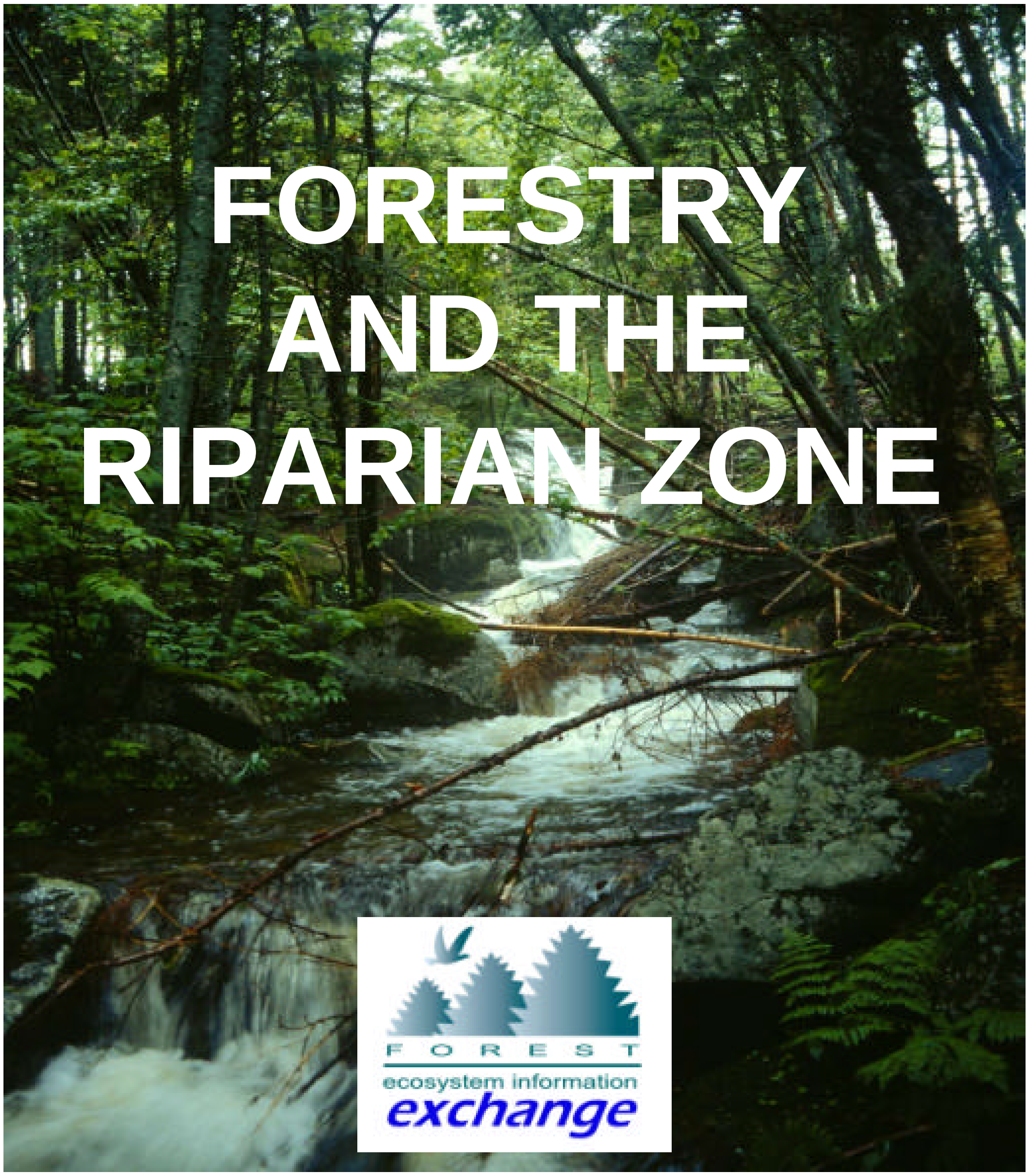
FORESTRY AND THE RIPARIAN ZONE



FOREST
ecosystem information
exchange

October 26, 2000
Wells Conference Center, University of Maine
Orono, Maine

Conference Proceedings

COOPERATIVE FORESTRY RESEARCH UNIT
UNIVERSITY OF MAINE
ORONO

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Editors:

Robert G. Wagner

and

John M. Hagan

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Hosted by:

Cooperative Forestry Research Unit, University of Maine
and
Manomet Center for Conservation Sciences

INTRODUCTION

WELCOME TO THE "FORESTRY AND THE RIPARIAN ZONE" CONFERENCE!
A better understanding about the relation between forestry practices and the riparian zone has been identified as a high priority by participants in the Forest Ecosystem Information Exchange, members of Cooperative Forestry Research Unit, and others interested in forestry issues in the state of Maine.

The purpose of this conference is to bring together scientists, forest managers, the environmental community, and others interested in forestry practices and the riparian zone for a state-of-the-art discussion about this topic as it relates to Maine's forests. We have brought a variety of leading experts from the Northeastern US, Canada, and other US regions to share their knowledge and research results. This document includes papers presented by the invited speakers as well as abstracts from the poster session.

FOREST ECOSYSTEM INFORMATION EXCHANGE STEERING COMMITTEE MEMBERS

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Si Balch	Mead Paper
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John Hagan	Manomet Conservation Sciences
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Forestry and the Riparian Zone: Why Do People Care?

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In a world characterized by uncertainty, a few facts are clear: more people are demanding healthier environments, greater recreational opportunities, and more products derived from wood. The demand for wood and wood products has increased dramatically since 1980. The rate of harvest (projected through 2005) is reminiscent of the wave of logging that surged through the Eastern States from 1865 through 1905. Today, as in 1905, the public debate revolves around questions of land use vs. protection. At the turn of the last century, many people were aware of the benefits of well-managed forests: "If you live at a distance [from the proposed Adirondack Forest Preserve], your benefits consist of not only wood in the form of houses, barns, furniture, paper or the cheerful fire in the grate, for there is no substance so widely used as wood, but the air you breathe and, in this instance, the stream that flows by or carries you or your product or turns wheels to give you light, transportation and large variety of other things." (O'Neil 1910).

The difference today is that more of us are closer, both physically and philosophically, to the water's edge in our eastern forests. From the viewpoint of society as a whole, the issues are deceptively simple. We want it all: intact, functioning ecosystems; continuous supplies of high-quality water; and lumber, paper, and other forest products. But as individuals, we see things differently. As individuals we fear losses.

If we protect riparian areas, we fear the loss of:

- Wood and wood products
- Access to minerals and mining
- Opportunities for hydropower
- Grazing and cropland
- Water withdrawals
- Freedom to manage private land

If we do not protect riparian areas, we fear the loss of:

- Water quality and quantity
- Habitats for plants and animals
- Native plant and animal species
- Recreation and aesthetic qualities
- Natural filtering of sediment
- Connectivity with other landscapes

Quite naturally, we want the opposite of these losses. As we struggle to achieve our goals for riparian area management, we need to know what the rules are. We need to know.

- How to define riparian areas
- How to classify waters and valleys
- How to assess the impacts that may have accumulated within a watershed
- How have riparian functions been impaired (what's the problem?)
- What silviculture is appropriate for riparian forests
- How does forest and water management influence animal populations
- How to balance & sustain agriculture, forestry, recreation, and urban land uses
- How to recognize and evaluate a healthy functioning condition of riparian areas
- How to plan for desired future conditions
- How to work together across landscapes with many ownerships
- What techniques can we use to restore riparian ecosystems
- How we can enhance natural processes to manage the routing of water and sediment

The challenge is not to find the easy answer but to find the knowledge to read the land and read the river.

SEEING WITH THE EYES OF A COMMUNITY

"Learn to read the land [the river], and when you do I have no fear of what you will do with it: indeed, I am excited about what you will do for it."

Aldo Leopold, 1966 — A Sand County Almanac

"There is a need to place such common resources as water, land, and air on a higher plane of value and to assign them a kind of respect that Aldo Leopold called the land ethic, a recognition of the interdependence of all creatures and resources."

Luna Leopold, 1997 — Water, Rivers and Creeks

Clearly, Aldo Leopold called those in natural resource management to do two things: read the land and manage it — ". . . I have no fear of what you will do for it." Thirty-one years later, Luna Leopold, Chief Hydrologist with the U.S. Geological Survey, Dean of Geology at The University of California-Berkley, and river restoration advocate, emulated his father's "Round River" when he called us to recognize the interdependence of land, water, air, and all creatures.

Neither rejected their past, and neither rejected the many uses nor many users of our forestlands. Aldo Leopold worked to restore his cut-over and worked-out Sand County farm and woodland to take a productive place in their Wisconsin community.

At the heart of managing for healthy riparian areas is seeing them with this same sense of community. A central challenge to many of us is managing with shared decisions. This may be the hardest task we have. To paraphrase Gifford Pinchot, first Chief of the U.S. Forest Service and Dean of the Yale School of Forestry, be absolutely honest and sincere, learn to recognize the point of view of the other person, and meet each other with arguments you will each understand.

The challenge of managing for healthy riparian areas means coming to grips with our heritage, understanding how the land and streams change, dealing with diverse and divisive issues, learning to read the land and rivers, expanding our set of management tools and most important, seeing with the vision of community.

Can we bring an understanding of riparian values and riparian functions to a community vision of place, a landscape that holds seasonal pools, ponds and lakes, grows forests, and gives of itself in a river that runs through it? This is a place where living includes both work and play, where working the land means improving the watershed’s landscape.

Our heritage is one of natural resource exploitation, of wresting from the forest a family living, one of population movement, one of balancing the need for food, fuel, and transportation. Our heritage now demands that we come to grips with sustainable resource use. Today we highly value streams and lakes and the land at their edge. Nevertheless, we either take for granted, or cannot see, the ties that bind a watershed to its streams and lakes.

Each of us sees riparian land and water differently; some of us see with eyes focused on opportunities for commerce, water supply, harvest of trees, fish, or waterfowl. Others see songbirds, willows, beavers and the subtle harmony of a natural community. Some see the power of water and sediment to shape channels into predictable patterns of stream and valley geometry (stream habitat and geomorphology). Some of us — a growing number — see people and burgeoning demands for goods, services, and amenities. Our challenge is to see with a community vision rather than the vision of single use. We must see beyond the simple juxtaposition of trees and water. Our challenge is to understand how current forest and stream conditions have come to be, how the land and water function together, how their functions can be optimized, and how we can manage for a community vision of future condition.

EUROPEAN ROOTS

As recently as a century ago in Europe, concepts of land and water stewardship were widely expanded, not unlike that occurring in North America today. The following are paraphrased from various parts of Europe in 1886 and capture the origin of many issues, values, and processes debated today (underlined below for emphasis) (Porter 1887).

From Germany: "squatters rights", and thus private rights, began about the year 300 when cleared-land on the river and the adjacent forests became a right of ownership for the heads of families and tribes. By the early 1700's, in Europe, more wood had been consumed than could be grown in several centuries. Tree planting was well established in the mid 1700's, and the regulation of tree harvest by age and acreage (as opposed to wood volume) was well established at the end of the 19th Century in parts of Germany.

From Italy: "Forests have been destroyed to gain lumber, pasture, and arable land. . . . the usual results have followed: a decrease in the depth of navigable streams, an increase in rainy season floods, avalanches, landslides and denudation of mountains." Flooding, erosion and sedimentation.

