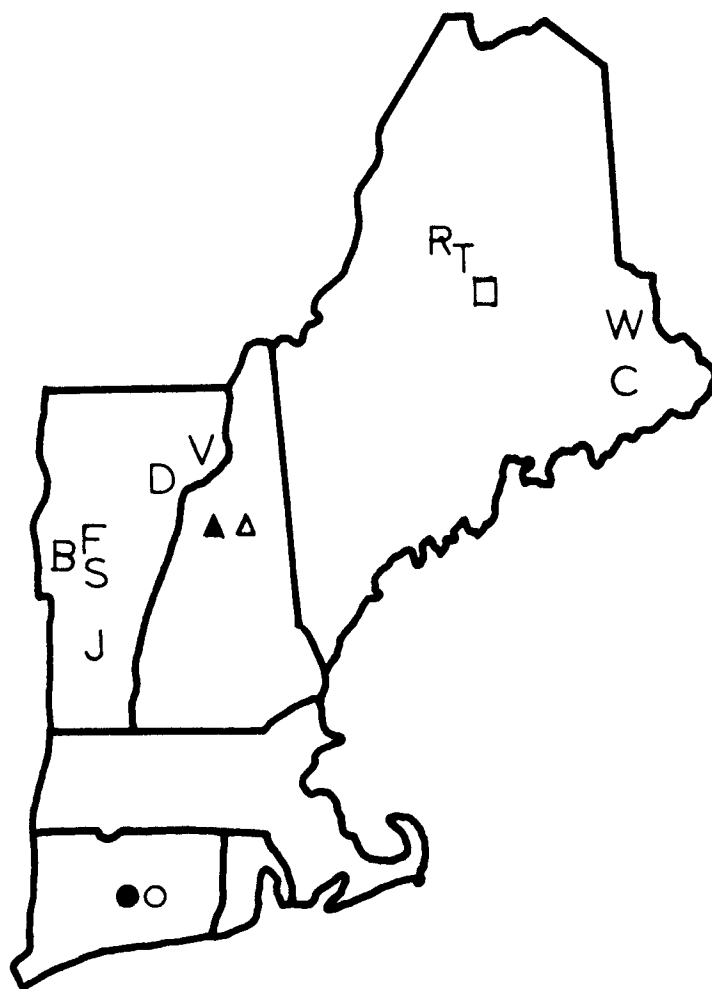
Figure 1: Map of the 15 research areas. The symbols refer to sites listed in Appendix, Tables 5 and 6. The same symbols are used in Figures 2-10.

Water samples were collected from the streams with 500 ml polyethylene bottles. The samples were refrigerated briefly until the chemical analyses were performed. Nitrate, sulfate, ammonium, and chloride analyses were run on a Technicon AutoAnalyzer II[1]. Magnesium, calcium, sodium, and potassium concentrations were determined on a Perkin-Elmer 306 atomic absorption spectrophotometer. The pH determinations were made in the laboratory on a Corning Digital 110 pH meter and conductivity determinations on a Lab-Line Lectro Mho meter.

All streams at a given location (Appendix, Table 5) were sampled simultaneously. Streams at different locations were sampled at different times because some were not located until later in the study, some dried up, and because of travel restrictions. Therefore it was impossible to test for differences among locations. All we can do is look at general trends in Figures 2 to 10.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Results

Our study sites were located in three broad forest cover types: coniferous--mainly spruce, fir and cedar; northern hardwood--mainly maple, birch and beech; and central hardwood--mainly oak, hickory, and maple. The largest clearcuts were in the coniferous forest and the smallest were in the central hardwoods. The site headings in Table 5 describe the predominant soils and geology of the areas.

Specific Conductivity

Within the coniferous forest sites the conductivity of the streams draining from uncut watersheds ranged from 20 to 34 μmhos (Table 5) in Maine and from 57 to 113 unhos in Vermont (Figure 2). The higher values in Vermont reflect the calcareous influence in the soils. At Ragmuff (R) and Telos (T), Maine, the conductivity in the streams from watersheds with more than 55 percent of the area harvested was less than from reference watersheds. In the coniferous forests of Vermont, there were differences between the streams draining reference watersheds and those from harvested watersheds. In two cases, conductivity was higher in the cutting but in one case it was lower.

The mean conductivities of the reference streams in northern hardwood forest ranged from 22 to 49 μmhos. There were no large differences in conductivity levels between reference streams and those from watersheds with less than 50 percent of the area cut. In the White Mountains of New Hampshire, the conductivity in the streams from the completely clearcut watershed was higher than from the reference watershed.

There were no large differences in the conductivities between any of the harvested streams and their references in the central hardwood forest of Connecticut.

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Figure 2: Specific conductance in μmhos/cm by the percent of the watershed area cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.
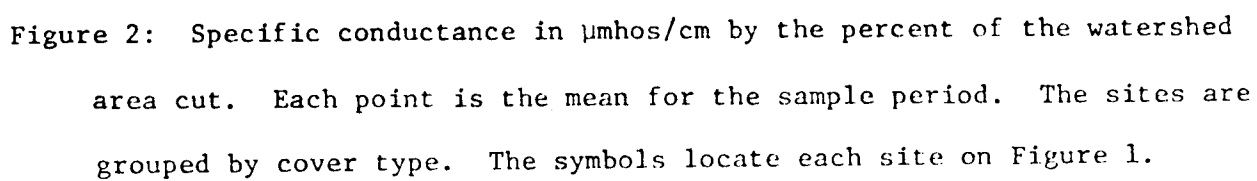
pH

In the coniferous forest of Maine, the average pH of the reference streams ranged from 5.5 to 6.4 (Table 5). At Ragmuff, Maine (R), the mean pH of the streams from watersheds with more than about 30 percent of their area cut were nearly a whole pH unit more acidic than the references, a drop from 6.4 to 5.5. In eastern Maine, (W,C), the streams from the cuts were slightly less acidic than those from the references. In the coniferous forest sites of Vermont, the average pH of the reference streams ranged from 6.8 to 7.4. The differences between cutover and reference areas were small and inconsistent.

The mean pH of the reference streams in the northern hardwood forest ranged from 4.9 to 7.1 (Figure 3). The mean pH of the streams from harvested watersheds ranged from 5.0 to 7.1. Given the variability between reference watersheds on similar soils and with similar land area, differences between reference and treatment streams were not obvious.

At one site in the central hardwood forest, the pH of the streams from the harvested areas were similar to the references. In the other, the streams draining the cuts were less acidic than the references.

Inorganic Nitrogen

In the coniferous forests of Maine and Vermont, mean inorganic nitrogen (nitrate plus ammonium) concentrations in reference streams ranged from less than 0.05 mg/l to 0.2 mg/l (Table 5). None of the streams draining harvested sites in Maine were different from the references with respect to nitrogen (Figure 4). In Vermont, nitrogen was higher in the treatment stream than in the reference stream at Danville (D), but was lower at the Sucker Brook (B) site.

Figure 3: The pH is plotted against percent of the watershed area cut.
Each point is the mean for the sample period. The sites are grouped by
cover type. The symbols locate each site on Figure 1.

In the northern hardwood sites, reference concentrations of nitrogen ranged from less than 0.05 mg/l to 0.8 mg/l. Nitrogen concentrations in the harvested watershed in central Maine were similar to those from the reference. In the White Mountains of New Hampshire, there were differences in the concentrations of nitrogen from those watersheds with at least 40 percent of the area cut. The White Mountain watershed that was entirely harvested produced the most nitrogen measured during the study (Table 6). In the northern hardwood sites of Vermont, nitrogen concentrations in reference streams ranged from 0.4 to 0.8 mg/l and treatment concentrations ranged from 0.1 to 1.1 mg/l. Some treatment streams had higher levels of nitrogen, some were similar to references, and at one (Fassett Place - F) the nitrogen levels in the treatment were lower than the reference. At the central hardwood sites all streams had nitrogen concentrations of less than 0.05 mg/l except for the entirely clearcut watershed which went up to 0.1 mg/l with a maximum single value of 0.3 mg/l.

Sulfate-sulfur

Sulfur concentrations in streams from clearcuts were similar to the references at the coniferous sites. In the northern hardwood sites in New Hampshire, sulfur concentrations were lower in the cuts than in the references. In the northern hardwood sites of Vermont and the central hardwood sites of Connecticut, sulfur concentrations were lower than reference levels in some cuts, similar at most sites, and higher in two cases (Figure 5).

Chloride

In the coniferous forest sites of Maine, chloride concentrations tended to be higher in the streams from the harvested watersheds than from the references. Chloride concentrations were lower in the clearcut coniferous

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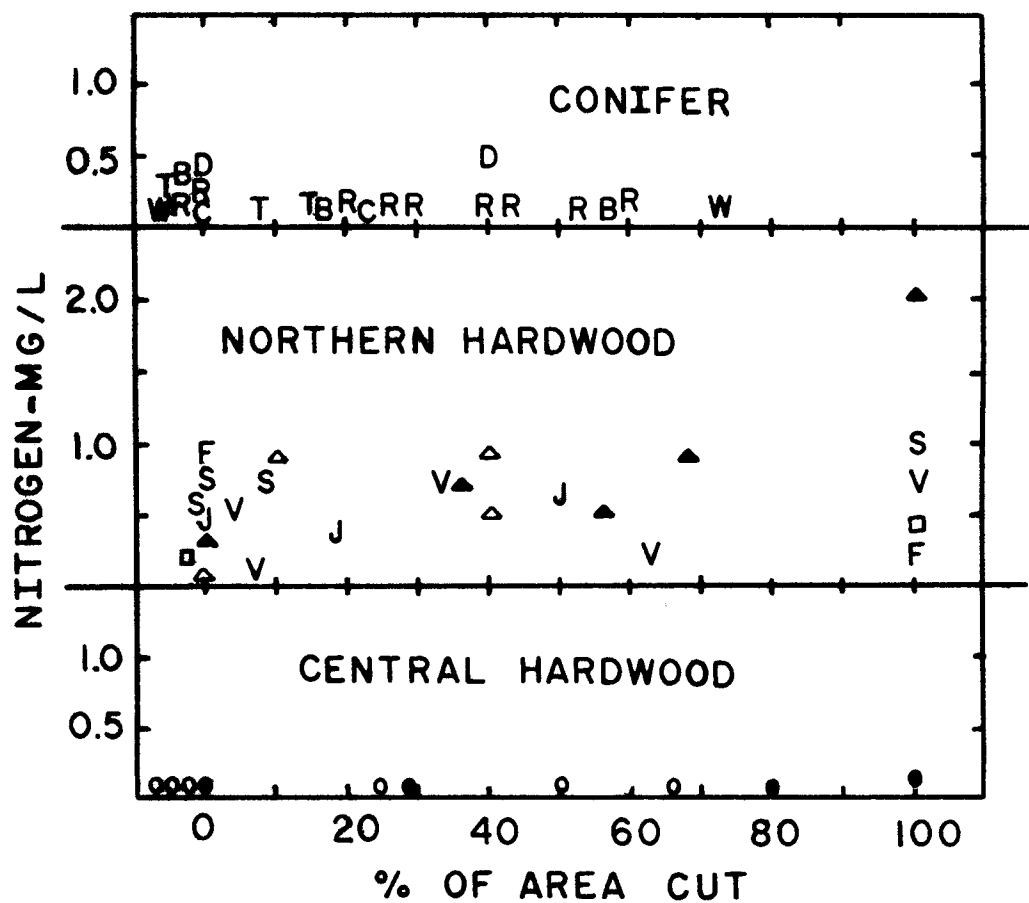
Figure 4: Nitrogen ($NO_3 - N + NH_4 - N$) in mg/l plotted against percent of the watershed area cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.
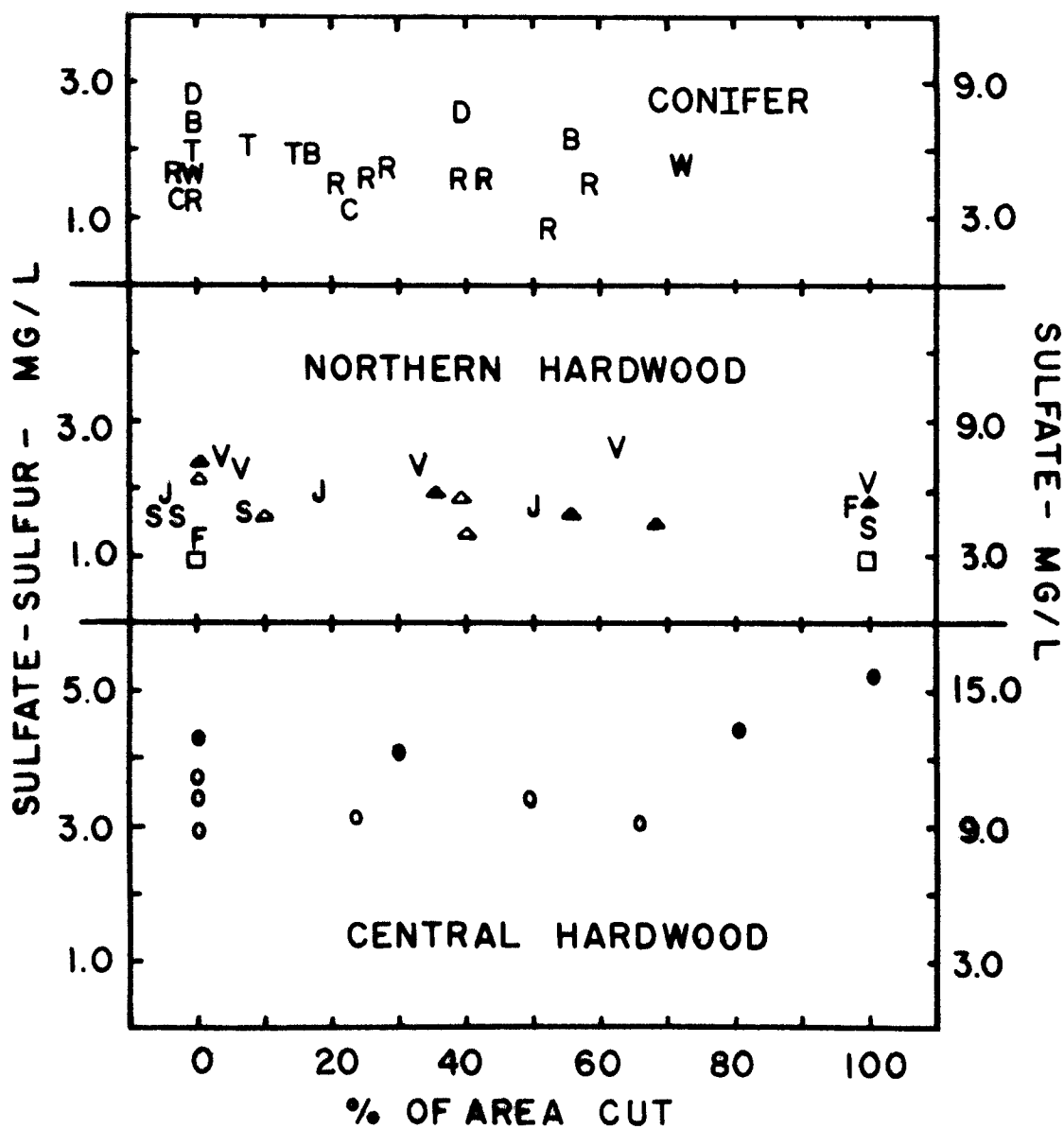
Figure 5: Sulfate-sulfur concentrations in mg/1 plotted against percent of the watershed area cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.

watersheds of Vermont than in their reference watersheds (Table 5).

