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Stream Research at Coweeta Hydrologic Laboratory

J. R. Webster* and W. T. Swank**

Abstract

Stream research at Coweeta Hydrologic Laboratory has been directed primarily towards an understanding of long-term responses to logging. Effects of logging on streams include physical alterations of habitat, changes in hydrologic, chemical, and thermal characteristics of the water, and changes in food resources.

Introduction

Coweeta Hydrologic Laboratory, a research area operated by the USDA Forest Service, began operation in 1934. This 1625-ha area is located in the southern Appalachian Mountains in southwestern North Carolina and is a site of long-term terrestrial and stream research. The objective of this paper is to summarize stream studies with emphasis on how forest management, particularly logging, affects the structure and function of small stream ecosystems.

Site and Program Description

Climate at Coweeta is characterized by cool summers and mild winters. Elevation ranges from 690 to 1600 m, and mean annual precipitation ranges from 160 cm at lower elevations to 250 cm at higher elevations. The regolith within the Coweeta Basin is deeply weathered and averages about 7 m in depth. Soils generally occur within two orders -- fully developed Ultisols and immature Inceptisols. The underlying bedrock consists of a series of metasedimentary and metaigneous rocks which overlie older rocks of Precambrian origin (6). The vegetation is comprised of uneven-aged, mixed hardwoods. The overstory is dominated by oak and hickory species, red maple, and yellow poplar, and the understory has an abundance of dogwood, mountain laurel, and rhododendron.

With deep soils and abundant rainfall in all seasons, stream flow is perennial from areas of only 5 ha. There are 69 km of first-, second-, and third-order perennial streams within the basin. The range of monthly streamflow is rather narrow, but discharge is highest and most variable during February and March and lowest and most stable during late summer and early fall. Quickflow (or direct runoff) varies between 7 and 22% of the total annual runoff, and there is no overland flow on undisturbed catchments.

* Biology Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061.
** Coweeta Hydrologic Laboratory, USDA Forest Service, Otto, North Carolina 28763.

Early research at Coweeta was designed to document the harmful effects on soil and water resources of mountain farming, woodland grazing, and unrestricted logging. Water yield experiments were also initiated to measure streamflow responses to complete or partial cuttings and conversion from hardwood forests to different cover types. These studies and more recent experiments utilizing cable logging methods and advanced forest road designs have provided improved methods for managing steep mountain land to minimize damage to soil and water. These landscape-scale experiments initially emphasized hydrologic processes but since 1970 have been expanded to include other major processes which regulate forest nutrient cycles. Early Coweeta studies were supported almost entirely by the Forest Service; however, since 1968 ecologically oriented research at Coweeta has been supported by a series of National Science Foundation (NSF) grants to the University of Georgia and other cooperating universities. Investigations became part of the International Biological Program, and since 1980 much of the non-Forest Service research has been supported by the Long-Term Ecological Research Program of NSF.

Hydrologic Responses

Long-term streamflow records for control and experimental forested watersheds at Coweeta have provided equations for predicting changes in annual water yield following cutting and regrowth of hardwood forests based on two parameters, proportion of the stand basal area cut and potential insolation of the watershed (1). Logging increases flow in most months with about 100% increase during low flow months when water demands are usually high. Recovery of streamflow to preharvest levels shows a dynamic relationship between evapotranspiration, changes in vegetation structure, and watershed physical characteristics (11). Experiments indicate that commercial clearcutting, with carefully located and designed roads, produces only small and acceptable (about 15%) increases in mean stormflow volumes and peak flow rates.

Stream Temperatures

Based on measurements of six different watersheds, Swift and Messer (14) found that logging increased summer maximum water temperatures in extreme cases as much at 7^{o} C. In the most recent logging experiment, daily maximum stream temperatures were increased an average of 3.3^{o} C the first two summers after logging (13). The increases declined in the next three summers to 1.2^{o} C. Minimum daily temperatures were increased about 1.3^{o} C both winter and summer but only during the first year.

Dissolved Nutrient Levels

Concentrations of most solutes are quite low (< 1 mg/L) in Coweeta streams. In low-elevation streams Na^{+} and HCO_3^{-} are the dominant ions, and streamwater is characterized as a cation-bicarbonate solution with a mean pH of 6.7. In high-elevation streams SO_4^{-2} and HCO_3^{-} are equally important indicating major differences in processes which regulate availability and mobility of solutes in high-and low-elevation streams. The major source of variation in stream water cations and SiO_2 among control watersheds appears to be differences in bedrock mineralogy and weathering rates, while differences in both physiochemical and biological processes are postulated to contribute to major anion differences (12).

Vegetation on 13 watersheds at Coweeta has been altered by experimentation. None of these disturbances has produced increases in solute concentrations of sufficient magnitude to have an adverse impact on water quality for human use or downstream fisheries resources (10). Annual increases in NO_3-N, K, and Ca export the first year after a commercial cable-logging study were 0.3, 2.0, and 2.6 kg/ha respectively. Elevated export, primarily related to increased discharge, declined toward pre-treatment levels by the fifth year after logging (10).