From Austria-Hungary:.. even on the steep rivers, stonework cannot withstand the torrents. Whenever a communal forest borders on these rivers, its maintenance is held to be of especial importance. In all these forests, therefore, not a tree can be felled without the consent of the state foresters. No animals are allowed to pasture, and the greatest precautions are taken to guard against fire. State regulation of land use with mandatory "BMPs."

From France: The law of 1882 provides for both stream and slope work to prevent sedimentation. The work is to be done directly by the state and by landowners with or without state aid. ".. . . .State and private landowner mitigation (with or without state aid – subsidies, tax breaks, or grants).

MEETING THE CHALLENGE OF THE 21ST CENTURY

Our challenge is first to understand current and healthy conditions for a wide range of riparian forest and water resources. This is the melding of management experience and the research that shows cause and effect along with the error of interpreting measured effectiveness. It is the base that defines the realm of possibilities. Equally important, or perhaps more important, is the common vision of what we want to see across our riparian landscapes. Deriving this vision, the socially derived, desired future condition will not be easy because of the very feature that makes it so powerful: all of us must participate.

Each of us realizes we must be competent in our own discipline, and each of us suspects we may lose competence as time moves on in spite of our experience. A training course to keep up is useful only when we apply our new knowledge with on-the-ground experience. Often, one course is not enough. We may need two, three, four . . . and more. We should not see disciplinary knowledge as the quiver of arrows carried into a consensus building session, but as our own base of confidence we can share with other disciplines and with other viewpoints. A greater challenge is to learn parts of other disciplines important to our own. Build not only your base of confidence but also your base of understanding.

When we walk beside streams and through forests, we sometimes are proud of what we see. We are sometimes discouraged by what we see. Sometimes we see evidence of stewardship and integrated management. At other times, we see a landscape (or pieces of a landscape) dominated by a single use. Is the integrated vision by chance? Or, did someone understand what it meant to do integrated management?

While today we seek to understand forestry and the riparian zone, we must realize that each of us needs the eyes of the other to develop a common understanding, a common appreciation, and common vision of what our riparian community is and what it means to our human community. Can we balance the avian cavity in large trees with a 2x4 to build our own home? Can the forester become enough of an engineer to select, size and install the right culverts or bridges to sustain a landscape of healthy fisheries? Can the fisheries biologist articulate fish and invertebrate needs at the site and landscape levels to allow flexibility in the choice of forest regeneration systems and a mix of old and new forests? Can the recreationist see the mosaic of forest life stages needed to sustain both a quality walk in the woods and sustain a quality forest products industry? I believe the answers are yes. I have seen it happen- - -one culvert, one bridge, one trial of silviculture at a time.

It depends on trust and responsibility. Trust enough to take criticism and turn it to help. Responsibility enough to not stop with saying "just do it right", but to help plan the vision, to commit time to installing the culvert, to commit money to carrying out the plans. Those I have been associated with are cost effective, do reduce maintenance needs, and serve many resources in the riparian area. Can the mill, the agency, or the landowner take responsibility for roads that serve the community, and not "leave it to the logger"? Can these folks take responsibility to train the logger, and use loggers with road building capacity to plan a limited road system, with narrow rights of way, and build them no faster than they can stabilize in a day? Can they limit access on a good, small, road system to walking or 4-wheeling after reforestation? I recently talked with a paper company forester that did just that. I saw a road system that protected riparian areas and ensured connection for fish communities throughout their landscape unit. Trust and responsibility are a hard basis to adhere to. We are not completely trusting, and we sometimes fail in our responsibilities, so that we always reserve a right to withhold trust, to withhold doing our part. Some in our communities will not seek our trust, and we will not offer our partnership, but for many we can have a common vision, a common commitment to sustainable fiber, fish, and green space. I trust this conference will help to reduce the element of chance we see in riparian area condition today, and build a common sense of community.

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For citations, charts, and pictures included in the presentation or this summary see:

Riparian Management in Forests of the Continental Eastern United States. 2000. E. S. Verry, J. W. Hornbeck, and C. A. Dolloff. Lewis Publishers. Boca Raton, FL. 402 p. Available from the website: crcpress.com.

Defining Riparian Areas

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INTRODUCTION

What is a riparian area? Does it include the aquatic environment or only the transition between aquatic and terrestrial environments? Does the transition include only lands with saturated or seasonally saturated soils or all land that influences or is influenced by the aquatic environment? Definitions vary with the perspective of the author and user. We review the many definitions available from agencies and from several disciplines and offer a definition based on the long-term sustainability of ecologic functions in riparian areas. We delineate riparian areas by examining how the ecosystem function changes with distance from the water. Finally we offer a field key to delineate riparian areas on the ground.

MANY DEFINITIONS

Many states define riparian areas to regulate land disturbance activities, to protect water quality, and to comply with the Federal Clean Water Act. “Streamside management zones,” “buffer zone” or “buffer strip” and “riparian management zones,” are the terms most frequently used and minimum widths are usually specified.

As with states, many federal agencies define riparian areas and identify riparian-area components. However, definitions are not consistent among agencies. The USDA-Forest defines riparian area to include the aquatic ecosystem, the riparian ecosystem and wetlands (USDA, Forest Service 1994), but the “riparian ecosystem” is restricted to those areas with soil characteristics or distinctive vegetation that requires free or unbound water (thus an adjacent upland area is not included. The Coastal Zone Management Act excludes the aquatic ecosystem, as does the USDI Bureau of Land Management but the similarity stops here since both have different definitions (USDI BLM, 1993).

The word “riparian” is drawn from the Latin word “*riparious*” meaning “bank” (of the stream) and simply refers to land adjacent to a body of water or life on the bank of a body of water. Following the Latin derivative, some authors exclude the aquatic component and apply the root word literally; using only single factors such as soils, groundwater and surface water hydrology or vegetative type (Karr and Schlosser 1978). Others support defining riparian areas more broadly (Swanson et al. 1982, Gregory et al. 1991, Verry, 1992, and Gregory, 1997).

It is not obvious how all these views of riparian-area definition should be reconciled. Upon closer examination, we see them as a reflection of how the professions dealing with riparian areas have evolved in the last three decades. First was the separation of ecosystems by discipline (aquatic vs. terrestrial). Next was the multidisciplinary approach (soils vs. hydrology) with definitions giving equal footing to each discipline. The multidisciplinary definitions describe the "state" or condition of an ecosystem. The most recent definitions deviate to include geologic and landscape setting and the geomorphology of streams and lakes. These definitions focus not on ecosystem state, but on ecosystem function.

Our functional definition of riparian area differs from those based on static state variables by using the flow of energy and materials (an ecosystem function) as the basis. It asks the questions: which linkages are important and where are they important enough to be included in a functional definition of riparian area. It includes the aquatic and parts of the terrestrial ecosystem. We consider the functional definition as an interdisciplinary approach that recognizes ecosystem functions developed and applied from many professional disciplines in a common landscape rather than the equal grouping of soil, water, and plant variables (multidiscipline).

A FUNCTIONAL DEFINITION

We offer the following function definition for "riparian area":

Riparian areas are the three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.

This definition is appropriate for natural resources management because it recognizes riparian areas by the ecological functions that occur at various scales. Riparian areas are more than just buffers, and this functional definition recognizes this.

Adopting a functional definition means recognizing that the riparian boundary does not stop at an arbitrary, uniform distance away from the channel or bank, but varies in width and shape. While riparian areas can be mapped, a functional approach to delineating their boundaries is preferable to applying a uniform width.

MOVING FROM DEFINITION TO DELINEATION

Delineating riparian areas requires that we see them in a landscape perspective. Landscape geomorphology constrains the stream valley, lake basin, and vegetative type (Swanson et al, 1982; Goebel et al. 1996; Naiman et al. 1997). Understanding the geology and landscape of the area will help us define riparian areas on the ground. It is in this context that we examine the geomorphic and other physical controls on riparian function. The presentation will address the specific factors that control longitudinal or downstream development and lateral development of riparian areas.

Defining riparian areas functionally avoids problems associated with assessing whether a terrestrial setting is part of the riparian area based solely on soils, or vegetation, or frequency of flooding. The extent of a riparian area into the terrestrial setting varies with the strength of each function rather than at a fixed distance from the water. The number of functions contributing to riparian and aquatic ecosystem processes decreases with distance from the water ecosystem. In other words, the probability of a function being riparian varies with each function across the riparian ecotone (Fig. 1).

However, the distance at which a particular function is no longer important may be difficult to determine with certainty. This is why professional judgment should be used, as needed, from site to site. Finally, a functionally delineated riparian area may not, and likely will not, translate directly into a riparian management zone designed to “buffer” the stream, but is usually larger. On the ground assessments of riparian area width based on functionality would be costly and complex, if not impossible, for natural resource managers. In addition, research on riparian functional delineation has lagged behind the need managers have to locate and delineate riparian areas. Modeling relationships between condition variables and riparian functions will assist riparian delineations based on land features rather those based on lines at a fixed width. However, until such models are widely available, understanding the geomorphic ecotone of riparian areas is a practical approach to on-the-ground riparian area delineation.

The field guide is based on quantifying the econtonal structure of riparian areas and the interrelationships among geomorphology, soil, and vegetation along this gradient. Understanding natural variability in structure and function among riparian areas is also necessary for developing functional delineation criteria of riparian area width; and for developing options for managing riparian areas. Scale can also affect your judgment of the riparian area extent, as illustrated in Figure 2.

IDENTIFYING FUNCTIONAL RIPARIAN AREAS ON THE GROUND

Features to understand and be able to recognize in the field include stream channels, floodplains, and terraces. Stream channels have a defined bank and a scoured bed whether they have water in them or not. Many are associated with a floodplain where the channel water spills at the flood stage (the bankfull elevation). A floodplain is the flat depositional area adjacent to the channel of some stream types. Terraces are abandoned floodplains and occur at a higher elevation than the active floodplain but may have been deformed over time by slumping.

Identifying the floodplain, the terrace, and the slope between the floodplain and terrace (terrace slope) in the field is the best way to define riparian areas. Always look for these features. However, because in some landforms these features do not exist, “rules of thumb” tempered with your professional judgment, can help delineate functional riparian area.

Consider the components in a functional riparian area. The water body (lake stream, pond, wetland) is always included. Second, the floodplain of streams is always included (and the highwater area of lakes), as well as the wetlands within the floodplain frequently adjacent to the stream or lake. The floodplain elevation is easily identified on the *inside* of meander bends where the slope of the point bar rising from the water flattens.

We have developed a dichotomous key for identifying functional riparian areas. One segment is for streams and the other for lakes and wetlands (Figure 3). For streams, the key has two forks: areas where the floodplain and terrace slopes are identifiable; and areas where either the floodplain or terrace slopes are NOT identifiable. Under the second fork, there is a further division based on slope (greater or less than than 5%); and where the slope is less than 5%, size of stream is addressed. For lakes, the division is based on slopes: those with greater than 5% slope and those with less than 5% slope. What remains is a key for vernal pools or ponds.

The key and some "rules of thumb" for identifying the features critical to using the key in the field, will be discussed. The key is a *guide*, and should be tempered by your professional judgment as to the importance of a particular ecosystem function. As Aldo Leopold said, "Learn to read the land, and when you do, I have no fear of what you will do with it…" (Leopold, 1949). In time, we have no doubt you will be able to read the land and the river, and we have no fear what you will do for them.