In both the northern hardwood sites and the central hardwood sites, chloride concentrations were essentially the same in reference streams and those from clearcuts of all sizes (Figure 6). But maximum chloride values from Victory, Vt. (V) were higher in the treatment than in the reference (Table 6).

Calcium

Calcium concentrations in reference streams ranged from about 1.5 mg/1 in the central hardwood sites in Connecticut to about 18 mg/1 in the calcereous soils of Vermont (Figure 7). In the coniferous forest, calcium concentrations in streams from clearcuts were similar to the references except at Ragmuff (R) and Sucker Brook (B). Streams from watersheds with more than 30 percent of the area clearcut at Ragmuff (R) contained less calcium than the references. At Sucker Brook (B) the results were inconsistent.

In the northern hardwood forest of New Hampshire and the central hardwood sites, more than about 60 percent of a watershed had to be clearcut before calcium concentrations became much higher than in the references. No large differences were readily apparent in any of the hardwood sites in Vermont.

Magnesium

Mean magnesium concentrations were similar in reference streams and in streams from clearcuts over the entire region (Figure 8).

Sodium

Sodium concentrations did not seem to change much because of timber harvesting anywhere in New England (Figure 9).

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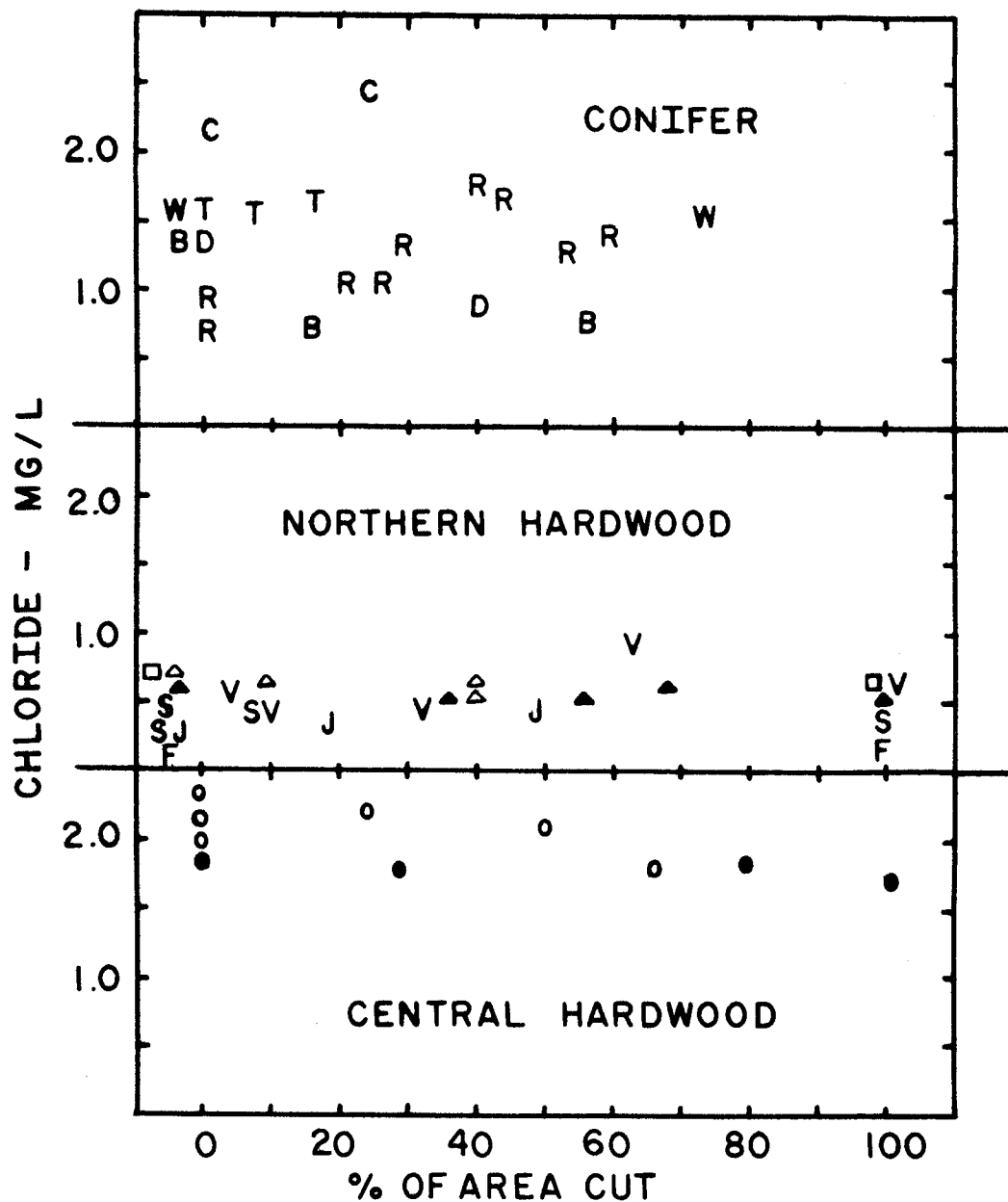
Figure 6: Chloride concentrations in mg/l plotted against percent of the watershed area cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.
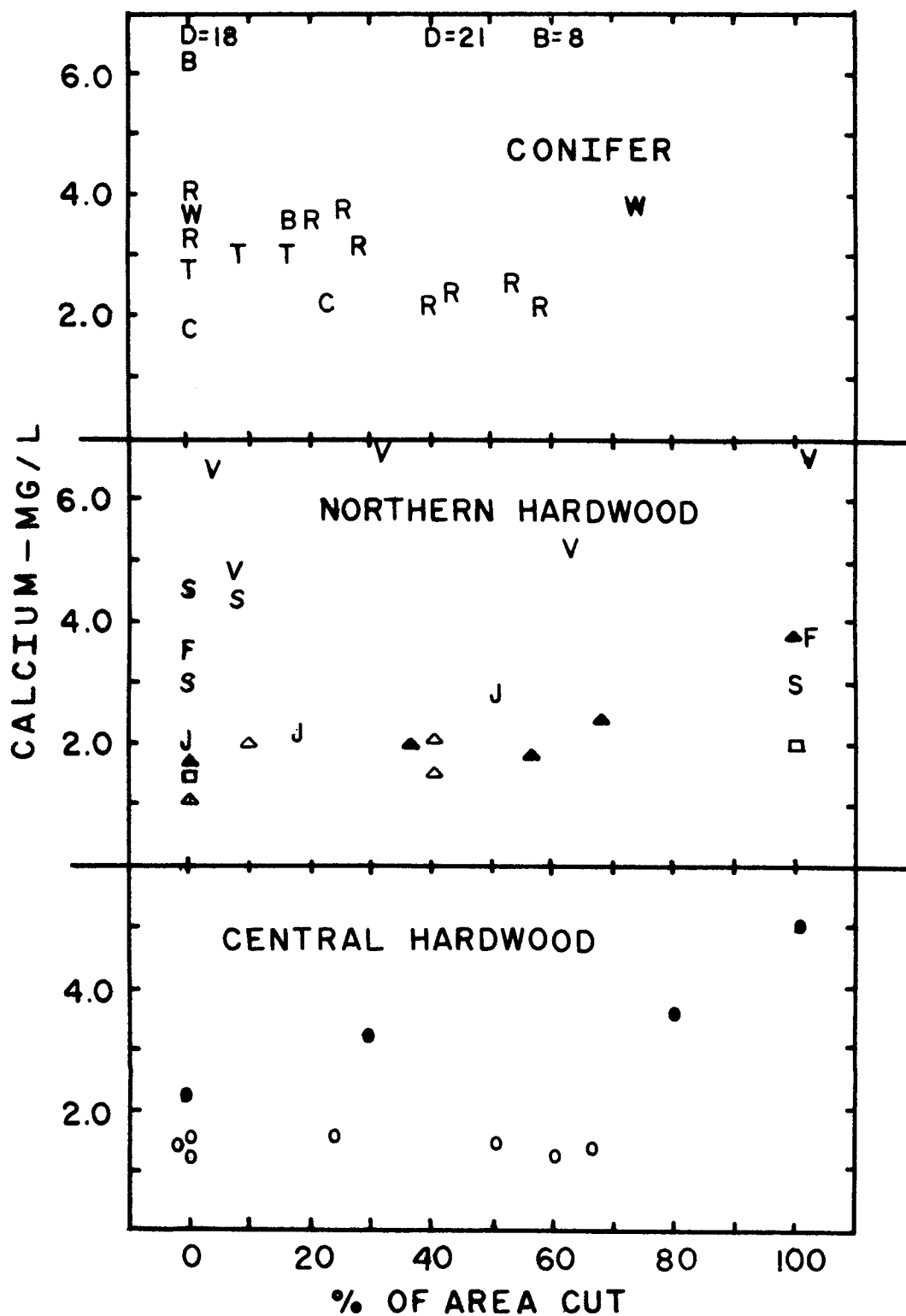
Figure 7: Calcium concentrations in mg/l plotted against percent of the watershed cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.

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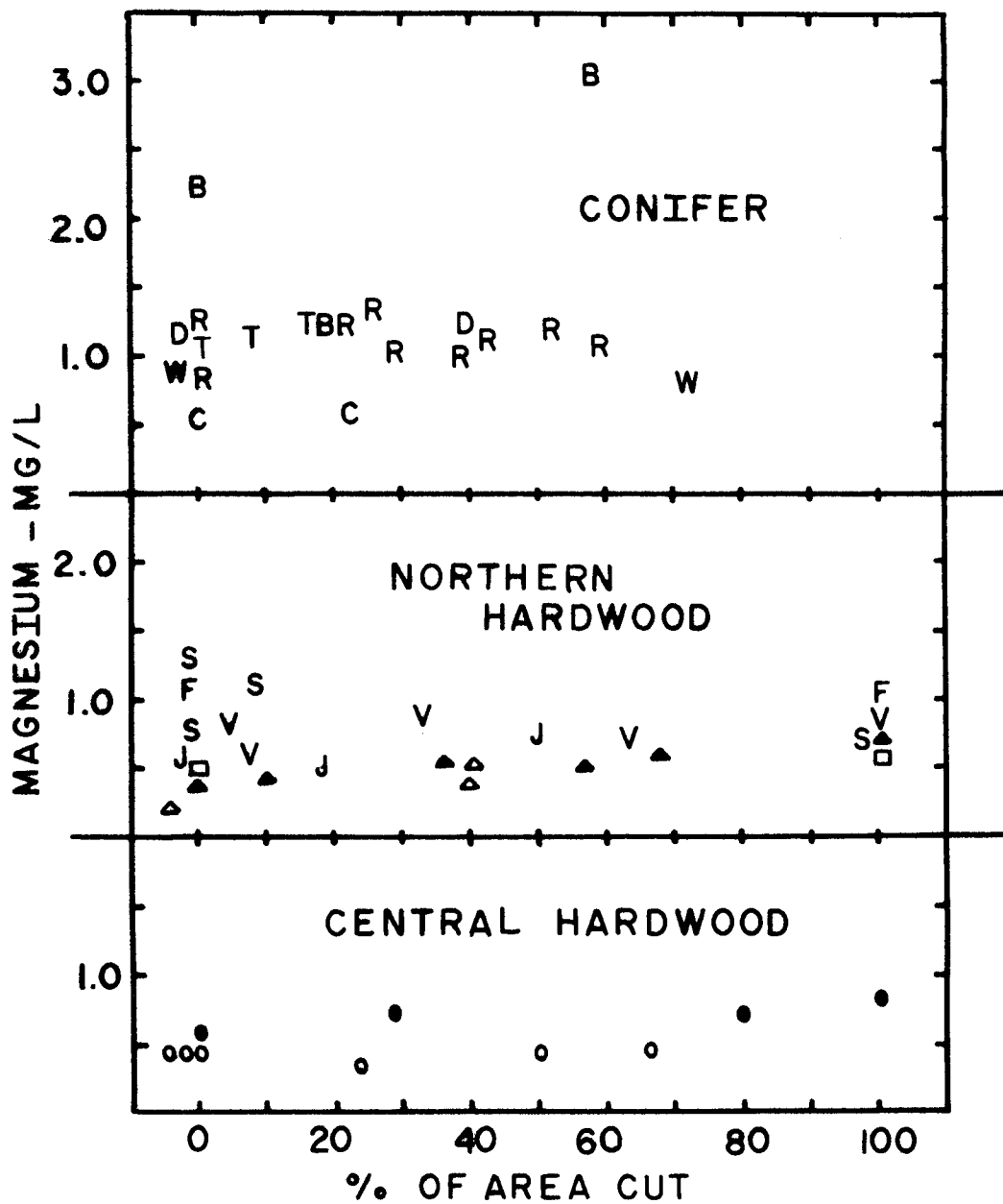
Figure 8: Magnesium concentrations in mg/l plotted against percent of the watershed cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.
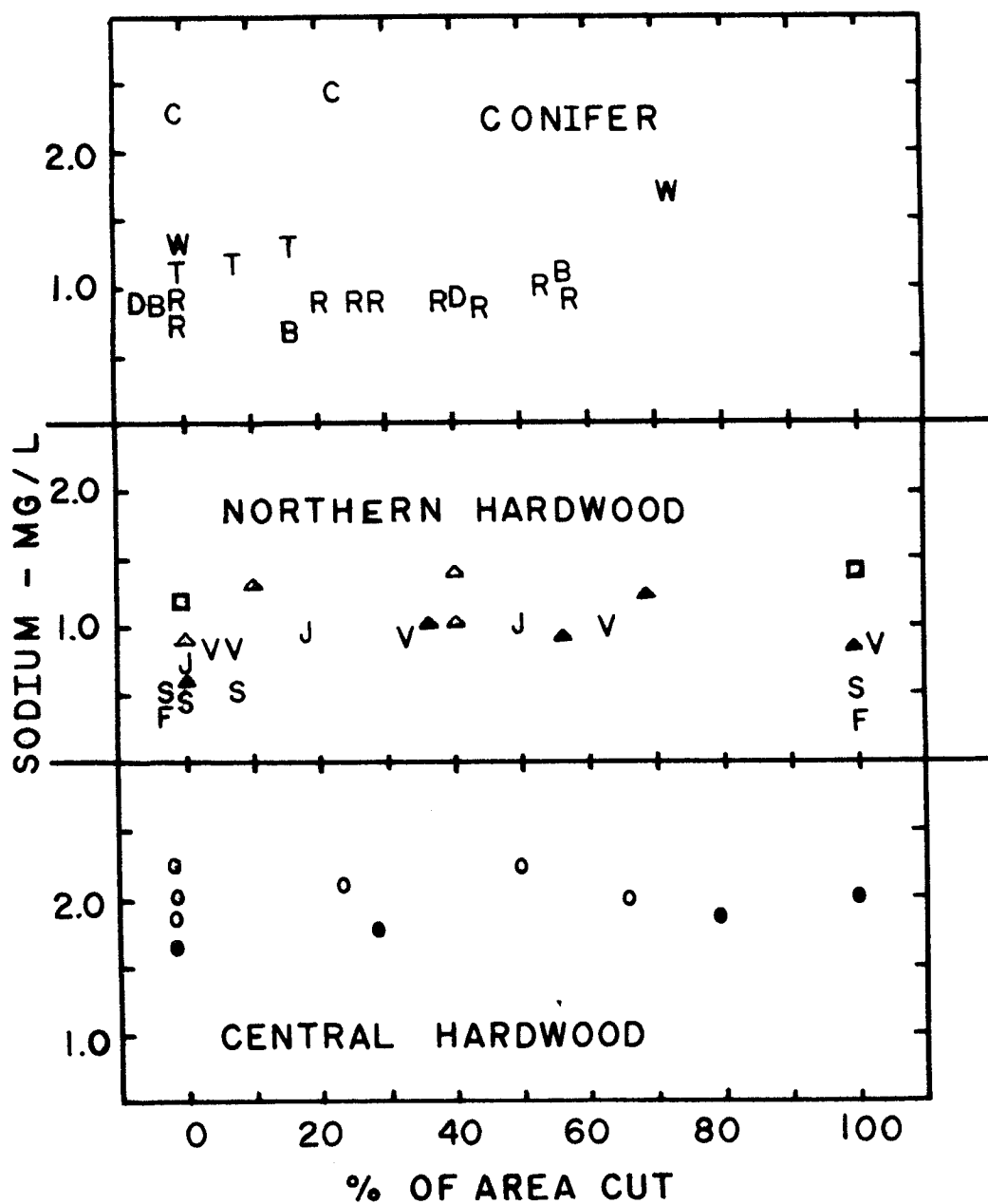
Figure 9: Sodium concentrations in mg/1 plotted against percent of the watershed area cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.