Transported Sediment

Soil disturbance, primarily due to road building and skidding methods associated with logging, increases sediment inputs to streams (7, 2). Although sediment input probably only occurs in the first few years following logging, redistribution and transport of this material may continue for many years. Streams draining watersheds disturbed as much as 20 years ago still carry elevated sediment levels even during non-storm periods (21). The long-term elevation of sediment levels may in part be due to increased erodability of the streambed resulting from the decay of woody debris dams (22).

Allochthonous inputs

Streams draining undisturbed watersheds at Coweeta are supported by autumnal inputs of energy from riparian vegetation. These inputs are reduced when streamside vegetation is cut; two years after logging, allochthonous inputs to a second-order stream were less than 2% of pre-logging levels (20). Seven years following logging, the quantity of inputs had returned to near original levels but input quality was still different (22). Originally, oak leaves accounted for more than 32% of the biomass input to the stream. Seven years after logging, oak leaves comprised less than 10% of the input, and other, less decay-resistant leaves, such as birch and dogwood, made up the difference.

Instream primary production

Because of heavy canopy shading, levels of instream primary production are very low in streams draining undisturbed watersheds. Calculations from the study by Hains (5), with adjustment for the areal extent of moss, give estimates of primary production of about 11 $g/m^2/yr$ in indisturbed streams, compared to total leaf input of 568 $g/m^2/yr$ (18). However, the open canopy, increased temperature, and elevated nutrient levels resulting from logging greatly increase the potential for photosynthesis. From Hains' study we estimate about a 10X increase, to 105 $g/m^2/yr$. Because of reduced leaf inputs, instream primary production becomes an important energy source for a few years following logging.

Dissolved Organic Carbon

Dissolved organic carbon (DOC) concentrations in Coweeta streams range around 0.5 to 2.0 mg/L at base flow and are somewhat higher during storms (8, 15). Meyer and Tate (8) found that growing-season DOC concentrations in a stream draining a recently logged watershed were significantly reduced below reference levels. They attributed the difference to reduced inputs from throughfall and leaching of fresh litter and most importantly to lower inputs in subsurface water. Tate and Meyer (15) compared DOC export from four watersheds with different treatment histories representing a 20-yr sequence of secondary succession. Although they found a trend of decreasing DOC concentration and export with succession, they concluded that differences caused by periodic variations in runoff were far more significant than successional changes.

Leaf Breakdown Rates

During the year in which a watershed was being logged, leaf breakdown rates in the stream draining the watershed were significantly reduced (20). However, by the next year, breakdown rates were equal to or faster than pre-logging rates. Sediment accumulation during logging was probably responsible for slowed breakdown rates. Accelerated breakdown the next year could have been related to increased temperature and nutrient levels but was complicated by the fact that the experimental leaf substrates represented islands of a scarce food source and attracted leaf feeding invertebrates. Meyer and Johnson (9) compared leaf breakdown in two streams, one draining an undisturbed watershed and one draining a 20-yr old clearcut. They found greatly accelerated breakdown in the disturbed stream, which they attributed to the higher stream water nitrate concentrations.

Benthic organic matter

Due to decreased allochthonous inputs and accelerated particulate transport losses, the accumulation of particulate organic matter in streams declines after logging. A long-term decline in woody debris in Coweeta stream channels following disturbance was suggested by Webster et al. (22). They found that the number of woody debris dams in streams draining watersheds disturbed 20-40 years previously was less than in undisturbed streams. If not removed in post-logging site preparation, logging slash may temporarily increase instream woody debris, but as slash and old pre-logging debris decays, little wood is added to the stream by the regrowing forest. Thus there may be a period 20-40 years after logging of minimum woody debris in streams. The result is decreased streambed stability and potentially accelerated downcutting (22).

Benthic invertebrates

Studies of benthic fauna have been the core of Coweeta stream research (16). Woodall and Wallace (23) found significant differences among invertebrate densities and biomass in four streams draining watersheds of different disturbance histories. Gurtz and Wallace (3) studied the benthic fauna of a stream draining a watershed that had been logged one year previously, and the changes that they observed were related to modifications of energy sources. Organisms that graze on algae and fine particulate material increased while leaf-feeding organisms decreased. Production by one grazing mayfly in particular was greatly increased (17). Haefner and Wallace (4) found that as forest succession proceeded, grazing invertebrates declined while leaf-feeders increased.

Summary

Forest logging causes many changes in streams including physical alterations of habitat, changes in hydrologic, chemical, and thermal characteristics of the water, and alterations in the quantity and quality of food resources. Studies at Coweeta have demonstrated that stream recovery from forest disturbance is a long-term process. While stream ecosystems have the potential for rapid recovery from disturbance, this potential is not realized because of stream dependence on inputs from the slowly recovering terrestrial vegetation (19).

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