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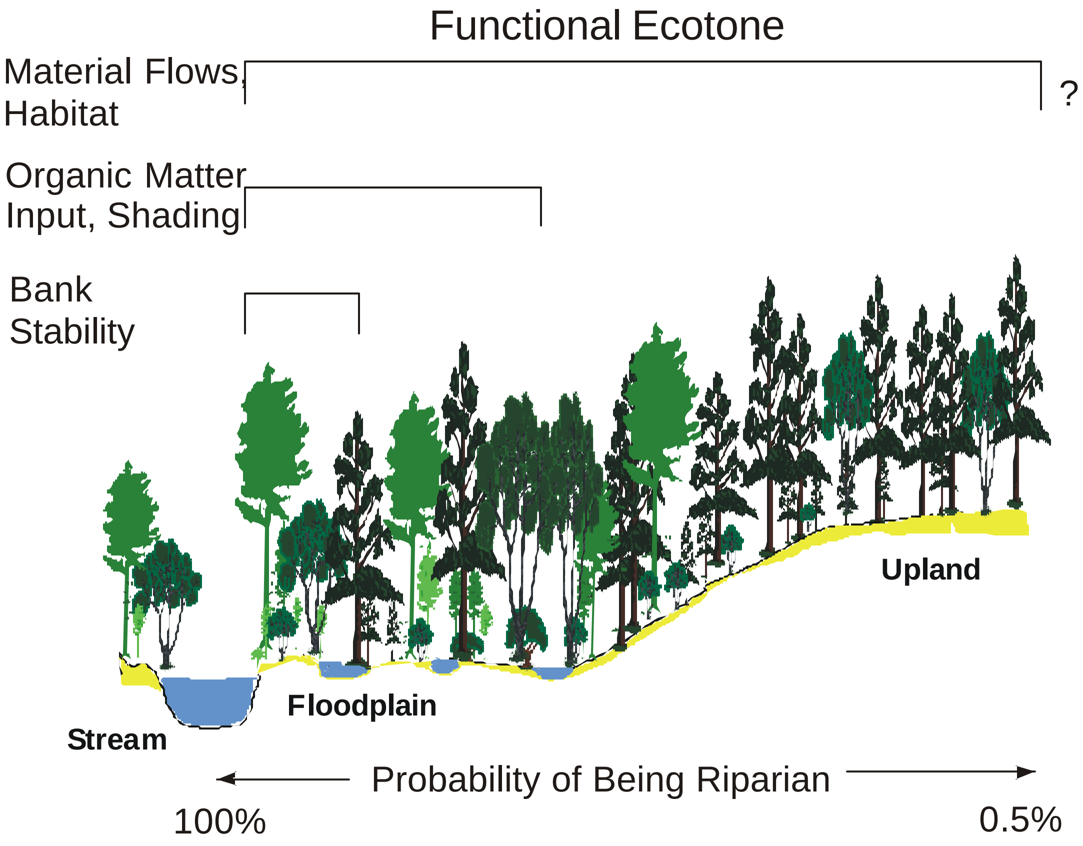


Figure 1 - The probability of a function being riparian varies with each function across the riparian ecotone.

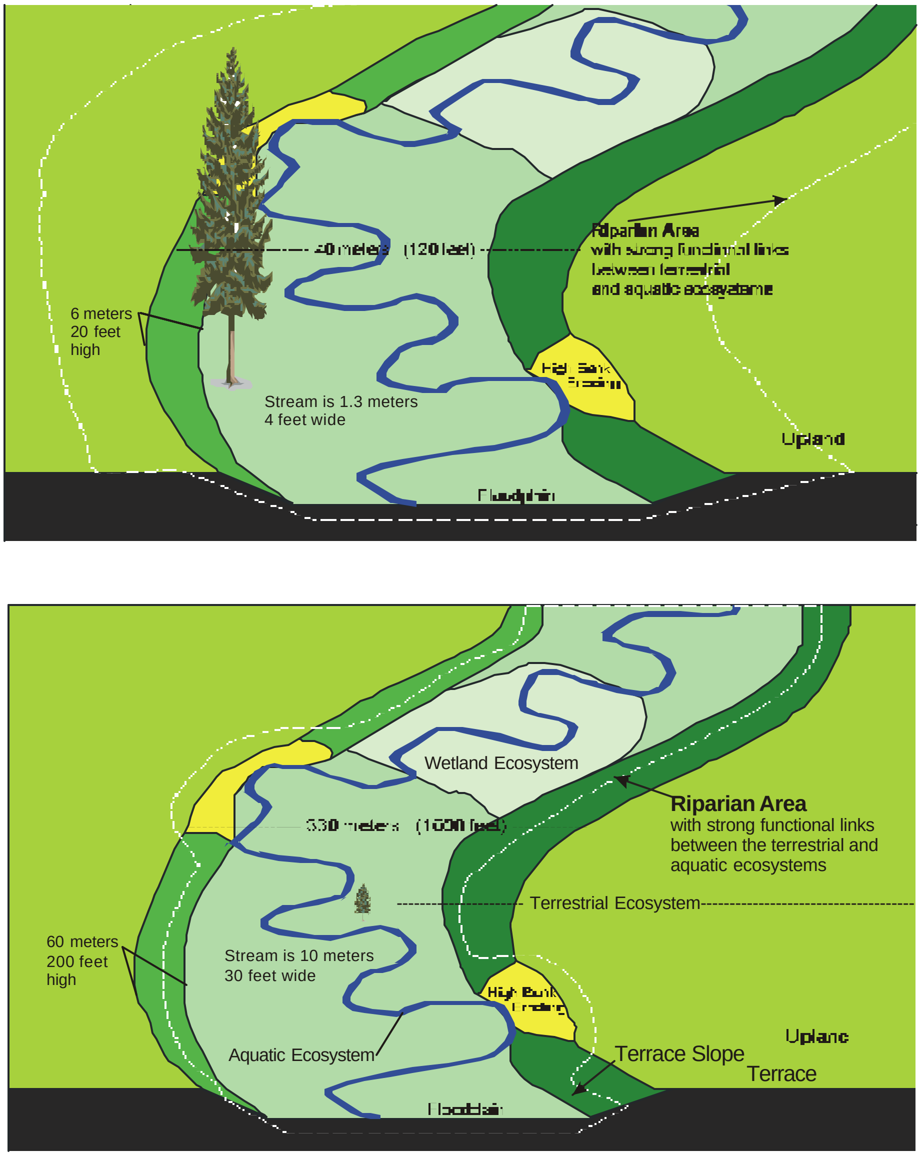
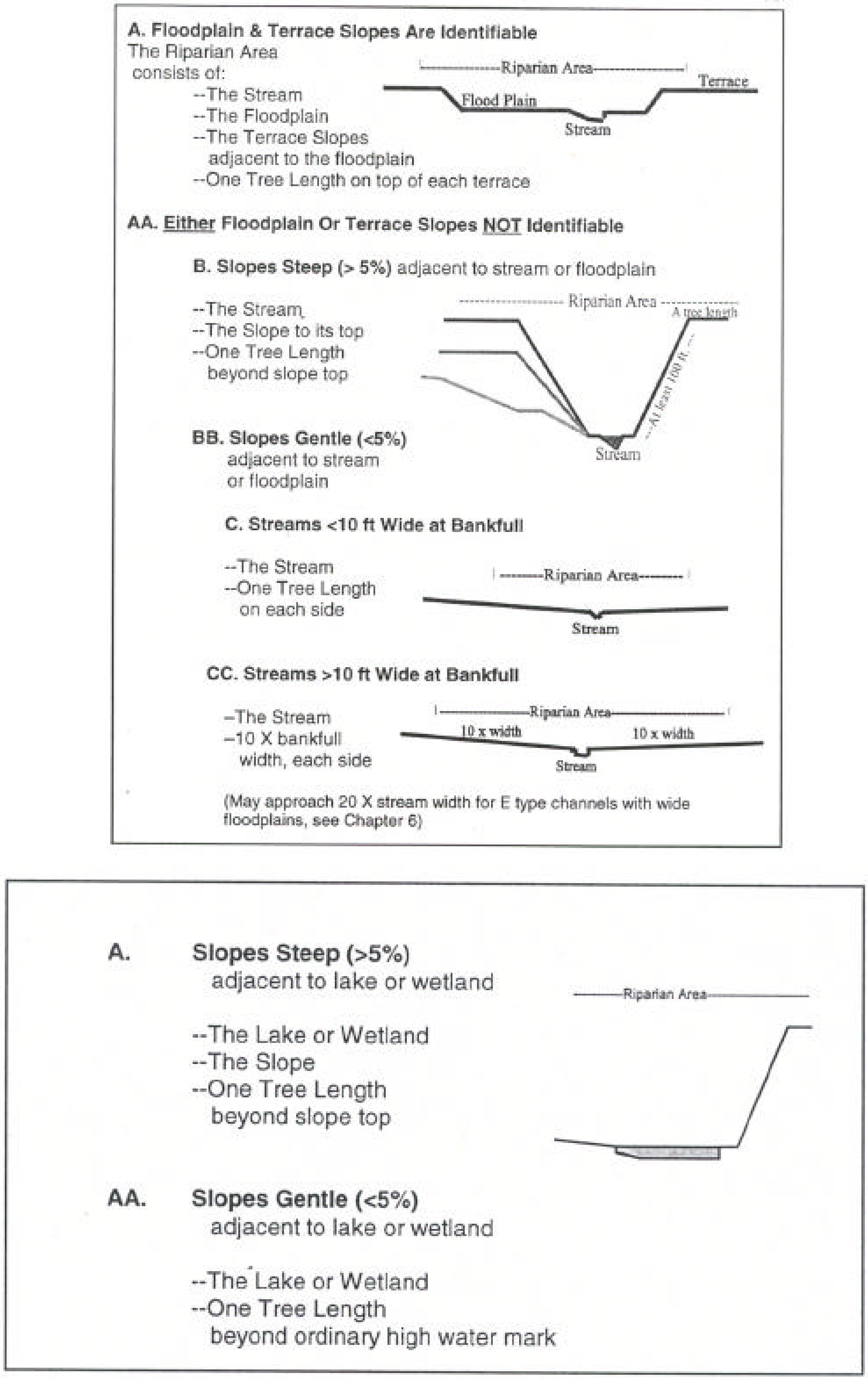


Figure 2 - This diagram shows how the scale of the stream and its valley impacts the delineation of a riparian area. The relative scale of the stream width and its valley are the same in each frame.



A. Floodplain & Terrace Slopes Are Identifiable
The Riparian Area consists of:
- --The Stream
- --The Floodplain
- --The Terrace Slopes adjacent to the floodplain
- --One Tree Length on top of each terrace

AA. Either Floodplain Or Terrace Slopes NOT Identifiable

B. Slopes Steep (> 5%) adjacent to stream or floodplain
- --The Stream
- --The Slope to its top
- --One Tree Length beyond slope top

BB. Slopes Gentle (<5%) adjacent to stream or floodplain

C. Streams <10 ft Wide at Bankfull
- --The Stream
- --One Tree Length on each side

CC. Streams >10 ft Wide at Bankfull
- –The Stream
- –10 X bankfull width, each side

(May approach 20 X stream width for E type channels with wide floodplains, see Chapter 6)

A. Slopes Steep (>5%) adjacent to lake or wetland
- --The Lake or Wetland
- --The Slope
- --One Tree Length beyond slope top

AA. Slopes Gentle (<5%) adjacent to lake or wetland
- --The Lake or Wetland
- --One Tree Length beyond ordinary high water mark

Figure 3 - Field key to define riparian areas for streams and for lakes and wetlands.