Potassium

Potassium levels were generally higher in streams from watersheds
with at least 20 percent of the area cut than in the references throughout
the region (Appendix, Table 5, and Figure 10).

Discussion

The best documentation of the effects of timber cutting on stream
chemistry in New England has been at the Hubbard Brook Experimental Forest
in New Hampshire. In 1965, all of the trees on one of the watersheds
were felled and left in place. For 3 successive years, the watershed was
sprayed with herbicides to eliminate all vegetation (Likens et al. 1970).
As a result of this drastic treatment, concentrations of the major nutrient
elements increased markedly in the stream draining the watershed (Appendix,
Table 7). Mean annual concentrations of nitrogen increased from 0.3 mg/l
to 12.0 mg/l. Calcium increased from 1.3 mg/l to 7.6 mg/l. Potassium
increased from 0.3 mg/l to 3.0 mg/l and conductivity increased from 20 to
160 μmhos. Sulfate-sulfur was the only ion to decline. This experiment
generated considerable concern about the leaching of nutrients following
clearcutting.

Five years later, a commercial clearcut was done on another watershed
at Hubbard Brook (Hornbeck et al. 1975). Again, the chemistry of the stream
in the cutting rose to an annual average of 42 μmhos vs 25 in the reference.
Nitrogen rose to 2.8 vs. 0.3 mg/l, calcium 2.7 vs 1.4 mg/l, and potassium
0.8 vs 0.2 mg/l. Initially the stream from the cutting became more acidic
than the reference, but by the third year after cutting it had become less
acidic.

Martin and Pierce (1980) studied eight other commercially clearcut

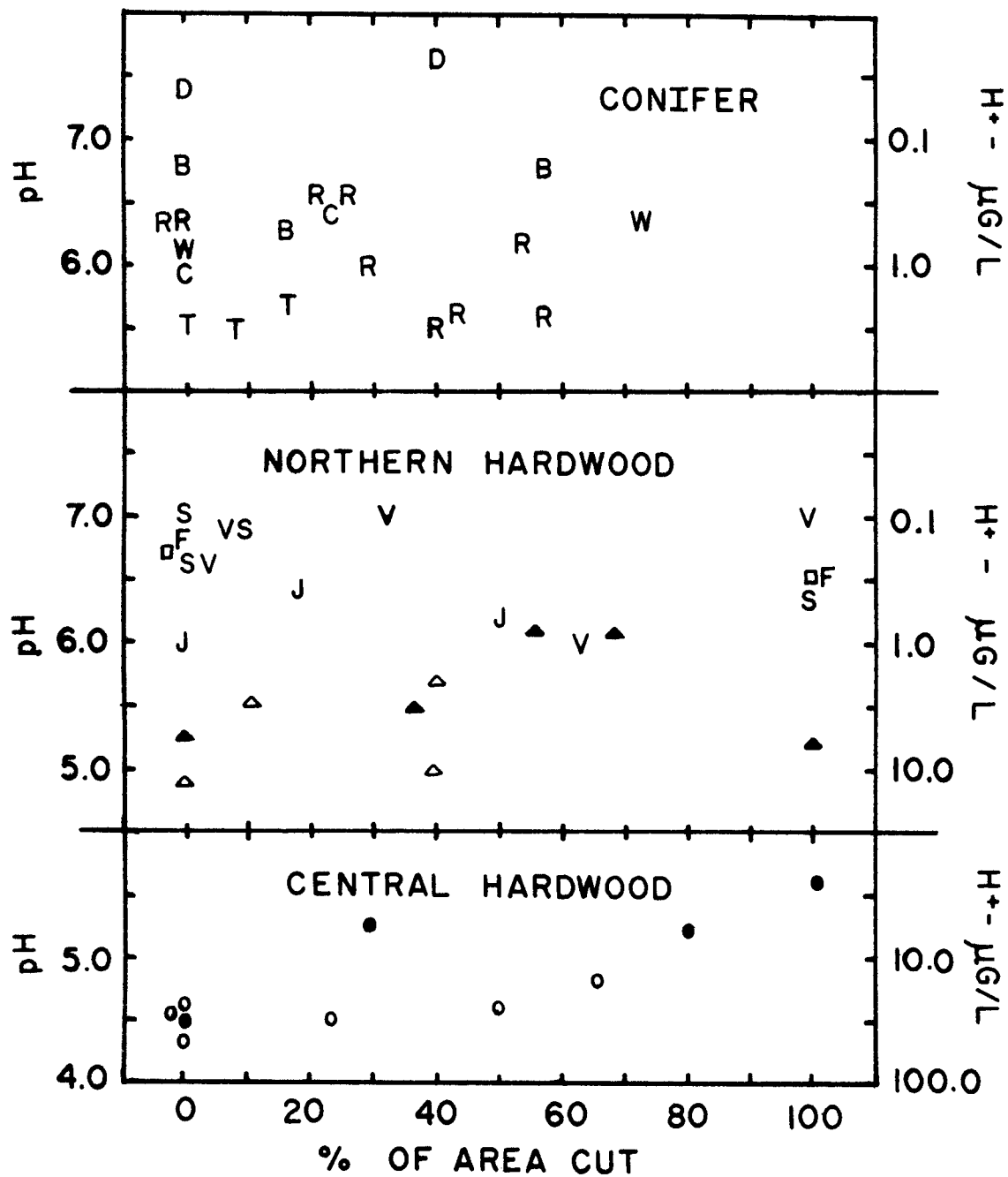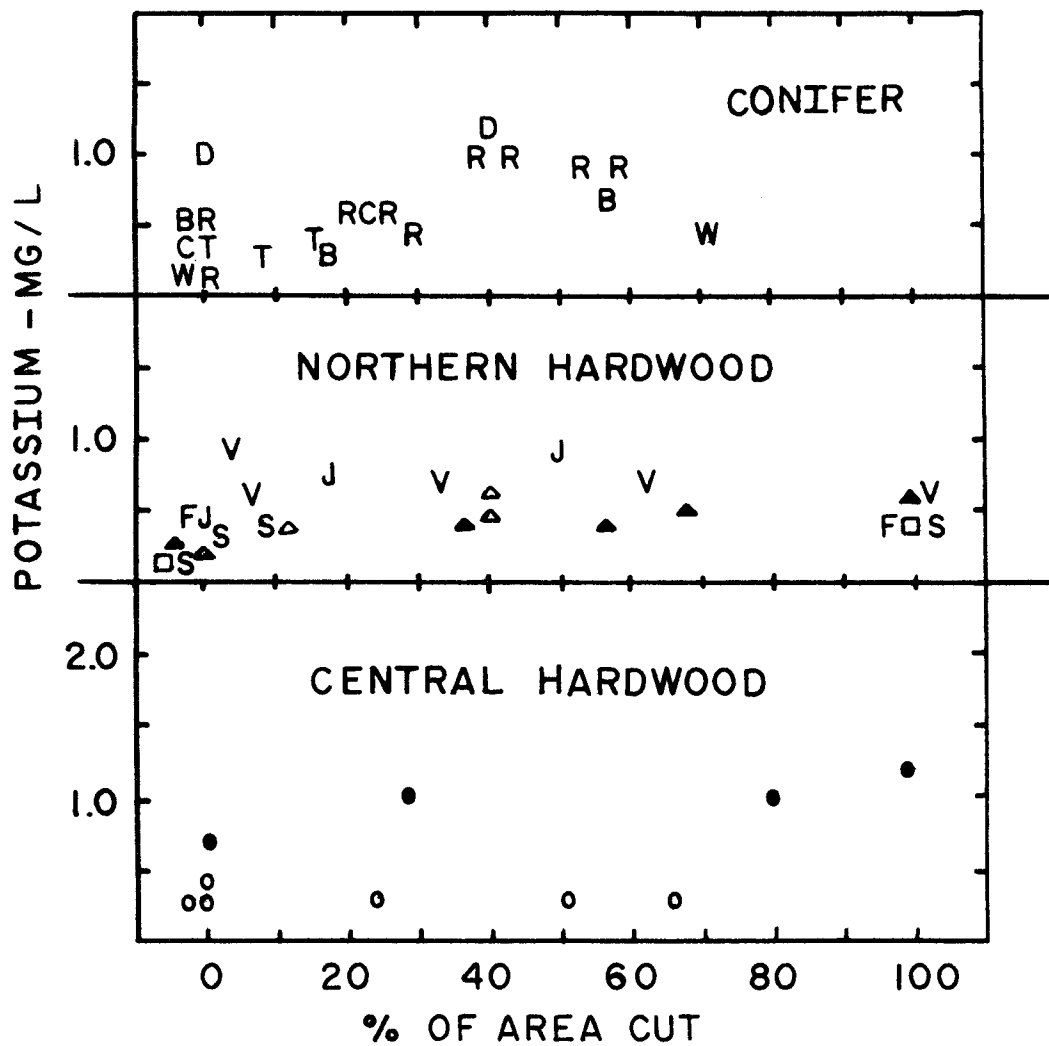Figure 10: Potassium concentrations in mg/l plotted against percent of the watershed area cut. Each point is the mean for the sample period. The sites are grouped by cover type. The symbols locate each site on Figure 1.

watersheds in the White Mountains of New Hampshire and found that nutrient concentrations in these streams were higher than those from the commercial clearcut at Hubbard Brook, but substantially lower than from the herbicide treated watershed. Concentrations had nearly returned to precutting levels by 5 years after cutting. Martin and Pierce also studied 7 watersheds where major blocks of the watershed had been clearcut, but not the entire watershed. Again, nitrogen and calcium concentrations increased in the streams draining the partially clearcut watersheds at least for the first 2 years. But clearcutting only part of the watershed and leaving buffer strips substantially reduced nutrient losses from these watersheds and reduced changes in stream chemistry (Appendix, Table 7).

In our study, we find that clearcutting, including the large whole-tree harvests of Maine, alters stream chemistry very little (Figures 2 to 10, Tables 5 and 6). The major exceptions were:

(1) At Ragmuff (R), in the coniferous forests of northwestern Maine, streams draining watersheds that were more than 20 percent clearcut were substantially more acidic than the references.

(2) In one totally clearcut northern hardwood forest in the White Mountains, mean annual and maximum values of conductivity, nitrogen, calcium and potassium were substantially higher than in the references. Also, sulfur concentration was lower in the stream from the cut than in the reference.

Timber harvesting, especially clearcutting and whole-tree harvesting, drastically alters the microclimate of the forest site. Removal of the trees greatly reduces evapotranspiration and shading, causing the surface horizons of the soil to become hotter and wetter and increasing microbiological activity. These upper soil horizons contain a very high proportion of organic matter and are a major pool of potentially available plant nutrients

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(Hoyle 1973). More rapid decomposition of this organic material releases soluble nutrient ions that may be leached to the streams.

Living vegetation on the site may limit the nutrient release. Advanced regeneration, herbaceous plants, stump sprouts, and new seedlings absorb the newly soluble nutrients. Revegetation also reduces soil-water movement by increasing transpiration and reestablishing the former microclimate with its lower decomposition rates. All these processes reduce the amount of nutrients moving to streams. Therefore, clearcutting practices that favor advanced reproduction and rapid regeneration of the sites should not produce excessive quantities of stream nutrients.

Also, roots from uncut trees extend tens of meters laterally into clearcuttings and extract water and nutrients from the cut area. Uncut trees also provide shading to cool the site. Therefore, clearcutting practices that maximize the edge effect, such as strip clearcutting, small patch cuts, buffer strips, and islands of unmerchantable trees, should reduce the quantity of nutrients reaching the streams (Martin and Pierce 1980). Orientation of the strips, patches, islands and buffers can take advantage of aspect to provide maximum shading, and use topography to allow nutrient-rich soil moisture to flow downhill through uncut areas before reaching streams.

The streams draining sites 3-43 (0) in Connecticut, were essentially unchanged by the cutting, and differences in stream chemistry at sites 3-21 (●) were minor. All of these cuttings were small patch cuts that maximized edge effect, and buffer strips were left. Because of the southern New England climate and length of growing season, the sites were almost entirely occupied by rapidly growing vegetation by the end of the first growing season.

The northern hardwood sites at Jones Brook (J) were either small patch cuts (4 ha only 50 percent cut) or strip cuts (89 ha only 18 percent cut in

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strips). The Victory (V) and Hix Mountain (△)sites were small patches, some
with buffer strips and some with islands of trees left. The northern hardwood
site in Maine was a commercial clearcut with all stems less than 10 cm dbh
left on the sites. Most of the other Maine sites have a lot of <u>Alnus</u> <u>rugosa</u>
growing along the stream banks and elsewhere in the more poorly drained parts
of the watersheds.

Partial cuts of watersheds also minimize nutrient increase by dilution.
Even though nutrient-rich soil water enters the stream, it may be diluted
by water coming downstream from above the cutting or entering from a tributary
from an uncut portion of the watershed. Of the 37 streams reported here from
harvested sites, only 6 were from watersheds entirely cut.

Soil morphology and topography of the watershed may affect the degree
to which nutrients reach a stream channel. Finely textured soils, especially
those with higher proportions of clay fractions, have higher cation-exchange
capacities. Soils containing higher proportions of organic matter should
also have higher cation and anion exchange capacities. Higher exchange
capacities tend to bind potentially available nutrients in the soil and
tend to resist leaching. Poorly drained soils and flat watersheds with
little relief may hold water on the site and prevent it from reaching the
stream. Poorly drained sites may be reducing environments where nitrogen
and sulfur may be biologically reduced to gases that escape directly to
the atmosphere and never reach the streams. The Inceptisol soils of Maine
and Thixotropic soils of Vermont such as at Sucker Brook (B), may react
this way.

Seepage of water through deep soils, glacial material, and bedrock may
carry nutrients from one watershed to another and therefore be missed in the
stream sampling system. The only site we sampled, where this seems to be a
factor was at Fassett Place, Vt. (F), where the waters from the reference

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were richer in nutrients than those from the harvested watershed.