Forestry Effects on Water Quality

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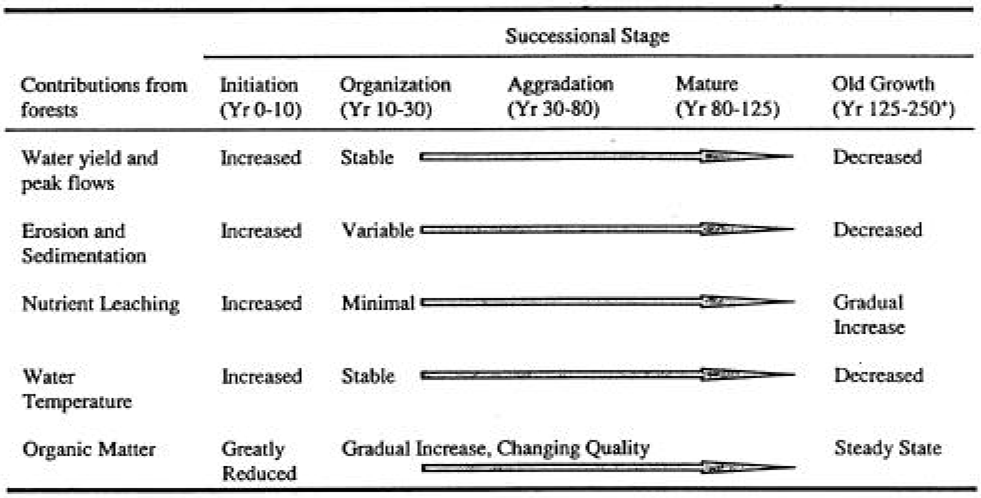
Over the past half century, knowledge about forestry effects on water quality has been gathered through watershed ecosystem research. Such studies, usually conducted on small, experimental watersheds, have shown how contributions of water, sediment, nutrients, heat, and organic matter from forests to streams change as forests undergo succession or experience natural and human-related disturbances. This paper reviews results from past studies and discusses how they can be blended with management practices to protect water quality.

The contributions from forests to streams are continuous and ever changing, depending on forest age and extent of disturbances. Table 1 summarizes how contributions from forests that affect quality of streams from small watersheds might change during five primary stages of succession. The five stages of succession are characterized by variables such as species composition, growth rates, biomass accumulation, and production of litter and woody debris. Disturbances such as harvesting, fire, or blowdown invariably occur at unpredictable times during any of the described stages. Depending upon severity of disturbance, succession will usually revert to an earlier stage, perhaps with a new species mix. As Table 1 and the following discussion show, each successional change, along with any reverting caused by disturbances, has implications for quality of forest streams.

Table 1. Contributions from forests to streams during successional stages.



	Successional Stage				
Contributions from forests	Initiation (Yr 0-10)	Organization (Yr 10-30)	Aggradation (Yr 30-80)	Mature (Yr 80-125)	Old Growth (Yr 125-250⁺)
Water yield and peak flows	Increased	Stable	→	→	Decreased
Erosion and Sedimentation	Increased	Variable	→	→	Decreased
Nutrient Leaching	Increased	Minimal	→	→	Gradual Increase
Water Temperature	Increased	Stable	→	→	Decreased
Organic Matter	Greatly Reduced	Gradual Increase, Changing Quality	→	→	Steady State

CONTRIBUTIONS FROM FORESTS

Water yield and peak flows. Disturbances over the course of succession will increase water yield, but basal area must be reduced by at least 25% to produce detectable increases in water yield. Unless large areas of forest are disturbed (on the order of square miles), increases in water yield and peak flows during any stage of succession usually have minimal downstream impacts.

Erosion and sedimentation. Depending upon the type and extent of disturbance, erosion and sediment yields will be greatest at the beginning and during the initiation stage of forest succession. The critical factor with harvesting disturbances is not the intensity of harvest, but the care taken during logging. The use of best management practices (BMPs) that minimize compaction and other disturbances limits erosion and sedimentation to small amounts, mostly along the stream channel.

Nutrient leaching. Immediately after a disturbance or early in the initiation stage, leaching of base cations and nitrogen from soils to streams usually is at a maximum. Such increases are due to increased nitrification in soil, increased decomposition stimulated by warmer and wetter soils, and the absence of vegetation to sequester nutrients. In most eastern forests the leaching losses are tempered quickly (usually within 5 years) as foliage production and plant uptake recover rapidly.

Water temperature. The principal source of heat for streams draining forests is solar energy striking directly on the surface of the stream. During the initiation stage, water temperature is high if stream shading has been severely reduced or eliminated. Once the stream channel is shaded by shrubs and regrowing trees, stream temperatures decrease and exhibit fairly uniform annual and seasonal variations through the remaining successional stages, or until another disturbance reduces or eliminates streamside shade.

Organic matter. After severe disturbances, organic matter contributions to and accumulations in streams can take a century or more to recover. Toward the end of the initiation stage and during the organization stage, contributions of litter and woody debris to streams begin a gradual increase that continues through aggradation and early maturation. There is controversy over whether logging slash should be retained in or added to streams. Arguments for leaving or adding slash include improving habitat, stabilizing the stream, and adding an energy source; arguments against include obstructing fish passage, plugging of culverts, blockage and rerouting of existing stream channels, and the possibility of decreasing dissolved oxygen.

BLENDING FOREST CONTRIBUTIONS WITH MANAGEMENT PRACTICES

As indicated above, there are good general understandings and sources of information about how contributions from forests affect quality of streams. The challenge is to incorporate this knowledge into management practices. This will be easier when pertinent information is available about rates of the various contributions from forests to streams. In the absence of site-specific information, computer models can be useful substitutes. In the absence of both site-specific data and use of computer models, general guides discussed below can be followed to protect streams. These guides have two things in common: (1) they emphasize protection during disturbance and the stand initiation stage or the time when linkages between forest and streams are most vulnerable (Table 1); and (2) they stress careful management of the riparian area that links forests and streams.

Best management practices. Adhering to BMPs, including construction and restoration of roads, landings, and stream crossings, before, during, and after logging, is a must in terms of being practical, obeying the law, and protecting linkages between forests and streams. The overriding goal should be the same as for any disturbance: limit impacts to the shortest possible time. In the case of erosion and sedimentation, this may mean special attention to disturbances such as landings, roads, and stream crossings that create chronic problems. In the case of nutrient leaching or water yield, promotion of rapid regeneration through management techniques, seeding, or planting may be necessary to help the site through the vulnerable initiation stage (Table 1).

Managing riparian areas. A properly designed and managed riparian area can provide a variety of amenities and still protect against stream temperature changes, assure a continuous supply of organic matter, absorb nutrients, sediment, and water from upslope, and maintain a diversity of species composition. Management of riparian areas is discussed more fully by other papers at this conference.

Managing upslope forests. The protection capabilities of riparian areas must be supported by careful management of forests upslope or outside the riparian area. In the case of harvesting, application of BMPs is a given, but beyond that it is helpful to think holistically in terms of forest-stream relationships. For example, will the harvesting disturbance affect streams? If yes, what steps are necessary to minimize harmful impacts and maximize beneficial impacts? One approach is to consider management objectives, including those for streams, in terms of present and desired future conditions with regard to stand age, stocking, and species composition. This can lead to selecting an appropriate silvicultural method, including cutting intensity and configuration.

TAKE-HOME POINTS

- Evaluate the relative contribution of your forests to streams and lakes on the basis of its successional stage (0 to 10, 11 to 30, 31 to 80, 81 to 125, and 126 to 250+ years old).

- Basal area of mature stands must be reduced by at least 25% to measurably increase the yield of water on an annual basis.

- Forests free of recent disturbance are the best possible vegetative cover for protecting against flooding. Peak flows usually increase after forest harvest, but effects of harvesting generally decrease as the magnitude of storm runoff increases. Thus increases in flood flows (flow levels exceeding bankfull) due to forest harvesting are relatively small.

- To protect water quality, intensify timber sale administration and use BMPs. Give special attention to chronic disturbance problems at landings, roads, and stream crossings.

- Sediment yields from carefully managed forests are small, generally in the 25 to 40 lbs/acre/year range.

- Site nutrient loss via leaching to streams is highest immediately after significant disturbances, and quickly moderates with regrowth.

- Loss of forest shade from stream channels can warm streams by as much as 9 to 18^o F.

- Computer simulation models such as JABOWA, FORTNITE, LINKAGES, NED, and BROOK can help assess changes in nutrients, woody debris, forest structure, and water yield.

- Use the combination of Current Condition, Desired Future Condition, and BMPs to manage riparian forests. Manage upslope forests first because they will change riparian conditions. Consider emulating the early mature stage (80 to 125 years old) near streams to provide a continuing supply of organic matter and large woody debris.

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The Effects of Timber Harvest on Insect Communities of Small Headwater Streams

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From the perspective of LURC, a stream is defined as "a channel between defined banks created by the action of surface water …. containing waterborne deposits …." As intended, this definition clearly includes intermittent and ephemeral streams. However, surprisingly little is actually known about the ecology of these "0-order" streams, how current guidelines suggested for their management might influence the communities of organisms that inhabit them, or their ecological interconnections with perennial reaches downstream. This abstract introduces the community of insects that inhabit these streams, in particular, and then considers some of the general connections between stream insects and the riparian zone, and how these might be affected by timber harvest.

BIODIVERSITY AND INTERMITTENT STREAMS

The insect fauna of intermittent streams in the United States is surprisingly rich. One study recorded >125 species from intermittent streams in Oregon, which exceeded the list of 100 species found in perennial streams of similar size (Dieterich & Anderson 2000). A similar study of headwater streams in Alabama also showed minor differences between the species richness in intermittent versus perennial streams (Feminella 1996). Although few hard data exist, it is apparent that the richness of the insects of intermittent streams in Maine may be similar. A preliminary survey of the insect fauna of two intermittent streams in the headwaters of the Narraguagas River (Bear Brook drainage) has revealed 10 species of stoneflies and 32 species of caddisflies (Chadwick & Huryn, unpublished). Six of the caddisfly species are known in Maine only from this single location. These totals represent about 10% of the richness for both insect orders in Maine. The headwater tributaries of the Bear Brook drainage are not accurately shown on 1:24,000 USGS topographical maps, their combined catchment area is only 24 ha, and their channels are usually dry from early July through late October. Nonetheless, they support a rich insect community containing a number of species that appear to be rare in Maine.

The assessment of the biodiversity of 0-order stream communities, and the development of land management schemes that ensure their protection should be of major concern to the state of Maine. Clearly, one of the major threats to these habitats is timber harvest. Current recommendations concerning such streams include maintenance of a buffer strip with a minimum width of 25 feet (7.6 m), and crossings constructed in such a manner as to not cause damage to the stream bank or erosion or sedimentation to the water body. Is this sufficient to protect these communities? This is a critical consideration because approximately 95% of channels within a typical watershed in northeastern North America are 2nd order or smaller (Sweeney 1993). Management protocols that are not sufficient to protect insect communities of small headwater streams have consequences for an unacceptably large proportion of total stream habitat.

ECOLOGICAL IMPORTANCE OF HEADWATER STREAMS AND THEIR INSECT COMMUNITIES

There is admittedly little information concerning the importance of 0-order streams to the overall ecological attributes of drainage networks. By virtue of their drainage-wide abundance and their close proximity to the surrounding forest, however, small headwater streams are thought to be major sites for the accumulation and processing of leaf litter that enters their channels during autumn. Much of this leaf litter is processed to fine organic particles by the feeding activity of their insect fauna. These fine particles are then rapidly washed into downstream reaches where they become available to insects that are specialized to feed upon them (Cuffney et al. 1990). In Maine, the efficiency of this important ecological process appears to be both a function of the number of species of litter-feeding insects present within a stream and the actual size of their populations (Huryn *et al*., in review). Thus the conservation of the biodiversity of stream insect communities in small headwater streams may be essential for maintaining drainage-wide ecosystem function at levels characterizing undisturbed systems.