Data from our sites in New Hampshire differ from previously published data in some respects, but not in others (Appendix 3). Nitrogen and calcium data from the three watersheds at Warren (▲) and Hix Mountain (△) that were 36 percent to 40 percent clearcut were similar to data previously published from watersheds 35 percent clearcut (Martin and Pierce 1980). The eighteen-month mean nitrogen concentration of 2.0 mg/l from the watershed at Warren (▲) that was entirely clearcut fell between the first and second year means of 1.4 mg/l and 2.8 mg/l reported by Hornbeck et al. (1975) at Hubbard Brook. The mean calcium concentration of 3.8 mg/l from the same watershed at Warren was higher that reported from Hubbard Brook. Both nitrogen and calcium data from the other partially clearcut watersheds reported by Martin and Pierce (1980) were considerably higher than our data (Tables 5 and 7). But, the two watersheds at Warren (▲) that were 56 percent and 68 percent clearcut were cut in three and four patches respectively over more than one year. In the previous study, 50 percent and 70 percent of the watersheds had been clearcut in single large blocks in one year. The 40-ha watershed at Hix Mountain (△) that was 40 percent clearcut (Appendix, Table 5) was also done as several small patches. Data from these cuttings more closely agree with the data from the strip cutting reported by Hornbeck et al. (1975).

Soil type, geology, topography, aspect, vegetation, and climate are features that make some sites more susceptible to leaching losses of nutrients to streams. Logging practices can either aggravate or ameliorate the situation. It appears that logging in New England today is being practiced in a manner that limits impact on the streams. Buffer strips along stream channels, partial cuts of watersheds, and spreading cutting over several years all help to reduce logging impacts on streams.

STREAM BIOLOGY STUDY

Site Description and Methods

Macroinvertebrate and periphyton populations in cutover streams were
compared with those in nearby reference streams. Two reference streams
were chosen for each one from a cutover watershed. Only two were selected
because of time constraints and the difficulty of finding more.

Sites were chosen where the cutting operation had removed all or most
streambank trees, leaving the stream largely unshaded, and where the stream
flowed through the cutting for at least several hundred meters. Some
sedimentation may have occurred at the study sites when culverts overflowed
or skid roads drained into streams after heavy rain or snowmelt, but this
was not a severe problem in any stream studied. When trees and limbs were
deposited in the streams during the logging operations, they were not removed.
Streams were selected at Crawford (C) and Waite (W), Maine, at Jones Brook
in Vermont (J) and at Warren, New Hampshire (▲) (Figure 1). The Crawford
and Waite, Maine sites shared the same two reference streams. Site
characteristics are provided in Tables 1 and 2.

Macroinvertebrates

Six bottom samples, three from areas of slow flow and three from areas of
fast flow were collected from each stream in the late summer of 1979. Only
slow flow samples were collected at one reference stream in New Hampshire
because there was no fast water. The sampler used was the "portable
invertebrate box sampler" (Ellis-Rutter Associates[1/]) with 0.1 m^2 base and
equipped with a 253-micron mesh net. The sampler was placed on the bottom,
then bottom material enclosed by the square base was agitated by hand and
carried into the collecting net by the current. Bottom sampling was confined
to 150-meter stretches at the downstream end of clearcuts and in the reference
streams. Both cutover and reference streams had similar width and depth,

gradient, and substrate type. Samples were preserved in 95% ethanol after inorganic materials were removed.

With one exception, all invertebrates were picked from organic debris under 10x magnification in the laboratory and stored in 70% ethanol. The Maine samples were too large and laden with organisms, particularly small ones, to be treated in their entirety. Therefore, after large insects were removed manually from these samples, they were subsampled with a rotary device modelled after Waters (1969) and at least 4 of the total 20 samples were counted. Insects were identified by genus in most cases, but occasionally only by family.

The null hypotheses of the logging effect on total macroinvertebrate numbers, numbers of mayflies (Ephemeroptera), number of true flies (Diptera) and number of taxa collected were tested using the nonparametric blocked Wilcoxon rank-sum test (Lehmann 1975). The test includes all streams, blocked by site. Within each block, streams were ranked based on mean numbers of organisms or taxa collected. Significance probabilities for the rankings were computed according to Lehmann (1975).

Periphyton

Two clean glass microscope slides (25x75 mm) were secured in a wooden rack and incubated in each study stream for one month periods from June through September 1979 to allow colonization by stream periphyton. Care was taken to provide uniform conditions of water velocity and depth in cutover and reference streams. Slides were stored in ice and returned to the laboratory for identification and enumeration of the fresh periphyton.

Physical Measurements

Maximum-minimum thermometers were positioned at the downstream ends of the study reaches by June 1979. At monthly intervals thereafter, maximum and minimum temperatures were recorded and the thermometers reset. Four monthly

readings were taken for three months. Only two readings were taken at the Vermont sites, after which most thermometers were lost in a hurricane.

Stream bottom composition was evaluated by placing a six inch square frame on the stream bottom at mid channel at intervals of approximately 8 m and by recording the most prevalent type (by surface area of stream bottom covered) of bottom cover. The types of cover recorded were detritus, flowering plants, and inorganic substrate materials (Cummins 1964).

During late summer of 1979 canopy photographs were taken at cutover and reference streams. Three to five photographs were taken along each stream using a Minolta fisheye lens. The photographic negatives were analyzed with a false color densitometer (International Imaging Systems[1]). The densitometer provides an index of the percent canopy cover (Johnson and Vogel 1978; Smart 1976).

Results

Temperature

Cutover streams tended to be warmer than reference streams during the summer months (Table 1). The greatest difference in monthly maximum temperature between cutover and reference streams (7°C) occurred at the Vermont site during the July-August sampling period. The highest maximum temperature recorded at any site was 29°C and occurred in the cutover stream at Waite, Maine, during the July-August sampling period. In Vermont, the highest temperature recorded in the cutover stream was 26°C during the July-August period. At the New Hampshire site the thermometer was dry during the warmest month and the highest temperature recorded from the cutover stream was 21°C. Differences in minimum temperatures between cutover and reference streams were small (2°C or less) and inconsistent.

Canopy Cover

All cutover streams had less canopy cover than reference streams as measured by whole-sky photographs (Table 1). Where buffer strips were left standing along stream banks, canopy cover was higher, relative to reference levels, than at sites with no buffer, but was still 20% less than the reference level in New Hampshire, and 30% less than the reference level at Crawford, Maine.

Bottom Cover

Detritus was an important component of the stream-bottom cover in cutover streams, but was seldom important in reference streams (Table 2). In three of the four cutover streams, but only one of six reference streams, detritus was the predominant bottom cover on more than 20% of the area sampled.

Cutover streams in Vermont and New Hampshire tended to have relatively higher levels of sand and gravel than did reference streams (Table 2). The

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pebble-cobble-boulder size category dominated in reference streams. In
cutover streams in Maine, the inorganic substrate materials were obscured
by the prolific growth of flowering plants. The data indicate, however, that
the larger size fractions of inorganic substrate were more abundant in
reference than in cutover streams.

Streamwater Chemistry

In Vermont, streamwater chemistry of the cutover stream and Reference 2
were similar, while Reference 1 tended to have lower pH and element
concentrations. The mean pH in Reference 1 was 5.6, compared with 6.6 and
6.8 in the cutover stream and Reference 2, respectively (Appendix, Table 8).

At the New Hampshire site, nitrogen concentrations were higher in the
cutover than in either of the reference streams. In the cutover stream the
mean nitrogen concentration was 0.8 mg/l compared with 0.2 mg/l for
Reference 2 and less than 0.05 mg/l for Reference 1. The pH and most
element concentrations were lower in Reference 1 than in the other reference
or the cutover stream. The mean pH in Reference 1 was 5.5 compared with
6.4 in the cutover stream and 6.5 in Reference 2 (Table 8).

In Maine, the pH was slightly higher in the cutover than in reference
streams. At Crawford, the mean pH in the cutover stream was 6.4 compared
with 6.0 in the reference, and at Waite the pH in cutover and reference
streams was 6.4 and 6.2, respectively. C ncentrations of elements were
similar in cutover and reference streams at Crawford and Waite, although
the water chemistry differed between Crawford and Waite for some elements
(Table 8).

Aquatic Plants

Cutover streams tended to produce higher densities of algae on glass
slides than reference streams (Table 3). In addition, heavy growth of
algae were often visible on the bottoms of cutover streams, but never under

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Table 1. Study Site Characteristics: Watershed Area, Dates of Logging, Buffer Width,

Canopy Cover, Temperatures

Site	Watershed area	Proportion of watershed cut	Length of stream in cutting	Buffer strip in sampled reach, width	Canopy cover	Range of monthly max. temp	Greatest deviation from cut-over stream max.
	ha	%	---------m---------		%	--------°C------------	
VERMONT - JONES BROOK - CUT 1976 - 1979 - NORTHERN HARDWOOD							
Clearcut	89	18	260	none	21	22-26	
Reference 1	89	0	--	--	92	19-22	-7
Reference 2	12	0	--	--	--	18-20	-6
NEW HAMPSHIRE - WARREN - CUT 1977, 1978, 1979 - NORTHERN HARDWOOD							
Clearcut	25	68	720	9m	65	19-21[a]	
Reference 1	21	0	--	--	79	--	
Reference 2[b]	21	0	--	--	--	15-19[a]	-4[a]
MAINE - WAITE - CUT 1976 AND CRAWFORD - CUT 1977 - CONIFER							
Waite Clearcut	71	72	1,200	none	6	17-29	
Waite Reference	345	0	--	--	82	16-20[a]	-5[a]
Crawford Clearcut	216	23	2,400	8m	60	16-21	
Crawford Reference	260	0	--	--	85	16-21	-1

[a] Missing data from warmest month

[b] Stream consisted of scattered pools at the time of bottom sampling

[c] 50:50 mixture 2,4,5-T and 2,4-D sprayed on the watershed, 1 gal/acre, in 1978; Glyphosate (Roundup) sprayed in 1979, 1/2 gal/acre.

Table 2. Study Site Characteristics: Gradient, Percent Pool, Stream Bottom Cover (in Percent)

| Site | Gradient | Pool | Predominant stream bottom cover type (% of samples) | | | | | | |
			Flowering plants	Detritus	Sand <2mm	Gravel 2-16mm	Pebble 16-64 mm	Cobble 64-256 mm	Boulder >256mm
VERMONT – JONES BROOK – NORTHERN HARDWOOD									
Clearcut	8	40	0	23	0	29	19	23	6
Reference 1	10	26	0	0	0	8	32	48	12
Reference 2	10	45	0	6	3	6	12	47	26
NEW HAMPSHIRE – WARREN – NORTHERN HARDWOOD									
Clearcut	4	55	0	32	11	27	3	18	11
Reference 1	6	100	0	8	15	18	18	20	23
Reference 2	6	70	0	11	13	13	5	50	8
MAINE – WAITE & CRAWFORD – CONIFER									
Waite Clearcut	2	80	48	31	2	4	10	2	2
Waite Reference	2	30	9	7	2	7	29	39	7
Crawford Clearcut	2	70	46	9	7	17	11	7	4
Crawford Reference	1	60	0	37	9	15	0	26	13

Table 3. Mean number of algal cells per mm^2 collected on glass slides in study streams. Mean of two slides except[d/]

Collecting site	Incubation period[a/]		
	May-June	June-July	July-Aug.
Vermont			
Clearcut	4,993	8,896	--
Reference	430[b/]	2,619[c/]	--
New Hampshire			
Clearcut	1,019	837	
Reference	1,341[c/]	76[d/]	
Maine			
Waite clearcut	5,918	9,215	6,434
Crawford clearcut	--	--	6,223
Waite reference	720	3,283	826
Crawford reference	--	1,169[d/]	1,100

[a/]Incubation periods were 7 May-13 June and 27 June-10 July in Vermont; 9 May-9 June and 9 June-2 July in New Hampshire; 23 May-21 June, 21 June-20 July, and 20 July-16 Aug. in Maine.

[b/]Reference 2

[c/]Reference 1

[d/]One slide

the summer canopy in reference streams.

Whereas diatoms (Baccilariophyceae) dominated algae collection from reference streams, green algae (Chlorophyta) dominated in cutover streams (Figure 11). Green algae accounted for 30 to 95% of algae cells collected in cutover streams, while in reference streams green algae constituted less than 15% of all algae. Diatoms made up from 5 to 50% of cutover stream collections and from 50 to 95% of reference stream collections (Appendix, Table 9).

In the Maine streams, the abundance of flowering plants as well as algae was greater in the cutover streams. Fifty percent of the stream bottom in cutover streams in Maine was covered by flowering plants, while reference streams had bottom coverage of 10% or less (Table 2). No flowering plants were found on the bottom of New Hampshire and Vermont streams.

Macroinvertebrates

Cutover streams in Maine had the highest densities of macroinvertebrates found in this study, approximately 40,000 per m^2. Reference streams in Maine contained macroinvertebrates in numbers as great as those in cutover streams in New Hampshire and Vermont (Table 4).

Logging had a significant effect on macroinvertebrate numbers (P=0.02). Cutover streams contained higher numbers of macroinvertebrates than reference streams at all sites. (Table 4 and Figures 12 and 13). In Maine, cutover streams had macroinvertebrate densities 3 times higher than reference streams. At the northern hardwood sites in Vermont and New Hampshire, cutover streams had 2 and 4 times, respectively, the macroinvertebrate densities of reference streams. Total and slow-flow samples from cutover streams in Maine had higher macroinvertebrate densities than those from reference streams, while in Vermont fast and total samples and in New Hampshire only total samples from cutover streams had higher numbers.

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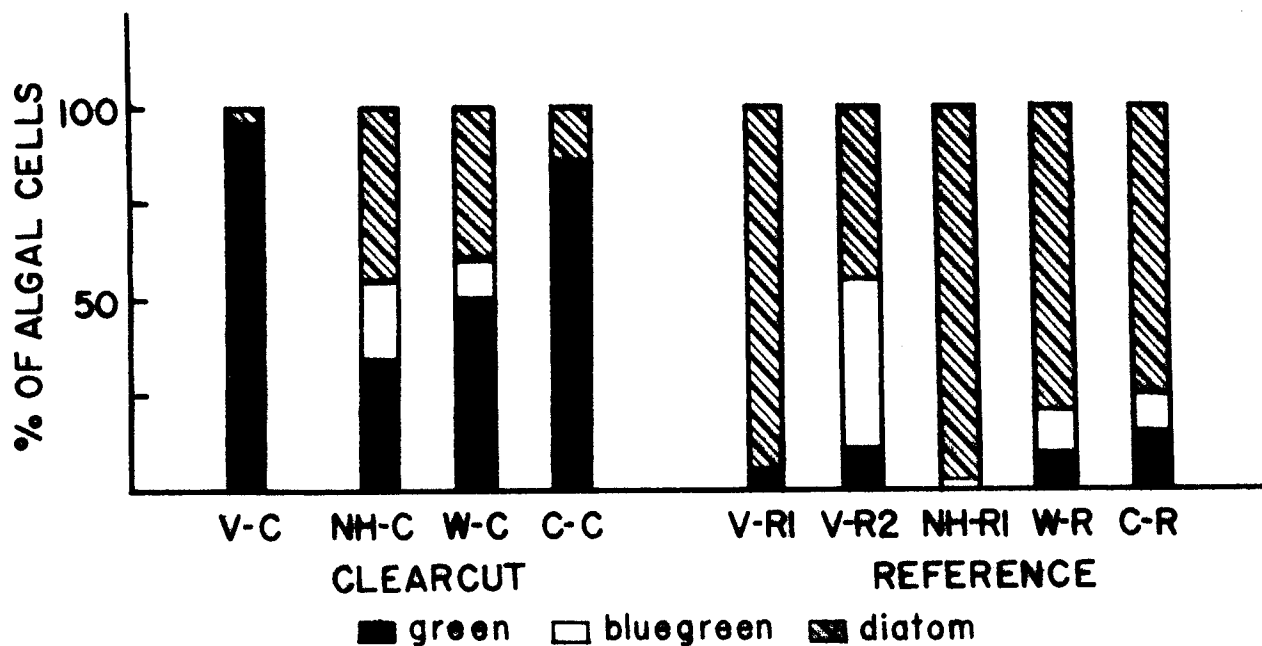
Figure 11: Percent of green and bluegreen algae and diatoms collected from study streams. Slide incubation periods: Vermont 6/27–7/10, New Hampshire 6/9–7/2, Maine 7/20–8/16. V–C = Vermont Clearcut; NH–C = · New Hampshire Clearcut; W–C = Waite Clearcut; C–C = Crawford Clearcut; V–R1, V–R2 = Vermont Reference 1 and 2, respectively; NH–R1 = New Hampshire Reference 1; W–R, C–R = Waite and Crawford Reference, respectively·

No logging impact could be detected on the number of taxa collected. Only at the New Hampshire site were there differences between cutover and reference streams; the cutover stream had more taxa.

The insect group whose densities were most affected by logging in Maine was the mayflies. Mayfly densities were significantly higher in cutover than in reference streams (P=0.02). Higher numbers of mayflies were found in fast and slow samples from cutover streams than from reference streams at all sites except Waite, Maine. At Waite, only fast-flow samples had higher numbers than the reference streams (Table 4 and Figures 12 and 13).

The true flies were found in higher numbers in samples from cutover streams in New Hampshire and in slow-flow samples from the cutover stream at Waite, Maine. However, no effect of cutting on the Diptera could be concluded (Table 4 and Figures 12 and 13).

At the Vermont site, the increase in total numbers was due mostly to an increase in mayflies, (Ephemeroptera) primarily Baetis (Figure 12 and Appendix, Table 10). In New Hampshire the increase in numbers compared to reference levels was due almost entirely to the increased Diptera populations, of which about 95% were Chironomids (Appendix, Table 10). Both the mayflies and Diptera were responsible for increases in insect density at cutover streams in Maine. As in New Hampshire, the Diptera in the cutover streams in Maine were essentially all Chironomids (Appendix, Table 10). The mayflies were mostly members of the family Leptophlebiidae and genus Ephemerella.

Northern Hardwoods
Vermont and New Hampshire
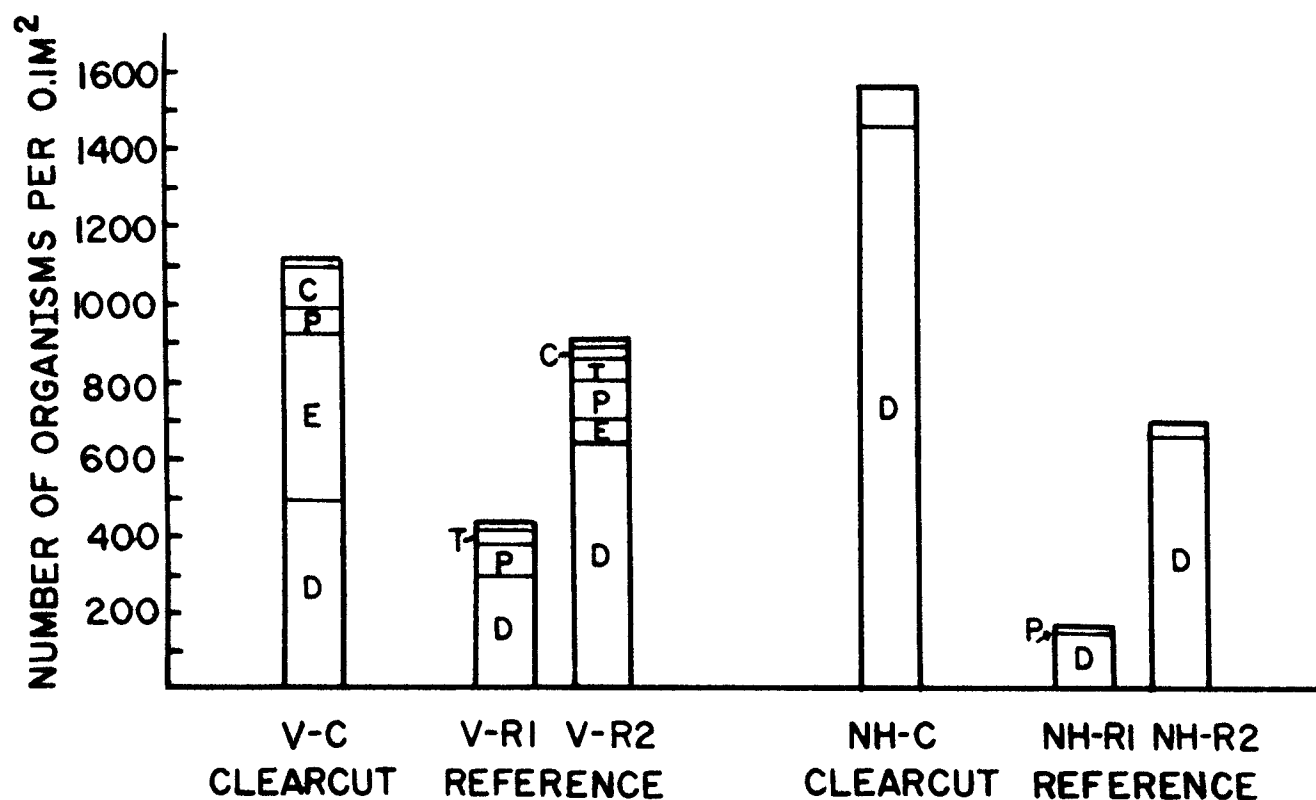
Figure 12: Mean number of organisms from six 0.1 m^2 stream bottom samples

from each stream in New Hampshire and Vermont. Sampling dates: V-C

(Vermont Clearcut) 9/5/79, V-R1 (Vermont Reference 1) 9/4/79, V-R2

(Vermont Reference 2) 9/20/79, NH-C (New Hampshire Clearcut) 8/28/79,

NH-R1 (New Hampshire Reference 1) 8/30/79, NH-R2 (New Hampshire Refe-

rence 2) 8/29/79.
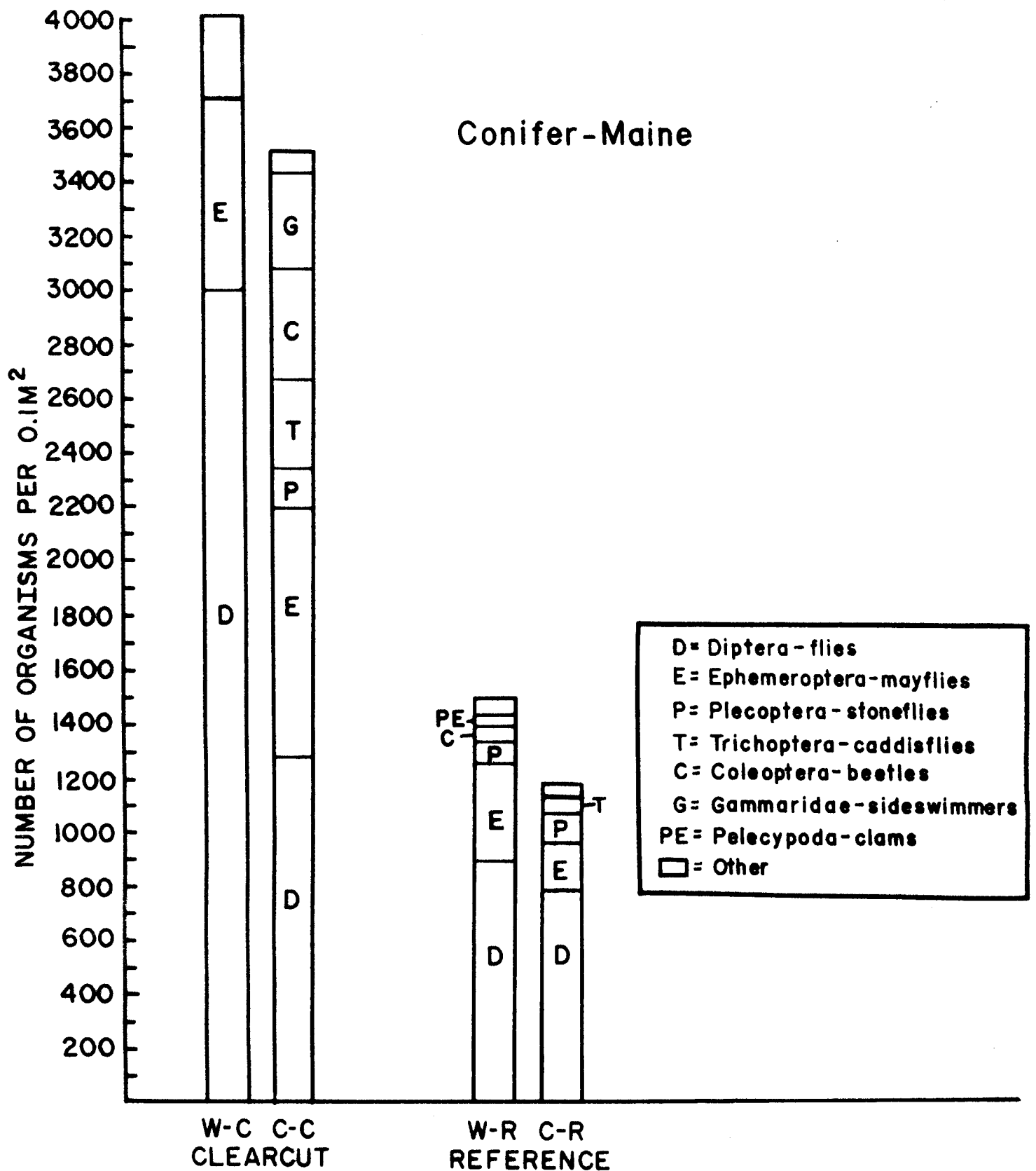
Figure 13: Mean number of organisms from six 0.1 m^2 stream bottom samples from each stream in Maine. Sampling dates: W-C (Waite Clearcut) 9/27/79, W-R (Waite Reference) 9/12/79, C-C (Crawford Clearcut) 9/12/79, C-R (Crawford Reference) 9/11/79.

Table 4. Mean (and standard deviation) of numbers of macroinvertebrates per 0.1 m^2 in samples from fast and slow stream sections, all sections combined, and number of taxa collected. C=Clearcut; R1, R2=References 1 and 2; W=Waite; CR=Crawford; V=Vermont; NH=New Hampshire.

	V-C	V-R1	V-R2	NH-C	NH-R1	NH-R2	W-C	W-R	CR-C	CR-R
Total Numbers										
Fast	1275(372)	372(124)	651(224)	1681(1186)	--	141(99)	5265(3304)	1953(626)	3927(1836)	1399(1262)
Slow	968(413)	500(483)	1154(1063)	1440(1112)	154(128)	1258(1758)	2754(589)	1045(95)	3095(1831)	1002(189)
All speeds	1122(390)	436(323)	902(740)	1561(1036)	154(128)	700(1263)	4010(2529)	1499(638)	3511(1702)	1200(836)
Diptera										
Fast	463(366)	194(45)	358(173)	1535(1092)	--	95(55)	3727(2160)	1164(784)	1368(1028)	928(1005)
Slow	527(513)	390(422)	936(1027)	1383(1091)	145(130)	1227(1746)	2280(514)	615(346)	1205(1445)	695(215)
All speeds	495(400)	292(289)	647(731)	1459(980)	145(130)	661(1267)	3004(1612)	890(620)	1286(1125)	812(662)
Ephemeroptera										
Fast	501(214)	1(1)	77(22)	65(94)	0	0	1162(1072)	460(57)	1095(438)	208(159)
Slow	353(351)	2(1)	47(6)	9(11)	0	1(1)	253(104)	292(189)	758(118)	124(123)
All speeds	427(272)	1(1)	62(22	37(67)	0	0	708(844)	376(155)	926(341)	165(135)
No. of taxa collected	40	23	40	34	21	28	34	24	37	43

Discussion

Woodland streams are characterized by a high degree of shading, by a
dependence on energy inputs from the streamside vegetation, and by
relatively low and constant temperatures. Algae are low in abundance in
these streams, and insects that feed on particulate organic material from
the forest are the dominant invertebrates (Cummins 1974; Anderson and
Sedell 1979). Clearcutting, with the removal of streamside vegetation,
exposes the previously well-shaded stream and produces basic changes in
the physical and biological character of the streams.

Increased inputs of direct solar radiation following clearcutting
result in increased streamwater temperatures (Burton and Likens 1973).
The increases are directly proportional to the surface area of the stream
exposed and are inversely proportional to discharge (Brown 1970). Therefore,
small streams with high surface-to-volume ratios, like the ones in this
study, should be highly susceptible to temperature increases following
clearcutting.

Temperature increases are reduced by leaving shade trees standing
along stream banks (Brown and Krygier 1970). The streams in this study
with buffer strips left standing along streambanks were cooler, relative
to reference streams, than those whose streambanks were completely cut over.
At the New Hampshire site, however, the 9-m buffer strip was not sufficient
to protect the stream against temperature increases. Temperature differences
between the cutover and reference streams were small at the Crawford, Maine,
site where an 8-m buffer was left standing along streambanks. Upstream
from the study area at Crawford, the buffer strip was much wider than 8-m;
this may be responsible for the lack of pronounced temperature difference at
Crawford compared with the New Hampshire site where the buffer was uniformly
narrow.

The bottoms of cutover streams tended to have more detritus than reference streams. The higher detritus levels were due in part to trees and logging slash introduced into the streams during the logging operations. At the Waite, Maine and Vermont sites, no buffer strip was established along the streambanks. Some streambank trees were felled across the streams and left in place. At the New Hampshire site, the buffer strip was occasionally broken and felled trees entered the stream. The stream at Crawford, Maine was least subject to logging slash and had the lowest detritus levels of any cutover stream. Crawford, the only reference stream with levels of detritus as high as those in cutover streams, had a very low gradient in the study area, which probably prevented flushing out of the detritus.

The higher levels of gravel observed in cutover compared with reference streams may be due to sedimentation (Murphy 1979). Sediment was observed entering the cutover stream at Waite, Maine, when a culvert overflowed onto a dirt road during a heavy rainstorm in May, 1979. Stream gradients tended to be lower in cutover than in reference streams, and that may also be responsible for the higher levels in cutover streams.

The higher periphyton populations, summer bloom conditions, and the shift from diatoms to green algae in the cutover streams compared with reference streams have been reported elsewhere (Lyford and Gregory 1975; Hansmann and Phinney 1973; Murphy 1979; Likens et al. 1970). In this study, cutover streams had less canopy cover and were generally warmer than reference streams. Both of these physical factors may be responsible for the observed differences in algal populations, although canopy cover is probably more important (Lyford and Gregory 1975; Burton and Likens 1973). The importance of canopy cover is evident at the Crawford, Maine, site. The cutover stream at Crawford, while similar in temperature to the reference streams, was

more exposed and had the higher algal populations and proportions of greens characteristic of all cutover streams studied.

The greater abundance of flowering plants in the cutover streams in Maine was probably due to the greater exposure of those streams compared with reference streams. Flowering plants may be absent from the northern hardwood sites because of the higher gradients in those streams.