GENERAL RIPARIAN FACTORS AFFECTING INSECT COMMUNITIES IN FORESTED HEADWATER STREAMS

Riparian management practices will influence stream insect communities most generally by affecting habitat structure, food, and water temperature.

<u>Larval habitat.</u> Most stream insects require particular substrate and current conditions as habitat. Thus any factor that affects the diversity and distribution of these habitat patches will be a fundamental determinant of the structure of their communities. Management practices that cause changes in patterns of discharge, sediment sources, or that disrupt other channel-forming process, such as the input of fallen timber, may have major effects on stream insect communities.

<u>Adult habitat</u>. In studies of the effects of land management on stream insect communities, essentially all effort is usually focused on habitat requirements of the aquatic larvae. What about the terrestrial adult stage? Consider the stoneflies as an example. Following emergence, the adults of many species of nemourid stoneflies(6 species in the Bear Brook drainage) disperse into the surrounding forest to feed on terrestrial algae, lichens, and pollen. Females may double their weight over a 2 to 6 week period before returning to the stream to lay eggs. Although appropriate terrestrial habitat is obviously required for the completion of the life cycles of these organisms, essentially nothing is known about exactly what such habitat requirements are.

<u>Larval food</u>. The primary energy source for stream insects in forested headwater streams in New England is tree leaf litter. Management practices that affect the amount, type and timing of leaf litter that enters a stream channel, and the ability of the channel to hold leaves in place, will affect the structure and production of stream insect communities. The total biomass of leaf litter

entering a stream channel, and its nutritional value, will have large effects on the production of stream insects. The species composition of trees in the riparian zone will determine the nutritional quality of this leaf litter. For example, litter from the American beech is relatively poor in nutritional quality when compared with that of sugar maple. The physical complexity of the stream channel, particularly the frequency of debris dams formed from fallen trees, will increase the retention, and thus the availability of leaf litter within a stream reach.

Light. The amount of light that reaches the bed of a headwater stream will influence the production of algae on stone surfaces (periphyton). The level of response will depend on concentrations of dissolved nutrients. Management practices that influence the balance between the relative availability of algae and tree leaf litter will affect the structure and production of stream insect communities. Although many stream insect species in New England are generalized in their food requirements, others specialize on either tree leaf detritus or periphyton. Changes in the relative amount of these food resources will elicit a change in the relative abundance of the insects that specialize on them.

Water Temperature. The metabolism of stream insects is determined primarily by water temperature, and different species of stream insects often have markedly different thermal requirements for successful completion of their life histories. Changes of only a few ^{o}C (e.g. 2-6^{o}C) may have major effects on the growth rate and developmental time of insect larvae, and the size, fecundity, and timing of the emergence of adults. Management practices that cause even modest changes in stream water temperature may have strong effects on the structure and production of stream insect communities.

GENERAL EFFECTS OF TIMBER HARVESTING ON STREAM INSECT COMMUNITIES

There have been numerous studies documenting the effects of timber harvesting on stream insect communities. The results of these studies are variable and sometimes contradictory (Brown *et al*. 1997). Nevertheless, useful generalizations can be made. Large-scale clearcutting, without maintaining a riparian buffer strip, causes increases in light, summer water temperature, and sediment input to the stream channel, while causing a decrease in inputs of leaf detritus. Increases in light and water temperature often cause an increase in algal production, which provides a high quality food source. In response, the abundance of selected stream invertebrates, typically herbivorous midges and the baetid mayflies, increases disproportionately (Newbold *et al*. 1980; Wallace & Gurtz 1986; Noel *et al*. 1986). These taxa are “weedy”, with rapid growth rates and short life cycles, which facilitates rapid population build up (Wallace & Gurtz 1986). Although an increase in insect abundance is usually reported, decreases also occur (Davies & Nelson 1994). Decreases in abundance are apparently due to the effects of sedimentation or decreased inputs of leaf detritus (Hartman *et al*. 1996). Compared with abundance, the response of taxonomic diversity is variable, with decreases (Newbold *et al*. 1980), increases (Carlson *et al*. 1990; Brown *et al*. 1997), or no change (Silsbee & Larson 1983) being reported. Although long term studies of invertebrate communities following clearcutting are rare, the few that exist indicate that effects on community structure may persist for 5 years or more (Wallace *et al*. 1988).

BUFFER STRIPS AND INSECT COMMUNITIES IN HEADWATER STREAMS

The extreme effects of clearcutting on stream insect communities are fairly well understood. The effects of harvesting techniques that include maintenance of a riparian buffer strip are not. The presence of a riparian buffer strip tends to moderate the most extreme effects of timber harvesting, which causes them to be more subtle and more difficult to detect given the extreme variability inherent among natural streams. However, some generalizations can be made based on the few existing studies of the relationship between buffer width and stream insect communities. Two comprehensive studies conducted on headwater streams in northern California (Newbold et al. 1980) and Tasmania (Davies & Nelson 1994) concluded that buffer strips ≥30 m (99 feet) were required to protect insect communities from the effects of timber harvesting. Buffer strips ≤30 m wide had measurable effects on attributes of macroinvertebrate community structure, such as abundance and diversity. A less comprehensive study based upon a number of streams in New England (including Maine; Noel et al. 1986) supported the conclusions of the California and Tasmania studies by reporting that an 8 to 9 m (26 to 30 foot) buffer strip was not adequate to prevent changes in the density and community composition of insect communities in streams draining logged catchments. In contrast to these studies, a study of the invertebrate fauna of intermittent streams ("0-order") and spring pools in Arkansas concluded that 10 m (33 feet) buffer strips provided adequate protection from timber harvesting (Brown *et al*. 1997).

THOUGHTS ON WHY BUFFER STRIPS CAN FAIL TO PROTECT STREAM INSECT COMMUNITIES

Regardless of their dimensions, buffer strips will not necessarily mitigate the effects of land management practices elsewhere within a watershed. For example, timber harvest may affect the amount of water entering a stream channel regardless of buffer width. A study of an intermittent stream in northern Arizona (Heede 1991) showed that timber harvest within the watershed (~28% of basal area) resulted in a significant increase in annual discharge (48%) even though 50 m buffer strips were maintained and BMPs were closely adhered to. This increase in discharge caused the channel sediments to readjust resulting in an enlargement of channel width and the loss of nearly 50% of the debris dam habitat. Such changes in habitat structure will have significant effects on the structure of stream insect communities.

Although buffer strips are assumed to provide shade to the stream channel, there have been few studies that have actually measured their effectiveness. One study conducted in western Washington (Brosofske *et al*. 1997) concluded that a buffer strip at least 45 m (148 ft) wide was required for maintenance of the natural light regime for a headwater stream. This may have important consequences for the relative abundance of herbivorous insects that specialize on algae. For streams where algal production is limited by nutrients, or streams that are dry during summer, the effect of light penetration of the canopy may be less critical for the insect community.

Does buffer strip width affect the eventual species composition of riparian trees? If so, such effects will have subtle but potentially important consequences for stream insect communities. Although field data are limited, many laboratory studies indicate that the species composition of the tree leaves that enter forested headwater streams will affect the species composition and growth rates of stream insects (Sweeney 1993). Different species of detritivorous insects may prefer different species of detritus. This preference is often correlated with growth rates and ultimately, fecundity and population viability.

The effect of buffer strip management on the eventual species composition of riparian trees should also be considered with respect to anticipated rates of debris dam formation. Present day debris-dam habitats are the legacy of riparian conditions and management practices occurring 5 or 10 or more decades ago (Wallace et al., in press). The buffer strips established today will thus be the source of habitat structure for invertebrates many decades into the future. The management of buffer strips should be based on a long term (~100 yr) perspective.

Several studies have indicated that the maintenance of buffer strips clearly are effective in maintaining temperature patterns similar to those of reference streams (e.g. Swift & Messer 1971). However, the temperature of headwater streams is strongly affected by the source of water to the channel (e.g. groundwater *versus* interflow) as well as processes occurring within the channel (shading, hydrological turnover rate, water clarity). Consequently the effect of buffer strips on stream water temperature will vary with landscape geology and geomorphology. These factors need to be incorporated as covariates in studies of the effects of buffer strip width on water temperature.

There are few studies that have attempted to quantify the activity area for the adult stages of stream insects. One study conducted in New Zealand (Collier & Smith 1996) indicated that the main area of activity of adult caddisflies is within 30 m of the stream edge. Another study conducted in West Virginia (Griffith et al. 1998) estimated mean maximum dispersal distances ranging from 56 to 91 m for adults of a diverse assemblage of insects from several headwater streams. The effect of buffer strip width on adult survivorship and reproductive success is unknown, but the results of these studies indicate that present guidelines for buffer strips in Maine (7.6 to 22.9 m, minimum) may not provide an optimal habitat area for the adult stage of many stream insects. Another related factor that remains unstudied is the effect of predation by birds. Birds are extremely effective predators of adult aquatic insects, particularly in the gallery forests of streams in arid regions (Gray 1989). The presence of a buffer strip surrounding a stream in a clearcut may mimic a gallery forest, perhaps resulting in unusually high levels of predation of adults.

HOW WIDE SHOULD A BUFFER STRIP BE?

How wide should a buffer strip be? No one really knows, of course. However, in the absence of information that is specific for a particular geographic region, it appears logical that buffer strips ≥30 m (99 ft) should be a minimum target for the protection of insect communities of headwater streams. The 25 foot (7.6 m) buffer strip suggested for 0-order streams in Maine is probably inadequate for substantive protection of stream insect communities.

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Forestry and the Biodiversity of Fishes in Eastern North America

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INTRODUCTION

Forests and their lakes and streams are dominant features of the eastern North American landscape. These natural resources have sustained the societies and economies of the east since even before the arrival of the first European settlers. An intimate connection between forests and humans exists and is a defining characteristic of this region. For this reason, there is a concerted effort made by users of these resources to work together to protect and conserve the integrity of the landscape. Timber harvesting has been the most extensive use of the forest. As forestry practices evolved into the mechanized harvests of today, there was an early period of transition when dramatic losses of aquatic habitats occurred. Operations tactics were improved to correct problems, but concerns persist about the preservation of habitats and thus the biodiversity of fishes.

Perhaps the best example of improved protection of aquatic habitats and the evolution of operations came when it was recognized that the forestry activities such as road building and heavy equipment travel had direct, detrimental impacts on streams and lakes. Regulations were established to create riparian buffer strips and appropriately constructed roadways to protect aquatic environments. These practices were specifically designed for and effective at minimizing the deposition of sediments in watercourses and maintaining coldwater environments by leaving trees to protect watercourses from direct solar heating. As long as industry is committed to these management practices, aquatic ecosystems receive a reasonable level of protection. Today, instead of chronic impacts, effects can be limited to acute events such as watercourse crossing failures or riparian buffer strip blow downs that can be mitigated and overcome.