In this study, cutover streams had macroinvertebrate densities 2 to 4 times higher than reference streams, but the number of taxa collected was generally the same. Similar results have been reported by Newbold (1977) for recently (1 to 3 years) cutover streams in northern California. Murphy (1979) found that insect predator density in riffle areas of cutover streams in Oregon was 75 percent higher than in reference streams. Conversely, where a trout stream flowed through a conifer plantation in Scotland, it had significantly lower numbers of invertebrates than where the forest was cleared (Smith 1980).

The mayflies and Chironomidae were responsible for the differences in total numbers of invertebrates in this study and in others from the northwestern United States (Newbold 1977; Grafius 1976). Higher numbers in cutover streams in California were due to increases in the mayfly genus Baetis, the stonefly genus Numoura and the Chironomidae (Newbold 1977) and to the mayflies and Chironomidae in Oregon (Grafius 1976).

Higher insect numbers in cutover compared with reference streams in California and Oregon have been attributed to increased primary production (Newbold 1977; Murphy 1979). The higher macroinvertebrate numbers at the New England sites can also be attributed, at least in part, to increased primary production. While primary production was not directly measured, the higher algae cell densities in cutover streams and visual observation indicate

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an increase. Both the mayflies and the midges are known to consume algae (Merrit and Cummins 1978; Fiance 1977). Baetis, which was responsible for most of the difference in total numbers at the cutover site in Vermont, is thought to be limited by algae standing crop in northern hardwood sites in New Hampshire (Fiance 1977).

Cutover streams in Maine had a greater abundance of flowering plants, as well as algae, than the reference streams. While flowering plants are not generally grazed by insects, they are consumed as detritus and support attached algae which are consumed by insects.

Detritus is known to be an important food source for stream insects (Egglishaw 1964; Minshall 1967; Cummins 1974). Detritus levels were higher in cutover than in reference streams, and may have been responsible for the higher invertebrate densities.

Sedimentation is usually associated with a reduction in the total numbers of stream macroinvertebrates (Lenat et al. 1979). While no reductions below reference stream numbers were observed in this study, effects of sedimentation could have been masked by increased food supplies (Murphy 1979).

Temperature may have been responsible for a portion of the observed differences in macroinvertebrate populations through direct effects on the organisms (Hynes 1970; Sweeney and Vanote 1978) or through indirect effects on food supply. Leaf-litter processing is a temperature-dependent process (Kaushik and Hynes 1971) that increases at higher temperatures. The cutover streams with their higher temperatures may have mineralized organic debris faster, making it readily available to stream macroinvertebrates as a food source.

Stream water chemistry does not appear to be a major factor in the differences between macroinvertebrate populations in cutover and in reference streams. Stream water chemistry was usually similar between the cutover and at least one reference stream at each site. However, some of the variability between reference streams may be attributable to differences in stream water chemistry. In both Vermont and New Hampshire Reference 1 had lower pH and element concentrations than Reference 2, and had correspondingly low invertebrate densities. Low streamwater pH and ion concentrations limit the distribution and population densities of some insects (Hall et al. 1980; Sutcliffe and Carrick 1973; Hynes 1970).

Streamflow was not measured in this study, but probably played a role in determining the low macroinvertebrate density at Reference 1 in New Hampshire. This stream consisted of pools at the time of sampling with reduced surface flow between pools.

Macroinvertebrate biomass was not evaluated in this study. However, differences in biomass of invertebrates between cutover and reference streams may have been much smaller than differences in total numbers. The organisms responsible for the increased in density, the Diptera and Ephemeroptera, were small organisms of a few millimeters or less, so their contribution to the biomass should be small. Newbold (1977) found that while differences in total numbers between his cutover and reference streams were significant, biomass showed the differences less clearly. He attributed this discrepancy to the small size of the organisms making up the differences.

This study has shown that clearcutting with removal of streambank vegetation results in major changes in the macroinvertebrate and algae populations of streams throughout New England 2 to 3 years after cutting. All cutover streams in this study showed similar changes from clearcutting despite the large differences in geography, geology, topography, and forest and soil types.

The most important change that clearcutting imposed on all streams in the study was to increase their exposure to the sky by removing streamside vegetation. Exposing the streams resulted in increased temperature and light levels and the ensuing increases in primary production and macroinvertebrate population. The removal of streamside vegetation also allowed logging debris into the stream, which could have increased macroinvertebrate habitat and food. It may be expected that algae and macroinvertebrate populations will return to precutting levels with reestablishment of the forest canopy over the streams.

Both the White Mountain National Forest and the Green Mountain National Forest have forest plans that require buffer strips along permanent streams (White Mountain National Forest 1974; Green Mountain National Forest 1977). The buffer strip includes all vegetation, which helps to stabilize the streambanks, shade the stream, and prevent water temperature increases. The consistent application of these regulations should prevent the alterations in stream water temperature, algae, and macroinvertebrates documented in this study.

This study was initiated partly as a response to the needs of land managers with respect to Section 208 of P.L. 92-500. We have shown that clearcutting causes some changes in streamwater chemistry and biology throughout New England. What to do about these changes in the context of Section 209 appears to be a political rather than scientific decision, and therefore one that we cannot make.

CONCLUSIONS

Clearcutting forest lands of New England can change the chemistry and biology of the streams that drain them. The magnitude of the change can be regulated by the intensity, location, timing, and configuration of the cuts. We studied 56 watersheds in 15 different areas of New England, in three vegetation types, under a variety of soil, climatic, and geologic conditions. The following are our conclusions:

1. In general, element concentrations in streams draining uncut forests, in the same vegetation type, varied over the same range as concentrations in streams from cutover areas. We detected surprisingly few situations in which the effects of cutting on stream chemistry were obvious.

2. However, at most of the sites, at least one of the nine chemical variables measured differed between the streams from the clearcut and streams from the uncut reference.

3. Most of the chemical changes were minor with the following exceptions:

   --Potassium concentrations were usually higher in streams from clearcuts than in those from references.

   --At Ragmuff, in the coniferous forest of northwestern Maine, streams from clearcuts were more acidic than those from references, often by a whole pH unit.

   --In the northern hardwood sites of New Hampshire, nitrogen concentrations were higher in the streams from completely clearcut watersheds than from the references.

   --In the central hardwood forest of Connecticut, nitrogen concentrations were very low; only in the stream from the watershed that was entirely clearcut was the concentration higher than trace levels.

--The greatest differences in stream chemistry between clearcuts
and references occurred in the northern hardwood forest, especially
in the White Mountains of New Hampshire.

4. Changes in stream chemistry following clearcutting seem to be greatest
in watersheds with steeper slopes and well-drained soils, and least
in flatter watersheds with poorly drained soils.

5. The greatest change in stream chemistry apparently occurred on entirely
clearcut watersheds. Clearcutting is not common in New England; we
were only able to locate 6 completely clearcut watersheds of 37 studied.

6. The following modifications of clearcutting techniques can ameliorate
changes in stream chemistry:

--clearcut less than entire watersheds

--clearcut small patches and strips rather than large blocks

--leave buffer strips of trees along both sides of a stream channel

--encourage advanced regeneration and revegetation as soon as possible

--orient patches and strips to allow nutrient-rich soil water to pass
through uncut forest before reaching a stream

--time clearcuts within one watershed over several years to stagger
the release of nutrients.

7. We noticed little serious erosion and sedimentation during our study.
Using harvesting techniques that reduce sedimentation is essential to
preserve streamwater quality.

8. Clearcutting in New England increased population densities of
macroinvertebrates in the cutover streams even where buffer strips
less than 9 m wide were left standing along streambanks.

9. The orders Ephemeroptera (mayflies) and Diptera (true flies), primarily
the family Chironomidae (midges), were the taxa most responsible for
the increases in total macroinvertebrate numbers.

10. Populations of attached algae increased following clearcutting. In Maine, populations of flowering plants also increased.

11. Green algae made up a large portion of the total periphyton numbers in cutover streams, whereas diatoms dominated in streams draining unlogged watersheds.

12. Buffer strips less than 9 m wide did not protect streams against temperature increases.

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APPENDIX

Table 5. Stream chemistry - mean (and standard deviation) of specific conductance, pH, and element concentrations

Area (ha)	% cut	n samples	Spec. cond. µmho	pH	N[a]	S	Cl	Ca	Mg	Na	K
								---mg/l---			
CONIFER - RAGMUFF, MAINE (R) - Cut 1977 - Sampled October 1978-November 1979											
Soils: Coffeelos - Coarse loamy, mixed, frigid Aeric Fragiaquept - Inceptisol - Slate bedrock											
173	0	6	34(7)	6.4(0.3)	0.1(0.1)	1.5(0.6)	0.9(0.4)	3.9(1.0)	1.2(0.3)	0.9(0.2)	0.5(0.1)
478	0	6	29(5)	6.4(0.3)	0.1(0.1)	1.6(0.4)	0.7(0.4)	3.3(0.6)	0.9(0.2)	0.8(0.1)	0.3(0.1)
326	21	6	32(6)	6.5(0.3)	0.1(0.1)	1.5(0.4)	1.0(0.4)	3.6(0.7)	1.2(0.3)	0.9(0.2)	0.6(0.1)
380	26	6	34(9)	6.5(0.3)	0.1(0.1)	1.5(0.3)	1.0(0.4)	3.7(0.9)	1.3(0.3)	0.9(0.3)	0.6(0.1)
4475	29	6	31(6)	6.0(0.5)	0.1(0.1)	1.7(0.6)	1.3(0.5)	3.2(0.9)	1.0(0.2)	0.9(0.3)	0.4(0.1)
142	39	6	26(4)	5.5(0.2)	0.1(0.1)	1.7(0.3)	1.7(0.5)	2.3(0.8)	1.0(0.3)	0.9(0.2)	1.0(0.2)
187	43	6	27(6)	5.6(0.2)	0.1(0.1)	1.7(0.3)	1.6(0.5)	2.5(0.8)	1.1(0.3)	0.9(0.2)	1.0(0.1)
144	53	6	29(10)	6.2(0.2)	0.1(0.1)	0.8(0.2)	1.0(0.5)	2.6(1.4)	1.2(0.7)	1.0(0.3)	0.9(0.3)
227	58	6	24(3)	5.6(0.2)	0.1(0.1)	1.5(0.3)	1.4(0.5)	2.2(0.5)	1.1(0.4)	0.9(0.2)	0.9(0.1)
CONIFER - TELOS, MAINE (T) - Cut winter 1977-1978 - Sampled October 1978-November 1979											
Soils: Coffeelos - Coarse loamy, mixed, frigid Aeric Fragiaquept - Inceptisol - Slate bedrock											
142	0	7	29(4)	5.5(0.4)	0.1(0.1)	2.1(0.5)	1.5(0.4)	2.8(0.5)	1.0(0.2)	1.2(0.3)	0.4(0.1)
183	8	7	29(3)	5.5(0.4)	0.1(0.1)	2.1(0.6)	1.5(0.3)	3.0(0.6)	1.1(0.2)	1.2(0.2)	0.3(0.1)
214	16	7	31(2)	5.7(0.5)	0.1(0.1)	2.0(0.6)	1.6(0.3)	3.0(0.6)	1.2(0.2)	1.3(0.3)	0.4(0.1)

Table 5. (continued)

Area (ha)	% cut	n samples	Spec. cond. (μmho)	pH	N [a/]	S	Cl	Ca	Mg	Na	K
								mg/l			
CONIFER - CRAWFORD, MAINE (C) - Cut 1977 - Sampled June 1978-November 1979											
Soils: Hermon - Loamy skeletal, mixed, frigid Typic Haplorthod - Spodosol - Metamorphic bedrock											
260	0	7	30(7)	6.0(0.3)	t [b/]	1.5(0.4)	2.1(0.4)	1.8(0.6)	0.6(0.2)	2.3(0.5)	0.4(0.2)
216	23	7	32(7)	6.4(0.3)	t	1.3(0.3)	2.4(0.4)	2.3(0.8)	0.6(0.1)	2.4(0.4)	0.6(0.1)
CONIFER - WAITE, MAINE (W) - Cut 1976 - Sampled June 1978-November 1979											
Soils: Easton - Fine loamy, mixed frigid Aeric Fragiaquept - Inceptisol - Metamorphic bedrock											
345	0	9	34(21)	6.2(0.2)	t	1.9(2.4)	1.5(0.3)	3.8(1.7)	0.9(0.5)	1.3(0.4)	0.2(0.1)
71	72	9	36(10)	6.4(0.2)	0.1(0.1)	1.5(1.0)	1.6(0.6)	3.7(1.0)	0.8(0.2)	1.7(0.2)	0.4(0.1)
CONIFER - DANVILLE, VERMONT (D) - Cut winter 1977-78 - Sampled April 1978-November 1979											
Soils: Cabot - Coarse loamy, mixed, frigid Typic Fragiaquept - Inceptisol - Schist & Limestone bedrock											
9	0	9	113(21)	7.4(0.3)	0.2(0.1)	2.8(1.1)	1.3(0.8)	17.9(5.8)	1.1(0.2)	0.9(0.2)	1.0(0.3)
15	40	9	126(30)	7.6(0.5)	0.5(0.3)	2.6(0.9)	0.9(0.3)	21.0(7.1)	1.2(0.2)	0.9(0.2)	1.2(0.3)
CONIFER - SUCKER BRK, VERMONT (B) - Cut winter 1977-78 - Sampled April 1978-November 1979											
Soils: Wilmington - Fine sandy loam, thixotropic Cryic Fragiaquod - Spodosol - Gneiss bedrock											
8	0	10	57(9)	6.8(0.1)	0.2(0.1)	2.5(0.1)	1.3(0.7)	6.2(0.6)	2.2(0.9)	0.9(0.1)	0.5(0.1)
12	16	10	32(6)	6.3(0.3)	t	2.1(0.6)	0.8(0.3)	3.4(0.7)	1.1(0.2)	0.6(0.1)	0.3(0.1)
7	57	10	64(27)	6.8(0.3)	t	2.2(0.5)	0.9(0.3)	8.3(2.7)	2.8(1.0)	1.1(0.2)	0.7(0.3)

Table 5. (continued)

Area	% cut	n samples	Spec. cond.	pH	N[a]	S	Cl	Ca	Mg	Na	K
(ha)			μmho					mg/l			
NORTHERN HARDWOOD - NIX MOUNTAIN, NH (△) - Cut winter 1977-78 - Sampled June 1978-November 1979											
Soils: Becket - Coarse loamy, mixed, frigid Typic Fragiorthod - Spodosol - Gneiss & Schist bedrock											
3	0	10	25(3)	4.9(0.5)	t	2.1(0.3)	0.6(0.1)	1.1(0.1)	0.3(0.1)	0.9(0.2)	0.2(0.2)
105	10	10	26(5)	5.5(0.4)	0.9(0.5)	1.6(0.2)	0.6(0.2)	2.0(0.5)	0.4(0.1)	1.3(0.3)	0.4(0.1)
5	40	10	30(5)	5.0(0.2)	0.9(0.6)	1.9(0.2)	0.6(0.2)	1.6(0.4)	0.4(0.1)	1.0(0.3)	0.6(0.2)
40	40	10	26(3)	5.7(0.4)	0.5(0.3)	1.4(0.4)	0.5(0.2)	2.1(0.2)	0.5(0.1)	1.4(0.3)	0.5(0.2)
NORTHERN HARDWOODS - WARREN, NH (▲) - Cut 1977, 1978, 1979 - Sampled October 1978-November 1979											
Soils: Becket - Coarse loamy, mixed, frigid Typic Fragiorthod - Spodosol - Granite bedrock											
6	0	7	25(4)	5.3(0.3)	0.4(0.5)	2.2(0.1)	0.5(0.1)	1.8(0.4)	0.4(0.1)	0.6(0.2)	0.3(0.1)
11	36	7	27(2)	5.5(0.3)	0.8(0.2)	1.9(0.1)	0.5(0.2)	2.1(0.3)	0.6(0.1)	1.0(0.2)	0.4(0.1)
16	56	7	24(7)	6.1(0.1)	0.5(0.8)	1.6(0.3)	0.5(0.1)	1.8(0.5)	0.5(0.1)	0.9(0.2)	0.4(0.2)
25	68	7	31(10)	6.2(0.2)	1.2(0.6)	1.5(0.1)	0.7(0.2)	2.4(0.8)	0.7(0.2)	1.1(0.2)	0.5(0.3)
2	100	7	41(28)	5.2(0.3)	2.0(1.9)	1.8(0.3)	0.5(0.1)	3.8(3.7)	0.7(0.6)	0.8(0.3)	0.6(0.2)
NORTHERN HARDWOODS - TBR10, MAINE (■) Cut 1978 - Sampled November 1978-November 1979											
Soils: Peru - Coarse loamy, mixed, frigid Aquic Fragiorthod - Spodosol - Schist & Gneiss bedrock											
6	0	6	22(6)	6.6(0.2)	0.1(t)	1.0(t)	0.6(0.1)	1.7(0.3)	0.5(0.2)	1.2(0.4)	0.3(0.1)
12	100	6	28(12)	6.5(0.2)	0.4(0.7)	1.0(t)	0.6(0.1)	2.1(0.8)	0.6(0.3)	1.4(0.4)	0.4(0.1)

Table 5. (continued)

Area (ha)	% cut	n samples	Spec. cond. μmho	pH	N [a/]	S	Cl	Ca	Mg	Na	K
							---------mg/l---------				
NORTHERN HARDWOODS - JONES BRK, VT (J) - Cut 1976-1979 - Sampled June 1978-November 1979											
Soils: Wilmington - Fine sandy loam, thixotropic Cryic Fragiaquod - Spodosol - Gneiss & Schist bedrock											
75	0	10	23(3)	6.1(0.4)	0.4(0.2)	1.9(0.1)	0.3(0.1)	2.1(0.2)	0.5(0.1)	0.7(0.2)	0.5(t)
89	18	10	25(3)	6.3(0.3)	0.3(0.1)	1.9(0.1)	0.3(0.1)	2.2(0.2)	0.5(0.1)	0.9(0.3)	0.7(0.1)
4	50	10	31(5)	6.2(0.4)	0.7(0.4)	1.6(0.2)	0.4(0.1)	2.9(0.2)	0.7(0.2)	0.9(0.3)	1.0(0.2)
NORTHERN HARDWOODS - VICTORY, VT (V) - Cut 1975 & 1976 - Sampled October 1978-November 1979											
Soils: Marlow - Coarse loamy, mixed, frigid Typic Fragiorthod - Spodosol - Schist bedrock											
23	4	8	49(8)	6.8(0.2)	0.5(0.2)	2.6(0.3)	0.5(0.2)	6.3(1.7)	0.7(0.1)	0.8(0.2)	0.9(0.2)
27	7	8	39(9)	7.0(0.2)	0.1(0.1)	2.3(0.1)	0.4(0.1)	4.8(1.4)	0.6(0.2)	0.7(0.2)	0.6(0.2)
3	33	8	51(9)	7.1(0.2)	0.7(0.3)	2.3(0.1)	0.4(0.1)	7.1(1.5)	0.8(0.1)	0.9(0.2)	0.7(0.2)
20	63	8	47(14)	6.0(0.7)	0.2(0.2)	2.6(0.8)	0.9(1.3)	5.1(1.6)	0.7(0.2)	1.0(0.8)	0.7(0.3)
5	100	8	58(11)	7.1(0.4)	0.7(0.3)	2.1(0.2)	0.8(1.1)	7.1(1.8)	0.8(0.2)	0.8(0.2)	0.7(0.1)
NORTHERN HARDWOODS - JOE SMITH BRK, VT (S) - Cut 1978 - Sampled June 1978-November 1979											
Soils: Mundal - Fine sandy loam thixotropic Cryic Fragiaquod - Spodosol - Schist bedrock											
5	0	10	29(2)	6.7(0.2)	0.6(0.2)	1.7(0.2)	0.4(0.1)	3.0(0.3)	0.7(0.1)	0.6(0.2)	0.2(0.1)
218	0	10	40(8)	7.1(0.2)	0.7(0.1)	1.7(0.1)	0.3(0.1)	4.6(0.8)	1.3(0.3)	0.5(0.1)	0.3(0.1)
260	8	10	39(7)	7.0(0.3)	0.7(0.1)	1.7(0.1)	0.4(0.1)	4.4(0.7)	1.1(0.3)	0.6(0.1)	0.4(0.1)
5	100	10	30(5)	6.4(0.2)	1.1(0.6)	1.6(0.2)	0.3(0.1)	3.1(0.5)	0.7(0.1)	0.4(0.2)	0.4(0.1)

continued

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Table 5. (continued)

Area	% cut	n samples	Spec. cond.	pH	N[a]	S	Cl	Ca	Mg	Na	K
(ha)			μmho					-----mg/l-----			
NORTHERN HARDWOODS - FASSETT PLACE, VT (F) - Cut 1977-1978 - Sampled June 1978-November 1979											
Soils: Hogback - Fine silt loam, thixotropic Lithic Cryothod - Spodosol - Schist bedrock											
1	0	8	34(5)	6.8(0.1)	0.8(0.6)	1.3(0.4)	0.3(0.1)	3.5(0.4)	1.1(0.2)	0.4(0.1)	0.4(0.1)
1	100	8	32(6)	6.5(0.1)	0.2(0.1)	1.8(0.1)	0.2(0.1)	3.9(2.1)	1.0(0.2)	0.3(0.1)	0.4(0.1)
CENTRAL HARDWOODS - 3-21, CT(●) - Cut 1975 - Sampled April 1978-November 1979											
Soils: Charlton - Coarse loamy, mixed mesic Typic Dystrochrept - Inceptisol - Gneiss bedrock											
9	0	5	50(4)	4.5(0.2)	t	4.3(0.3)	1.8(0.3)	2.1(0.2)	0.5(0.1)	1.7(0.2)	0.7(0.1)
21	29	5	42(3)	5.2(0.1)	t	4.1(0.3)	1.7(0.3)	3.2(0.2)	0.6(0.1)	1.8(0.2)	0.9(0.1)
3	80	5	47(5)	5.2(0.1)	t	4.3(0.3)	1.7(0.3)	3.4(0.2)	0.6(0.1)	1.8(0.2)	1.0(0.1)
2	100	5	57(10)	5.6(0.2)	0.1(0.1)	5.2(0.7)	1.7(0.2)	5.0(1.0)	0.8(0.1)	2.0(0.3)	1.2(0.2)
CENTRAL HARDWOODS - 3-43, CT (O) - Cut 1977 - Sampled June 1978-November 1979											
Soils: Charlton - Coarse loamy, mixed mesic Typic Dystrochrept - Inceptisol - Gneiss bedrock											
1	0	9	45(4)	4.6(0.1)	t	3.7(0.1)	2.0(0.4)	1.5(0.2)	0.4(t)	1.9(0.2)	0.4(0.2)
0.1	0	9	44(5)	4.6(0.1)	t	3.5(0.4)	2.1(0.2)	1.5(0.1)	0.4(t)	2.2(0.3)	0.3(0.1)
23	0	9	44(5)	4.4(0.1)	t	2.9(0.3)	2.3(0.6)	1.3(0.3)	0.4(0.1)	2.0(0.3)	0.3(0.1)
37	24	9	42(5)	4.5(0.1)	t	3.2(0.4)	2.2(0.6)	1.4(0.2)	0.4(0.1)	2.1(0.3)	0.3(0.1)
1	50	9	43(4)	4.6(0.1)	t	3.4(0.2)	2.1(0.4)	1.5(0.2)	0.4(t)	2.2(0.2)	0.3(0.1)
1	66	9	36(3)	4.8(0.1)	t	3.1(0.2)	1.8(0.3)	1.4(0.1)	0.4(t)	2.0(0.2)	0.3(0.1)

a/ N = NO$_3$ - N + NH$_4$ - N

b/ t = ≤ 0.05 mg/l

Table 6. Stream chemistry – maximum values

Area (ha)	% cut	n sam- ples	Spec. cond. µmho	pH min.	N [a]	S	Cl	Ca	Mg	Na	K
					mg/1						
CONIFER – RAGMUFF, ME											
173	0	6	46	6.1	0.3	2.0	1.4	5.7	1.7	1.3	0.7
478	0	6	34	6.1	0.2	2.0	1.1	4.1	1.1	0.9	0.4
326	21	6	39	6.2	0.3	1.9	1.6	4.3	1.5	1.3	0.7
380	26	6	47	6.2	0.3	1.9	1.7	4.9	1.7	1.4	0.6
4475	29	6	38	5.8	0.2	2.2	1.9	4.3	1.2	1.4	0.5
142	39	6	33	5.3	0.3	2.2	2.6	3.7	1.5	1.2	1.3
187	43	6	39	5.4	0.4	2.0	2.5	3.9	1.6	1.1	1.2
144	53	6	51	5.9	0.2	1.1	1.8	5.7	2.7	1.5	1.7
227	58	6	31	5.4	0.4	1.8	2.3	3.1	1.9	1.2	1.0
CONIFER – TELOS, ME											
142	0	7	34	5.0	0.2	3.1	2.0	3.6	1.2	1.7	0.6
183	8	7	33	5.1	0.2	3.2	1.9	3.6	1.3	1.5	0.4
214	16	7	33	5.2	0.3	3.1	1.9	3.7	1.4	1.9	0.7

Table 6. (continued)

Area (ha)	% cut	n sam-ples	Spec. cond. µmho	pH min.	N [a/]	S	Cl	Ca	Mg	Na	K
									mg/l		
CONIFER - CRAWFORD, ME											
260	0	7	40	5.7	0.1	2.2	3.0	2.8	1.0	3.0	0.6
216	23	7	42	6.2	t	1.6	3.4	3.6	0.9	3.1	0.7
CONIFER - WAITE, ME											
345	0	9	82	5.9	0.1	8.2	2.1	7.0	2.1	2.1	0.4
71	72	9	54	6.1	0.1	3.6	2.7	5.3	1.1	2.0	0.5
CONIFER - DANVILLE, VT											
9	0	9	135	7.1	0.3	4.8	2.8	26.9	1.6	1.3	1.7
15	40	9	170	7.1	1.0	4.1	1.4	29.0	1.5	1.2	1.8
CONIFER - SUCKER BROOK, VT											
8	0	10	70	6.6	0.4	2.7	3.3	7.3	4.7	1.2	0.8
12	16	10	40	5.9	0.1	3.0	1.4	6.9	1.6	0.8	0.5
7	57	10	98	6.3	0.3	2.9	1.2	13.1	4.1	1.3	1.4

Table 6. (continued)

Area (ha)	% cut	n samples	Spec. cond. µmho	pH min.	N[a]/	S	Cl	Ca mg/1	Mg	Na	K
NORTHERN HARDWOOD - HIX MTN., NH											
3	0	10	28	4.7	0.1	2.5	0.8	1.3	0.4	1.2	0.5
105	10	10	32	4.9	1.8	1.9	0.8	2.8	0.6	1.9	0.6
5	40	10	38	4.8	2.0	2.1	0.8	2.3	0.6	1.4	0.9
40	40	10	28	5.1	1.1	1.9	1.1	2.3	0.6	1.8	0.8
NORTHERN HARDWOOD - WARREN, NH											
6	0	7	34	4.9	1.4	2.3	0.6	2.4	0.7	1.1	0.6
11	36	7	30	5.1	1.2	2.0	0.9	2.5	0.7	1.5	0.7
16	56	7	37	6.0	1.9	2.1	0.6	2.7	0.7	1.2	0.8
25	68	7	50	5.9	2.4	1.8	1.1	4.2	1.1	1.4	1.3
2	100	7	105	4.9	6.1	2.0	0.8	12.1	2.0	1.3	1.1

Table 6. (continued)

Area (ha)	% cut	n samples	Spec. cond. µmho	pH min.	N [a]	S	Cl	Ca	Mg	Na	K
								mg/l			
NORTHERN HARDWOOD – TBR10, ME											
6	0	6	31	6.4	0.1	1.1	0.8	2.1	0.9	1.9	0.4
12	100	6	41	6.3	1.7	1.1	0.9	3.4	0.9	1.9	0.5
NORTHERN HARDWOOD – JONES BRK, VT											
75	0	10	29	5.6	0.8	2.1	0.4	2.4	0.5	1.1	0.6
89	18	10	29	5.8	0.6	2.1	0.5	2.6	0.6	1.8	0.9
4	50	10	42	5.5	1.2	1.9	0.7	3.6	0.9	1.4	1.4
NORTHERN HARDWOOD – VICTORY, VT											
23	4	8	60	6.7	0.9	3.0	0.7	8.7	0.9	1.1	1.2
27	7	8	56	6.8	0.2	2.5	0.6	7.4	0.9	0.9	1.0
3	33	8	67	6.9	1.0	2.4	0.5	9.1	1.0	1.3	1.0
20	63	8	76	5.2	0.6	4.3	3.9	7.1	0.9	2.9	1.2
5	100	9	75	6.5	1.2	2.4	3.5	10.8	1.0	1.1	0.9

Table 6. (continued)

Area	% cut	n sam- ples	Spec. cond.	pH min.	N[a]	S	Cl	Ca	Mg	Na	K
(ha)			μmho					mg/l			
NORTHERN HARDWOOD - JOE SMITH BRK., VT											
5	0	10	32	6.6	0.8	2.0	0.6	3.4	0.7	0.8	0.3
218	0	10	56	6.5	0.8	1.9	0.5	6.1	1.8	0.6	0.4
260	8	10	53	6.7	0.9	1.9	0.5	5.6	1.5	0.8	0.5
5	100	10	39	6.0	2.0	1.8	0.5	3.8	0.9	0.6	0.6
NORTHERN HARDWOOD - FASSETT PLACE, VT											
1	0	8	42	6.6	2.1	1.6	0.4	4.4	1.5	0.6	0.5
1	100	8	42	6.4	0.3	2.0	0.3	9.2	1.4	0.4	0.4
CENTRAL HARDWOOD - 3-21, CT					t[a]						
9	0	5	55	4.4	t	4.5	2.1	2.3	0.5	1.9	0.8
21	29	5	46	5.2	t	4.4	2.1	3.5	0.7	2.1	1.2
3	80	5	52	5.1	t	4.8	2.1	3.6	0.7	2.1	1.2
2	100	5	67	5.4	0.3	5.8	2.0	6.0	0.9	2.4	1.5

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Table 6. (continued)

Area (ha)	% cut	n samples	Spec. cond. _µmho_	pH min.	N [a]	S	Cl	Ca _mg/l_	Mg	Na	K
					CENTRAL HARDWOOD - 3-43, CT						
1	0	9	49	4.5	t	3.9	2.6	1.8	0.5	2.1	0.9
0.1	0	9	53	4.5	t	4.5	2.5	1.6	0.4	2.8	0.4
23	0	9	56	4.2	t	3.2	3.6	1.6	0.4	2.4	0.6
37	24	9	51	4.3	t	3.8	3.7	1.8	0.4	2.7	0.5
1	50	9	48	4.5	t	3.7	2.8	1.8	0.4	2.4	0.4
1	66	9	40	4.7	0.1	3.4	2.2	1.6	0.4	2.2	0.5

[a] N = NO_3 - N + NH_4 - N

[b] t = $\leq$ 0.05 mg/l

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Table 7. Mean stream chemistry data from clearfelling and clearcutting experiments at the Hubbard Brook Experimental Forest (Pierce et al. 1970; Hornbeck et al. 1975) and from partially clearcut watersheds in the White Mountain National Forest (Martin and Pierce 1980).