TODAY’S CHALLENGES

Appropriate designs and construction of watercourse crossings for larger systems > 1m in width are well established and implemented by responsible industries. As long as crossings are monitored and maintained on a regular basis, negative impacts on watercourses can be minimized. Today’s problems with crossings occur in small, headwater watersheds. Watercourses are defined differently among regulatory agencies in the region. The definition is important because it dictates the management action to be applied. For example, watercourses < 0.5 m in width or draining areas < 600ha in New Brunswick, not existing on 1;50,000 topographic maps in Newfoundland, or 1:10,000 topographic maps in Ontario, are not insured of receiving an appropriately constructed crossing. In other words, there are no guarantees these small watercourses are protected at crossing locations. Research has established that these small watercourses are critical aquatic habitats. In one lake system, an estimated 80% of the young brook trout spawned in the lake migrated and resided in three tributary streams during the summer at least (Curry et al. 1997). Ongoing studies in the Catamaran Brook Watershed Study (Miramichi River, NB) are demonstrating similar residence in small tributary streams by brook trout, Atlantic salmon, and slimy sculpins, of which the first two spawn in the main river (Curry and R.A. Cunjak, unpublished data). The small streams appear to provide stable, coldwater refugia during summer and potential warm water refugia in winter because of their forested catchments, which sustain groundwater regimes and block direct solar inputs to the streams. The input of sediment from improper crossing and the negative impacts are well established, particularly for salmon and trout and benthic species such the slimy sculpin and including alterations in fish fauna (Waters 1995). Other species also use these smaller streams as spawning and incubation habitats. In Lake Utopia of southwestern NB, the “threatened” dwarf smelt is dependent on two small streams as reproductive habitats (Curry, unpublished data). Such increasing evidence demonstrates that small watercourses in forested landscapes can provide significant habitats for fishes, at least.

The design of riparian buffer strips has been the focus of countless studies. Their function in protecting watercourses from direct impacts is not questioned. Instead, we are learning that their placement and structure within the landscape can influence their success at mitigating impacts from forestry operations. Failures of buffer strips to meet their intended objectives generally arise with their width in relation to the hydrological processes within the forest. Narrow strips are prone to wind throws that can block stream flows and eliminate the original protective strip. Narrow strips can also be navigated by runoff along overland pathways through the strip during storm and snowmelt events delivering sediment from disturbed areas to watercourses. Earlier studies suggested buffer strip width must be designed in the context of the hydrology of a forest’s surface and ground waters (Curry and Devito 1995). Clear cut operations alter groundwater regimes despite riparian buffer strips (Bren 1997, Peck and Williamson 1995). Riparian buffer strips provide protection from direct solar inputs to watercourses (Rishel et al. 1982). Recent evidence indicates that even with a buffer strip, stream temperatures can be elevated and more variable in catchments with < 30% clear cut, i.e., the effects of operations on catchment scale groundwater regimes can be translated to the watercourse (Curry, unpublished data).

Challenges with riparian buffer strips also exist in the small catchments where crossings are problematic. Without a clear definition of a watercourse, it is difficult for managers to appropriately delineate strip boundaries. If the catchment includes wetland areas, the boundaries are further confused because there is no definitive watercourse and sometimes no apparent surface water to aid in delineation. It is not uncommon for operations to invade wetland areas when strip boundaries are inaccurately defined in the field (Curry, unpublished data). The invasion brings the operations area in direct contact with the watercourse system and therefore elevating the risk potential for damaging aquatic habitats initially identified for protection.
The greatest problem plaguing the application of riparian buffer strips is our lack of understanding of hydrological process in forested catchments in relation to forestry operations. Despite many studies, managers and regulators are still struggling to define useful protection

measures for aquatic ecosystems. The problem exists because past study designs addressed either hydrological or biological issues, but not a full integration of both processes in aquatic ecosystems. Our poor comprehension is apparent in our failure to appropriately manage small watercourse crossings and protect small, headwater catchments. Forest managers will continue to struggle and face opposition to harvesting until answers to hydro-biological questions are answered. The best management plans will have to incorporate all elements of the ecosystem to be successful socially and economically.

SUMMARY

The impacts that persist in today's forests are acute incidences of sediment deposition, e.g., unrepaired watercourse crossing failures, poor understanding and design of buffer strips, and the chronic and cumulative effects of not effectively protecting small, headwater watercourses and watersheds. Good management that insures appropriate designs and diligence of maintenance (even after operations have ceased) easily overcomes the first problem. In the small, headwater catchments, the mechanisms of impact are sediment deposition and alteration of thermal regimes at small scales we have yet to recognize as significant. Moreover, we have yet to determine how we translate scale level effects across multiple scales, e.g., first to second order streams, or what the cumulative effects of changes at small scales are on the whole watershed. Until these problems are resolved, the effects on fishes must be accepted as real threats.

Sediment will impede reproductive success of species dependent on gravel and cobble substrates such as trout, salmon, sucker species, and smelt. Species classified as benthic may be most impacted by the loss of habitat structure from sedimentation, e.g., slimy sculpin (Curry and K. Munkittrick, unpublished data). The increased sediment could create more habitat for juvenile lamprey and foraging habitats for free-swimming life stages of suckers, but both species depend on gravel substrates for spawning and incubation. Elevated water temperatures in summer will result in loss of thermal habitats for coldwater species. Trout will be the first to disappear, followed by salmon and sculpins. Cool and warm water species may initially benefit from rising water temperatures, e.g., dace, perch, and sunfishes. However, replacement of indigenous coldwater species with the latter group will not be well accepted by society, which has traditionally targeted our forest's cold and cool water species for recreational and aboriginal purposes.

We don't know how forestry operations in small, headwater catchments are affecting fish habitats and fauna. We don't know how to effectively use riparian buffer strips for complete protection of aquatic habitats. We do know how poorly managed operations alter and eliminate fish habitats. We do know how these habitat changes will translate into changes in the fish fauna. The best management plans of the future need a resolution to some basic questions about hydrological and biological interactions in small, headwater catchments and in relation to the application of riparian buffer strips. The risk assessment for the loss of the biodiversity of fishes will remain high until these issues are resolved.

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Forestry Effects on Vertebrate Species Habitats in the Riparian Zone

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Three factors influence a coarse-filter approach to the providing wildlife habitat in riparian areas in the northeastern United States. These are: 1) degree of riparian-upland forest connectivity; 2) water regime; and 3) key vegetation structures present in riparian areas that are important to terrestrial vertebrate species.

Nearly eighty vertebrate species in the northeastern US have a strong preference for riparian habitats (DeGraaf and Yamasaki 2000; Pauley et al. 2000). The degree of forest cover across a watershed influences amphibian species richness in permanent wetlands in southern New Hampshire (Givens 2000). As adjacent upland conditions and riparian habitats become more similar (e.g., forest-forest edges as opposed to forest-nonforest edges) as in much of the state of Maine (Hooper 1991), avian communities also become more similar to adjacent habitats. Higher avian abundance and species richness occurs in boreal riparian conifer stands than stands farther from water due to the presence of aquatic-dependent species and others associated with the shrub and grass wetland habitat in boreal riparian forests (Larue et al. 1995).

Lacustrine, palustrine, and riverine habitats are important commuting, foraging, and roosting habitats for northeastern bats (Krusic et al. 1996; Krusic and Neefus 1996; Sasse and Pekins 1996). Most small mammal species use a broad range of forest and nonforest types, stand conditions, and stand ages (Miller and Getz 1977; DeGraaf et al. 1991; DeGraaf and Yamasaki (in press)). Small mammal communities in extensive forests generally respond more dramatically to changes in annual food availability and weather than silvicultural treatment (Healy and Brooks 1988). Riparian habitats are recognized as important to many furbearer species such as beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), raccoon (*Procyon lotor*), fisher (*Martes pennanti*), weasels (*Mustela frenata* and *M. erminea*), mink (*M. vison*), and river otter (*Lontra canadensis*) (Novak et al. 1987). Black bear (*Ursus americanus*), white-tailed deer (*Odocoileus virginianus*) and moose *(Alces alces)* find important seasonal habitat requirements in riparian habitats (Schooley 1990; Banasiak 1961; Leptich and Gilbert 1989).

Timber harvesting effects in riparian areas influence the spatial presentation and duration of elements of forest structure. Key considerations are: 1) effects on cavity trees (Leak 1982; DeGraaf and Shigo 1985; Tubbs et al. 1987); 2) nesting and perching sites (DeGraaf et al. 1992; Elliott 1988); 3) dead/down woody debris (Rabon 1994); 4) shrub and herbaceous wetland inclusions (Elowe 1984; Larue et al. 1995); and 5) softwood composition (Banasiak 1961; Kelly 1977; Weber et al. 1983; Reay et al. 1990; Thomasma 1996).

Buffer zones are commonly used to protect riparian area values (Naiman et al. 1993; Small 1986; Johnson and Brown 1990; Darveau et al 1995; 1998; Noble 1993; Vander Haegen and DeGraaf 1996; Meiklejohn and Hughes 1999). Criteria used vary greatly depending on agency or company needs, riparian type, topography, slope, and soils. Common considerations in buffer-zone design generally include a no-cut or lightly cut area of variable width that minimizes soil erosion and maintains streambank stability (Small and Johnson 1985; NH Div. Forests and Lands, DRED and SPNHF 1997) and an adjacent zone where some of the overstory remains over time. There are many questions still to be investigated whether or not riparian management areas serve as vertebrate species' travel corridors, refugia, sources or sinks, and critical wildlife habitats.

RECOMMENDATIONS

There are no one-size-fits-all recommendations to guide habitat management guidelines in riparian areas at present. Variety in buffer widths, disturbance regimes, adjacent land uses, and vegetative structure is an important consideration. Habitat management of riparian areas includes landscape-level, stand-level and within-stand or structure considerations.

Landscape-Level Considerations

At this scale, several items need consideration in developing habitat management plans:

a) Consider variable riparian area management widths with some regard to stream order hierarchy or stream width.

b) Limit new roads in riparian areas; consider the reducing the traffic on existing roads in riparian zones at certain times of the year (e.g. bear hunting season).

c) Avoid patterns of long linear clearcuts adjacent to riparian areas, especially if the other side of the drainage was recently cut or soon-to-be cut.

d) Consider tree species composition potential -- are long-term changes in composition warranted, possible, or necessary?

e) Consider using wider riparian management zones than those normally prescribed to protect streambank stability, provide brook shading, and limit sedimentation where agricultural or urban landscapes predominate.

f) Consider: 1) limiting grazing activities at the water's edge with fencing when necessary; and 2) limiting borrow pit development and reclaiming existing borrow pits with native species.

Stand-level Considerations

Vertebrate species composition benefits from a variety and diversity of vegetative conditions, forest types, sizes, and age-classes (DeGraaf et al. 1992). Again, there are no one-size-fits all solutions. Site, slope, aspect, soil types, and seasonal limitations (e.g. raptor nesting concerns) all bear on potential stand-level prescriptions. Opportunities are normally present with both even-age and uneven-age management systems to meet wildlife habitat landscape goals; consider how one might implement landscape goals at the individual stand level.

Within-Stand or Structure Considerations

The vegetation structures to be maintained or developed need to be based on the site specific potential. For example, in seasonally flooded drainages, it might be very difficult to establish and maintain a dense shrub zone or dense herbaceous ground cover; yet in other less frequently disturbed drainages, the likelihood of success is much greater. To provide an array of structural components over time:

a) Consider higher densities of cavity trees and snags, especially larger diameter trees; think hard before immediately prescribing salvage harvests.

b) Consider a variety of canopy closures; raptor nesting and perching tree potential, softwood-to-hardwood or mast-to-non-mast basal area ratios.

c) Consider the opportunity to increase the dead and down woody debris component in drainages not only for stream channel modifications but also for terrestrial wildlife.

c) Encourage the development or maintenance of distinct shrub layers, thickets, and grass/sedge and herbaceous ground cover. These add important habitat elements to any riparian area.