Area (ha)	% cut	Year after cut- ting	Spec. cond. µmho	pH	N[a/]	S	Cl	Ca	Mg	Na	K
						mg/l					
NORTHERN HARDWOOD – HUBBARD BROOK EXPERIMENTAL FOREST – Reference watershed and watershed clearfelled 1965 and sprayed with herbicides 1966, 1967, 1968											
13	0	--	20	5.1	0.3	2.0	0.6	1.3	0.4	0.9	0.3
16	100	1st	65	4.3	8.7	1.3	0.9	6.5	1.4	1.5	1.9
		2nd	160	4.3	12.0	1.3	0.8	7.6	1.5	1.5	3.0
NORTHERN HARDWOOD – HUBBARD BROOK EXPERIMENTAL FOREST – Reference and commercial stem-only clearcut – cut 1970											
13	0	--	25	4.9	0.3	2.2	0.5	1.4	0.3	0.9	0.2
12	100	1st	34	5.0	1.4	1.5	0.7	2.0	0.5	1.0	0.7
		2nd	42	4.8	2.8	1.5	0.6	2.7	0.7	1.0	0.8
		3rd	24	5.2	0.7	1.6	0.4	1.7	0.4	0.8	0.6
NORTHERN HARDWOOD – WHITE MOUNTAIN NATIONAL FOREST											
--	0	--	--	--	0.4	--	--	1.8	--	--	--
--	70	1st	--	--	1.1	--	--	2.5	--	--	
--		2nd			2.0			3.2			

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Table 7. (continued)

Area (ha)	% cut	Year after cutting	Spec. cond. (μmho)	pH	N[a]	S	cl	Ca	Mg	Na	K
					mg/l ----------						
upper 50		1st			1.8			3.3			
		2nd			2.6			3.5			
lower 50		1st			1.8			4.0			
		2nd			1.2			3.4			
35		1st			1.5			2.6			
		2nd			0.8			2.1			

[a] N = $NO_3 - N + NH_4 - N$

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Table 8. Stream chemistry for streams used in biological study - means (and standard deviation). All streams at a site were sampled on the same dates

Watershed	n samples	Spec. cond. (μmho)	pH	N[a]	S	Cl	Ca	Mg	Na	K
							mg/l			
VERMONT - JONES BROOK - NORTHERN HARDWOOD - sampled June 1979-November 1979										
Clearcut	6	23(2)	6.6(0.2)	0.2(0.1)	1.9(0.1)	0.3(0.1)	2.2(0.2)	0.5(0.1)	0.9(0.1)	0.7(t)
Reference 1	6	20(2)	5.6(0.1)	0.2(0.1)	2.1(0.1)	0.3(0.1)	1.7(0.2)	0.4(t)	0.7(0.1)	0.4(0.1)
Reference 2	6	25(2)	6.8(0.1)	0.1(t)	1.9(0.1)	0.4(0.1)	2.2(0.3)	0.6(0.1)	1.1(0.3)	0.8(0.2)
NEW HAMPSHIRE - WARREN - NORTHERN HARDWOOD - sampled June 1979-November 1979										
Clearcut	4	27(4)	6.4(0.1)	0.8(0.5)	1.4(0.1)	0.6(0.1)	2.2(0.1)	0.6(0.1)	1.2(0.2)	0.5(0.1)
Reference 1	4	19(4)	5.5(0.1)	t	1.7(0.1)	0.4(0.1)	1.5(0.2)	0.3(0.1)	0.9(0.5)	0.1(t)
Reference 2	4	25(2)	6.5(0.1)	0.2(0.1)	2.0(0.1)	0.5(0.1)	1.8(0.5)	0.5(0.1)	1.2(0.2)	0.3(0.1)
MAINE - WAITE AND CRAWFORD - SPRUCE-FIR - sampled July 1978-November 1979										
Waite Clearcut	6	38(11)	6.4(0.2)	0.1(0.2)	1.8(1.1)	1.7(0.6)	3.9(1.1)	0.8(0.2)	1.7(0.2)	0.4(0.2)
Waite Reference	6	38(25)	6.2(0.2)	t	2.4(2.9)	1.7(0.3)	3.8(2.0)	1.0(0.6)	1.4(0.4)	0.2(0.1)
Crawford Clearcut	6	30(6)	6.4(0.2)	t	1.2(0.3)	2.4(0.5)	2.1(0.6)	0.6(0.1)	2.3(0.3)	0.6(0.1)
Crawford Reference	6	28(5)	6.0(0.2)	t	1.4(0.5)	2.1(0.5)	1.8(0.7)	0.6(0.2)	2.2(0.5)	0.4(0.2)

a/ $N = NO_3 - N + NH_4 - N$

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Table 9. Taxa collected--percentage of total algae collected at study sites.
C=Clearcut; R1, R2=Reference 1 and 2; W=Waite; CR=Crawford; R=Reference

Taxon	Vermont 6/27-7/10			New Hampshire 6/9-7/2		Maine 7/20-8/16			
	C	R1	R2	C	R1	W-C	CR- C	W-R	CR- R
CYANOPHYTA - BLUE-GREEN ALGAE									
Chroococcus [a]									<1
Oscillatoria geminata [a]			46	20	2	5		12	5
Oscillatoria limosa						2			2
CHLOROPHYTA - GREEN ALGAE									
Carteria			1	2		<1	<1		
Chaetophora				<1					
Characium [a]									<1
Family Chlamydomonadaceae								<1	
Closterium				<1				1	<1
Coccomyxa [a]	97	2							
Coleochaete orbicularis						<1	<1		
Cosmarium	<1			<1					
Dactylococcus						<1		1	5
Mougeotia				<1		4	1		
Oedogonium/ Mougeotia				1					
Oedogonium				28		2		1	
Palmodictyon								1	
Penium								<1	
Stigeoclonium [a]/1			1		1	<1	<1	1	4
Stipetococcus									<1
Family Tetrosporaceae					40		82		1
Ulothrix									
Ulothrix subtilissima						<1		1	
Ulothrix variabilis				1		<1		<1	
Ulothrix zonata						<1			
Unidentified Chlorophycean				1				<1	
BACCILARIOPHYCEAE - DIATOMS									
Achnanthes	2		2		34	36	7	18	26
Achnanthes/Navicula			12						
Cocconeis							<1		
Diatoma			1						
Eunotia	<1	96	44	23	60	1	6	43	42
Fragellaria crotonensis				1					
Frustulia rhomboides				<1				1	

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Table 9. (continued)

Taxon	Vermont 6/27–7/10			New Hampshire 6/9–7/2		Maine 7/20–8/16			
	C	R1	R2	C	R1	W–C	CR–C	W–R	CR–R
Gomphonema				<1		1		8	5
Melosira						<1			
Meridion circulare				<1				1	
Navicula a/			1		2	<1	<1	1	1
Nitzschia						<1	1	<1	
Pinnularia								<1	<1
Surirella				<1					
Synedra a/				<1	<1				
Tabellaria fenestrata					-	<1		2	
Tabellaria flocculosa		2		a.	<1				
Unidentified pennate diatom			4	<1	<1	<1	<1	4	3

CHRYSOPHYCEAE – GOLDEN ALGAE

Taxon	C	R1	R2	C	R1	W–C	CR–C	W–R	CR–R
Chrysosphaera a/				<1	<1				

RHODOPHYTA – RED ALGAE

Taxon	C	R1	R2	C	R1	W–C	CR–C	W–R	CR–R
Roya sp.				<1					
Total cells/mm^2	8896	2619		1019	1341	6434	6223	826	1100

a/Tentative identification

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Table 10. Number of organisms collected from study streams in total fast (f) and slow (s) samples. C=Clearcut; R=Reference

Taxon	VT C f	VT C s	VT R1 f	VT R1 s	VT R2 f	VT R2 s	NH C f	NH C s	NH R1[a/] f	NH R1[a/] s	NH R2 f	NH R2 s	Waite C f	Waite C s	Waite R f	Waite R s	Craw C f	Craw C s	Craw R f	Craw R s
ARACHNIDA Acari	32	15	2	5	16	4	37	1			4	1	63	18	155	65	258	102	21	8
CRUSTACEA: Gammaridae																	780	1321	25	25
GASTROPODA													5							4
HIRUDINEA													78	178	5			36		
INSECTA Collembola	12	6	32	31	5	5	1	1	2	2	5	5	8	5	5	5	5	9	12	1
Ephemeroptera																				
Arthroplea			1																	
Baetis[b/]	1255	916					141						69	19	75	40	774	100	130	221
Baetis	73	5			33	30														
Cleon/Centroptilum		7																		
Epeorus	21				34	1	4	2										8		
Ephemerella	116	81	2	3	104	66				5	2	2	773	157	605	255	641	163	57	20
Ephemeroptera[e/]	3	5			1	5						3			15	30	128	5	5	5
Habrophlebia	1				1	1														
Heptagenia[c/]					25	1							14	4	30	10	16	5	5	
Heptageniidae[c/]	1														10	5				
Leptophlebia							8	22					2518	527	540	525	1835	1818	419	125
Leptophlebiidae[c/]	27	45	2		13	23							53		65	10	5	10		
Litobrancha[b/]							20													
Paraleptophlebia					19	14							112	53						

continued

Table 10. (continued)

Taxon	Vermont C f	Vermont C *	Vermont R1 f	Vermont R1 *	Vermont R2 f	Vermont R2 *	New Hampshire C f	New Hampshire C *	New Hampshire R1[a] f	New Hampshire R1[a] *	New Hampshire R2 f	New Hampshire R2 *	Waite, Maine C f	Waite, Maine C *	Waite, Maine R f	Waite, Maine R *	Crawford, Maine C f	Crawford, Maine C *	Crawford, Maine R f	Crawford, Maine R *
Stenonema	6	1													35		25	38		
Odonata																				
Aeschna		1						7					18	13		1			1	
Cordulegaster	3	1						9				1	2	16		1	1	21		18
Gomphidae[c]																			2	
Lanthus	6	1		2	7	3							1				3	3	6	
Somatochlora													1	10						
Plecoptera																				
Allonarcys	1																			
Capniidae (Paracapnia?)	17	4	45	27	11	5	16		22	1		9	118		230	155	294	323	226	200
Chloroperlidae	71	9	40	4	30	9			9			7					38	9	5	
Leuctridae (Leuctra?)	174	72	340	113	255	301	34	22	33			18	18		45		154	39	273	45
Peltoperla	49	2		2																
Perlodidae	2																			
Plecoptera[b]	3	3	2		1	8		1					88		10	10				
Megaloptera																				
Sialis						7	1	26		1		7			15	5			7	5
Trichoptera																				
Apatania	5	11			16	1									1				5	
Diplectrona	1				3		21	1		3					35				9	
Dolophilodes			2																	
Dolophilodes/ Wormaldia							1		37			4								

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Table 10. (continued)

Taxon	Vermont C f	C s	R1 f	R1 s	R2 f	R2 s	New Hampshire C f	C s	R1[a/] f	R1[a/] s	R2 f	R2 s	Waite, Maine C f	C s	R f	R s	Crawford, Maine C f	C s	R f	R s
Glossosoma	38	1				3											4			
Hydropsyche					13	3	7						29				371	379	5	25
Hydroptila			10	27	33	33					2	17		5			54		15	15
Lepidostoma					1	1		2					47	20						
Limnephilidae c/							1						9	23					1	
Limnephilus													38	23			5			5
Lype																				5
Mayatrichia							3										8			
Micrasema				48	20	45	1	6				2	1				5		35	29
Molanna					1	1		6				2								
Neophylax	7															1				
Oligostomis		3				6											5	80		
Oxyethira																	5			
Palaeagapetus																				
Parapsyche					11														1	
Phylocentropus	15		6		1	2											5	75		5
Polycentropus					1														1	3
Psychoglypha	6		5		7	12	19			3	1	4			35	8		5		23
Psilotreta		9					14				1	5	11	8						
Ptilostomis		1		1			1		1		1	-2'	20	18						
Pycnopsyche/Hydatophylax				1			3				18		6	15	35		49		29	15
Rhyacophila	25	3	44	11	76	8	1		18				31		5	5	754	184	10	5
Trichoptera genus A							1													
Lepidoptera										1										

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Table 10. (continued)

Taxon	Vermont						New Hampshire					Waite, Maine				Crawford, Maine			
	C f	C s	R1 f	R1 s	R2 f	R2 s	C f	C s	R1 a/ f	R1 a/ s	R2 s	C f	C s	R f	R s	C f	C s	R f	R s
Coleoptera:																			
Agabus										2									
Amphizodiae	1	1								2									
Anacaena b/																	5	47	
Donacia			1																
Dytiscidae genus A							1												6
Elmidae	479	105	4	1	116	45	51	3		22	8	191	157	180	65	1579	813	52	
Helichus b/	1																		
Hydrobius												8							
Hydrophilidae genus A								1		1									
Psephenidae										1		4							
Diptera																			
Antocha	3																		
Atherix	1			8		2													
Ceratopogonidae	24	35	20	7	64	100	386	214	25	18	87	160	86	50	40	67	47	55	62
Chaoboridae	1					4		4	1										
Chelifera			2	1	1			3											
Chironomidae	1341	1542	588	1157	952	2645	4170	3899	484	239	3471	10,973	6740	3426	1800	3906	3552	2545	1987
Chrysops/Tabanus	1	3				3		3			10	1	10	5		10	4	57	10
Dicranota	6	1	2	2	5		19	13	1	11	10		5	5		10	5	5	20
Diptera b/							4		2	2	9								
Dixa				1	1				1	1		5		5	5				
Empididae							4												
Hemerodromia					1		1												

Table 10. (continued)

Taxon	Vermont C f	Vermont C s	Vermont R1 f	Vermont R1 s	Vermont R2 f	Vermont R2 s	N.H. C f	N.H. C s	N.H. R1[a] f	N.H. R1[a] s	N.H. R2 s	Waite C f	Waite C s	Waite R f	Waite R s	Crawford C f	Crawford C s	Crawford R f	Crawford R s
Texatoma	9				26	18	16	7	12	51	81					8	1	26	5
Hydrophorus											4								1
Limnophila				3	12	11	5		1	1								16	
Limnophora		1			1	4													
Molophilus						17		9			7								
Ormosia																			
Pilaria								9					5						
Psychodidae												3							
Simuliidae b/												38				38		15	
Simulium	2																		
Tipula	1						4	3	2			6		2	1	68		5	20
Tipulid genus A																			
Tipulidae b/					4	6	1			3	11		5		5	5			
PELECYPODA	17				16		62	35		3	3	336	152	230	100	16		37	135

a/ Slow-water samples only; there was no fast water in this stream.

b/ Tentative identification

c/ Further identification prevented by damage or small size

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