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Cumulative Watershed Effects of Forestry

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ABSTRACT

Cumulative Watershed Effects (CWEs) result when multiple actions, occurring at different locations or at different times, combine to cause impacts that are *usually* greater than either of the individual actions. In reality, the difference between cumulative and individual impacts is largely artificial since all management practices interact with other practices and watershed conditions. Several important principles can be used to guide management of CWEs. Perhaps the most important principle to understand the link between specific management practices and watershed response based on watershed conditions and processes. Three alternative approaches have been developed for landscape management based on Best Management Practices (BMPs), conservation biology, and historic disturbance patterns. Each approach has its strengths and weaknesses. A practical management approach will fall somewhere in the middle of these alternatives. Watershed Analysis provides some key central concepts for CWE assessments including the needs to be systematic, structured, reproducible, defensible, and adaptive. Some tools that are being developed to address CWEs questions are described including DHSVM, SEDMODL2, BASIN2S and Habplan. An effective CWEs program for forestry must balance between being so reductionist that essential processes and control options are missed and being too detailed so that it becomes overly expensive and cumbersome to apply.

WHAT ARE CUMULATIVE EFFECTS?

Just what are Cumulative Watershed Effects (CWEs)? The definition has been the subject of extensive debate and multiple definitions. For example:

The Idaho Forest Practices Act (FPA) defines CWEs (IDL 1995) as follows:

> “*Cumulative effects means the impact on water quality and/or beneficial uses which can result from the incremental impact of two (2) or more forest practices. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time.*”

Green et al. (1993) define cumulative effects from forestry as

> “*…changes to the environment caused by the spatial and temporal interaction of natural ecosystem processes resulting from two or more forest practices.*”

The Dictionary of Forestry (Helms 1998) defines cumulative effects as

> "*…the combined effects resulting from sequential actions on a given area—note significant cumulative effects can result from individually minor but collectively important actions taking place over a period of time because of their being interconnected or synergistic*."

The central thought in these definitions is that multiple actions occurring at different locations or at different times can combine to cause impacts that are greater than either of the individual actions. In order to model and manage for cumulative effects we need to be able to predict the scale and timing of individual impacts and route these impacts to critical locations in the watershed. Unfortunately, concerns about "how much" management is occurring often overshadows equally important questions about "how, where, and when" operations are carried out and which are critical to predicting the magnitude and routing of individual impacts. To successfully manage for CWEs requires that a few key principles be recognized. These are described below.

PRINCIPLES FOR PREDICTING AND MANAGING CUMULATIVE EFFECTS

Recent reports provide some key principles for understanding and managing for CWEs related to forestry. These reports include: *Cumulative Effects of Forest Practices in Oregon* (Beschta et al. 1995), *A Draft Proposal Concerning Oregon Forest Practices* (NMFS 1998), *Forest Practices Cumulative Watershed Effects Process for Idaho* (IDL 1995), *Board Manual: Standard Methodology for Conducting Watershed Analysis* (WFPB 1997), and *Status of the NCASI Cumulative Watershed Effects Program and Methodology* (NCASI 1992). A synthesis of some of the key principles follows.

- Cumulative effects are real and logical, but it is very difficult to define in advance thresholds beyond which significant effects will occur.
- The distinction between CWEs and individual effects is largely artificial.
- We typically can not measure small incremental changes and may not need to.
- CWEs move from a reductionist approach of cause and effect to complex multivariate relationships.
- While everything is connected to everything else, impacts from management activities are not all equal. We can generally identify and distinguish between those having large and small effects.
- Forest management needs to be linked to water resource impacts through an understanding of watershed processes. This will allow for the most efficient design of management solutions.
- In general, the intensity of the cumulative effect is inversely proportional to the distance between the activities and point of measurement. Pollutants are non-conservation.
- The ability to assign cause and effect diminishes with time and distance, and complexity of the process linkage.

- Hazards on the watershed and risks in the stream system vary and must be understood to effectively manage CWEs.
- An external event may be necessary to expose a cumulative effect, so plan for failure.
- Any CWEs assessment process should be systematic, structured, reproducible, defensible, and adaptive.

MANAGEMENT APPROACHES TO ADDRESS THESE PRINCIPLES

Given this long, and yet incomplete, list of CWE principles, just how does a forest manager develop a method that will not be reductionist to the point that management impacts are imprecisely, and even inaccurately, linked to water resource impacts, but not so cumbersome that decisions can never be made? There have been three general approaches to managing for CWEs and other landscape management values (Figure 1) (NMFS 1998; Swanson 2000). These are:

- the agricultural model of specific control practices to reduce impacts from management, best represented by forest practice rules and BMP programs
- the conservation biology approach which is designed to manage forests to provide for the needs of a specific species or group of species
- the ecosystem dynamics approach which seeks to restore the historic range of forest and watershed conditions based on historic disturbance patterns

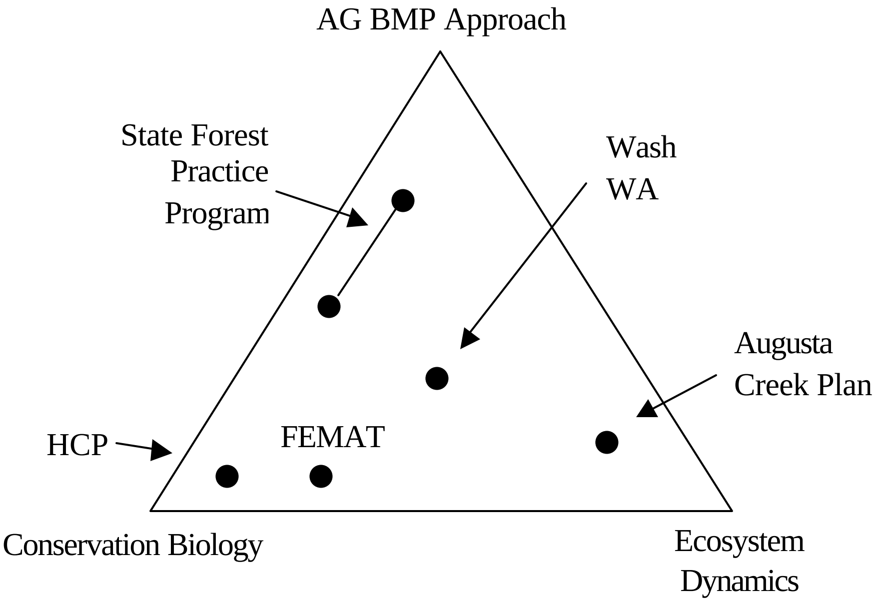

Figure 1 - Management Triangle for Forest CWEs (based on Swanson 2000)

Which of these alternatives is the most appropriate approach? We believe that each brings values and flaws and that the answer lies somewhere in the middle.

BMP Approach

We know that specific management practices can be used to reduce the on-site impacts of forest management activities. Reducing on-site impacts and their delivery to streams will reduce the opportunity for impacts to accumulate (Ice 1986). In fact, there are only two ways to control cumulative effects. One is to impose specific on-site management practices that reduce individual management impacts or delivery of material and energy. The other is scheduling to reduce the overlap of impacts.

The biggest problem with the BMP approach is that the same practice on different sites or in different watersheds, or even with different weather patterns, can result in different impacts. This means that in some sites, BMPs over-protect and are excessively expensive for the benefits they provide. In other sites, they are underdesigned and result in undesirable impacts.

One solution to this dilemma is customizing BMPs to their setting. Usually this involves a classification scheme. A simple example of customizing BMPs is spacing for waterbars based on road grade. Table 1 provides an example from the *Best Management Practices Field Handbook* for the spacing of water bars on roads, i.e., the steeper the grade, the closer the spacing of waterbars. But, does road gradient capture the essential watershed conditions needed to space waterbars to minimizing erosion? What about soil type or precipitation intensity? Research from Oregon on roads shows that the soil makes an important difference in performance. The trick is to design methods that are as simple, but as robust, as possible to set appropriate BMPs.

Table 1 - Waterbar Spacing from BMP Field Handbook (MFS 2000)

Road Grade (Shown as percent)	Spacing (Shown in feet)
1-2	250
3-5	200-135
6-10	100-80
11-15	80-60
16-20	60-45
21+	40

Classification schemes are now beginning to look at connections between the managed site or stream reach and conditions upstream or downstream. For example, small, non-fish-bearing streams that deliver directly into fish-bearing streams may be treated differently than those farther removed. This increasing level of classification sophistication requires an understanding of the beneficial uses to be maintained, many having to do with fish, which brings us to the next approach, using conservation biology.

Conservation Biology Approach

The conservation biology approach manages for a particular species or group of species. An example is the *Plum Creek Timber Company Native Fish Habitat Conservation Plan* (NFHCP) (PCTC 1999). The NFHCP is designed to protect bull trout and other native salmonids on 1.7 million acres of Plum Creek Timber Company land in Montana, Idaho, and Washington. Biological goals involve what are called the "Four C's."

- Cold - Protect stream temperatures and contribute to restoration where past management has elevated temperatures to unsuitable levels.
- Clean - Protect in-stream sediment levels and contribute to restoration where impacted by past management.
- Complex - Protect in-stream habitat diversity and contribute to restorations where past management has impacted.
- Connected - Protect and contribute to restoration of connectivity in the project area.

There are 53 individual conservation commitments to achieve these four biological goals.

A concern about the biological conservation approach is that it ultimately selects specific species and manages for conditions that favor those species. In the case of the NFHCP, decisions are based on the biology of bull trout. Other fish or aquatic organisms not selected will either be "brought along for the ride" (assuming they are co-dependent on the same conditions) or may even be negatively impacted. Management targets may change over time. For example, lobster was once considered a trash species that only the poor would eat. Kokanee/sockeye salmon were once poisoned by the Idaho Department of Fish and Game to promote trout fishing in lakes (Buchal 1997). Now sockeye salmon are listed as endangered and severe management actions, including removal of Snake River dams, is contemplated.

Some efforts using the conservation biology approach have focused on protecting reserves where high quality habitat exists. Yet, ecologists know that ecosystems are not static and change over time. In fact research has shown that in some cases, what is considered catastrophic in the short term can be beneficial in the long-term (Burke and Nutter 1995; Miller and Benda in press). In some cases, a sequence of conditions, such as changes in forest cover from conifers to hardwoods and back to conifers, is necessary to achieve optimum habitat conditions (Connolly and Hall 1994). This dynamic process is captured in a third approach based on historic disturbance regimes and conditions.

Ecosystem Dynamics

Forests are dynamic and will never be static. Some forest managers are now trying to use historic disturbance patterns and resulting conditions as a template for how to manage forests. The objective is to develop a distribution of conditions across the landscape that mimic those created by natural disturbance. An example of this approach is a management plan for Augusta Creek (Cissel et al. 1998) in the Oregon Cascades, designed to mimic the conditions created by the historic fire regime of the area. The August Creek Plan used a dendrochronological study to interpret the fire patterns and forest conditions over the last 500 years. This information was used to set different rotation ages (from 100 to 300 years), green-tree retention levels (15 to 50% of canopy cover), and distributions of residual trees. This approach is challenged by public preferences for certain conditions, a range of natural conditions that fully encompasses all management impacts, and the need to produce commodities for an economic return on forestland investment.

The public's preference for specific forest and watershed conditions is highlighted in the recent wildfire conflagration in the West. Clearly fire suppression efforts and selective harvesting methods have allowed fuel levels to increase and dense understories of light tolerant species to develop. Many of the problems can be addressed through mechanical and chemical treatment and prescribed burns. But not all forest types are well adapted to both wildfire and people. Wet fir-dominated forests burned infrequently but catastrophically. It is unlikely that we would accept let-burn policies for these types of forests where human life and property are at extreme risk. One of the reasons private investment has become attractive for forestry is the reduced risk of having assets consumed in a wildfire. Other consequences, such as increased smoke, may also be unacceptable to the public.

In some cases fish habitat may be closely linked to conditions that the public finds offensive. In the Pacific Northwest debris torrents can scour fish habitat and result in temporary reductions in fish habitat. However, they also create sediment waves in streams that result in the creation of favorable off-channel habitat (Miller and Benda in press). Similarly, abusive agricultural practices in the South choked streams with sediment but some watershed managers are now concerned about wetlands (off-channel habitat) that are being disconnected from streams as channels incise though these historic sediment deposits (Burke and Nutter 1995).

Putting These Approaches Together

Each of the approaches described above has its benefits and its drawbacks. An appropriate management strategy for cumulative effects draws elements from each. Watershed Analysis (WA), as developed in Washington, represents this type of combination. It uses the forest practice rules as a primary control. Rules or BMPs are set for specific landscape conditions and, in some cases, scheduling is used to avoid adverse accumulations of impacts. Materials and energy are routed to critical stream reaches to address public resources at risk, including fish habitat (based on the biology of key species). There is feedback between the management activities on the watershed slopes and the predicted in-stream conditions in the stream that affect fish biology. Historic conditions in the watershed are also simulated and used to compare outputs and distributions of water, energy, and material. Thus WA uses elements from all three landscape approaches. It also has monitoring to provide feedback on whether hypotheses about watershed response prove realistic and formal protocol that make it systematic, structured, reproducible, and defensible.

WA (or some modification of it) has been widely adopted in the Pacific Northwest as the method of choice to assess CWEs. Yet it is interested to find that WA has essential ceased in Washington. Companies that conducted WA still indicate that the information is the best synthesis of how the watershed operates, where management can be improved, and if practices are sufficient to achieve watershed goals. But the cost, time invested, political grief, requirements for periodic updating, and meager management returns have not supported its continued use. To overcome some of these problems, some companies have used detailed WA combined with classification methods to extend assessments and BMP recommendations to similar watersheds and conditions.

TOOLS FOR ASSESSING CUMULATIVE WATERSHED EFFECTS

One of the most appealing tools for forester watershed specialists is the development of realistic models that can simulate response to forest management practices at both the site and watershed scale. Unfortunately, more work has gone into developing various watershed models, while little work has gone into validating these models, calibrating them to different watershed conditions, and making them user friendly.

DHSVM

NCASI has been working with the University of Washington and Battelle Northwest Laboratories to refine and validate the Distributed Hydrologic-Soil-Vegetation Model (DHSVM) using watershed data collected by companies for different conditions. "DHSVM accounts explicitly for the effect of topography and the spatial distribution of land surface processes at the scale of currently available Digital Elevation Models (30 to 90 m)" (Wigmosta 1996). Features include a spatially distributed, digital elevation model grid-based approach; an automated model setup using the GIS ARCINFO; explicit, spatially distributed representation of road networks; spatially distributed vegetation and soils properties; topographic control on absorbed short-wave radiation, precipitation, and downslope water movement; a two-layer soil rooting zone model; a spatially distributed two-canopy evapotranspiration model; simplified topographically driven surface and subsurface flow routing; GIS post-processing of model outputs; and channel flow routing (Figure 2).

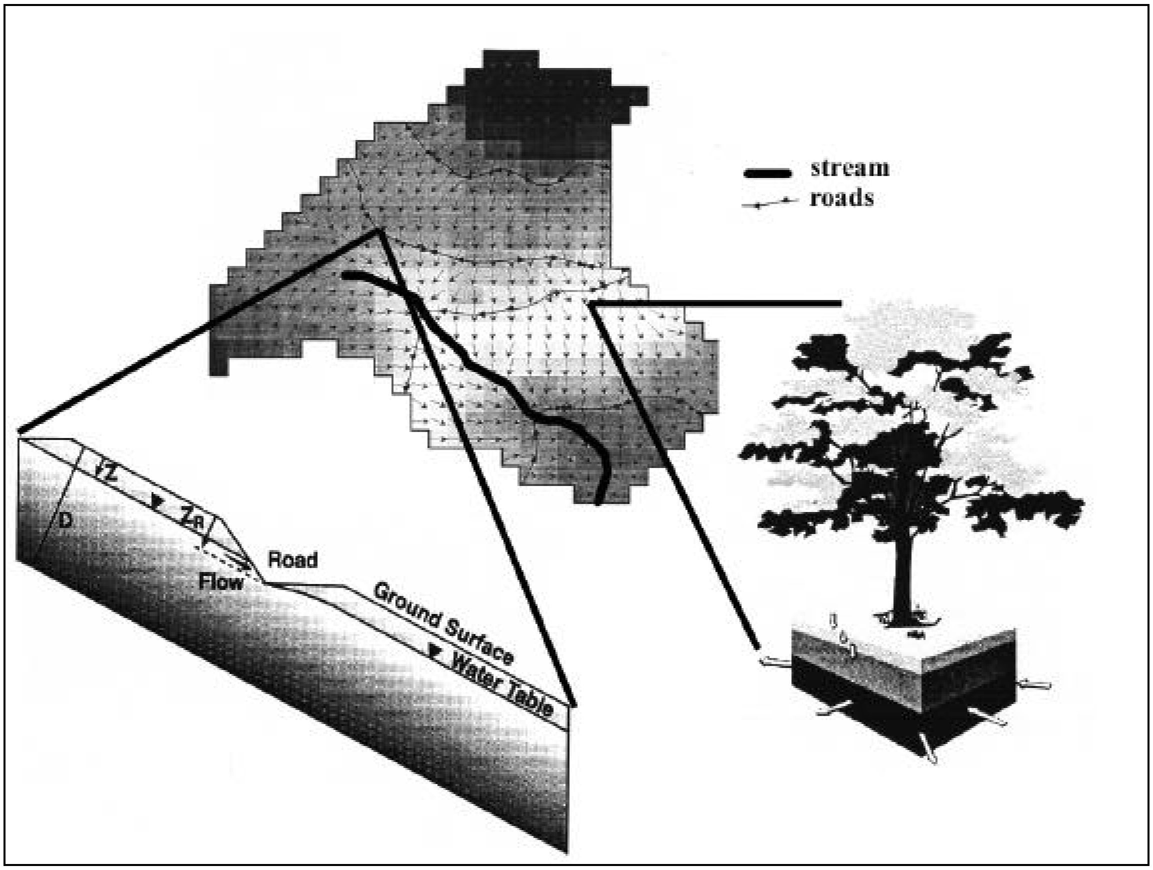

Figure 2 - DHSVM Model Utilizes GIS Data to Simulate Spatially Explicit Hydrologic Response and Route Discharge Through Road and Stream Reaches

Testing of DHSVM is occurring on gaged industry watersheds, including the Little Naches in eastern Washington, the Deschutes in western Washington, Mica Creek in northern Idaho, and Carnation Creek on Vancouver Island (Figure 3). This model has been converted from requiring a mainframe computer to a PC-based Windows NT environment.

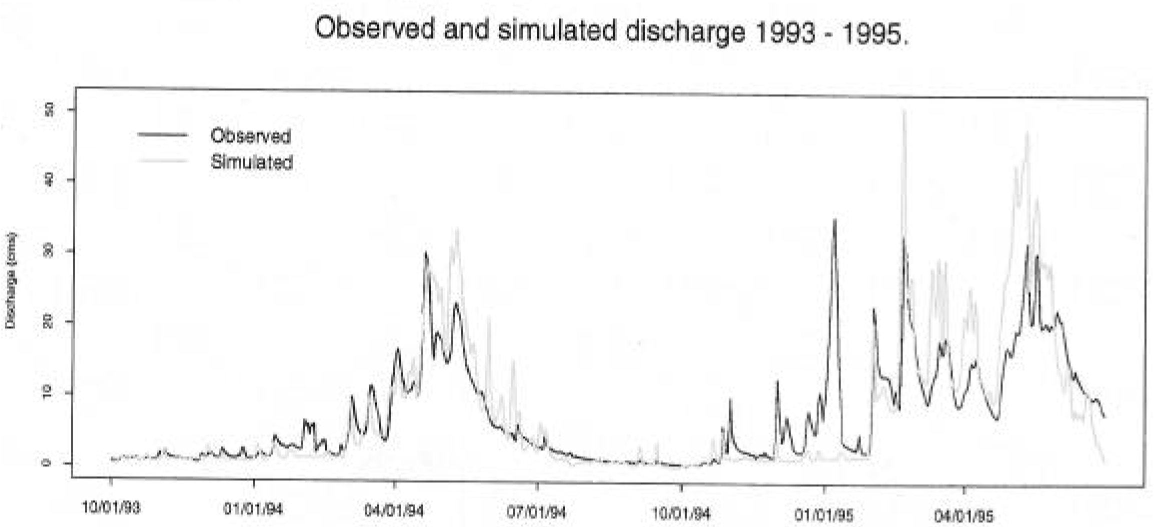

Figure 3 - Comparison Between Observed Discharge for the Little Naches River in Central Washington and Simulated Discharge Using DHSVM
(from Wetherbee and Lettenmaier 1996)

SEDMODL2

SEDMOD is a GIS-based road erosion/delivery model, developed by Boise Cascade Corporation, designed to identify road segments with high potential for delivering sediment to streams. SEDMODL2 is an updated version being developed by NCASI and Boise Cascade that will be more user-friendly. The model uses an elevation grid combined with road and stream information layers to produce a computer-generated version of the Washington surface road erosion module (Figure 4). It estimates background sediment, generation of sediment for individual road segments, finds road/stream intersections, and estimates delivery of road sediment to streams. At the recent American Fisheries Society National Convention session on Fish and Fiber: Can They Coexist, speakers consistently referred to the 20/80 rule: 20% of roads cause 80% of the problem. SEDMODL2 identifies segments with a high potential for contribution of sediment to streams.

ROAD SEDIMENT

Total Sediment Delivered from each Road Segment (tons/yr.) =*TREAD + CUTSLOPE*

Tread = ***Geologic Erosion Rate * Tread Surfacing Factor *Traffic Factor * Segment Length * Road Width *Road Slope Factor * Precipitation Factor *Delivery Factor***

Cutslope = ***Geologic Erosion Rate * Cutslope Cover Factor * Segment Length * Cutslope Ht * Delivery Factor***

SEDMOD

Figure 4 - Basic Framework of SEDMODL2 for Calculation of Road Sediment Delivered from Each Road Segment (from Glass and Megahan 2000)

BASINS2

An emerging tool for modeling is BASINS2 (Whittemore and Ice 1998). BASINS2 is a comprehensive EPA software package recently released by the Office of Water. It is designed to enable water quality analysts and watershed managers to perform studies using a geographic information system (ArcView), watershed landuse and water quality monitoring data, and state-of-the-art environmental assessment tools. BASINS2 provides information for any of the 2,150 watersheds in the conterminous United States. It incorporates models such as HSPF, TOXIROUTE, and QUAL2E. BASINS2 has much promise, but its coarse spatial scale and treatment of land use activities do not support assessments of alternative forest management activities at this time (Figure 5).

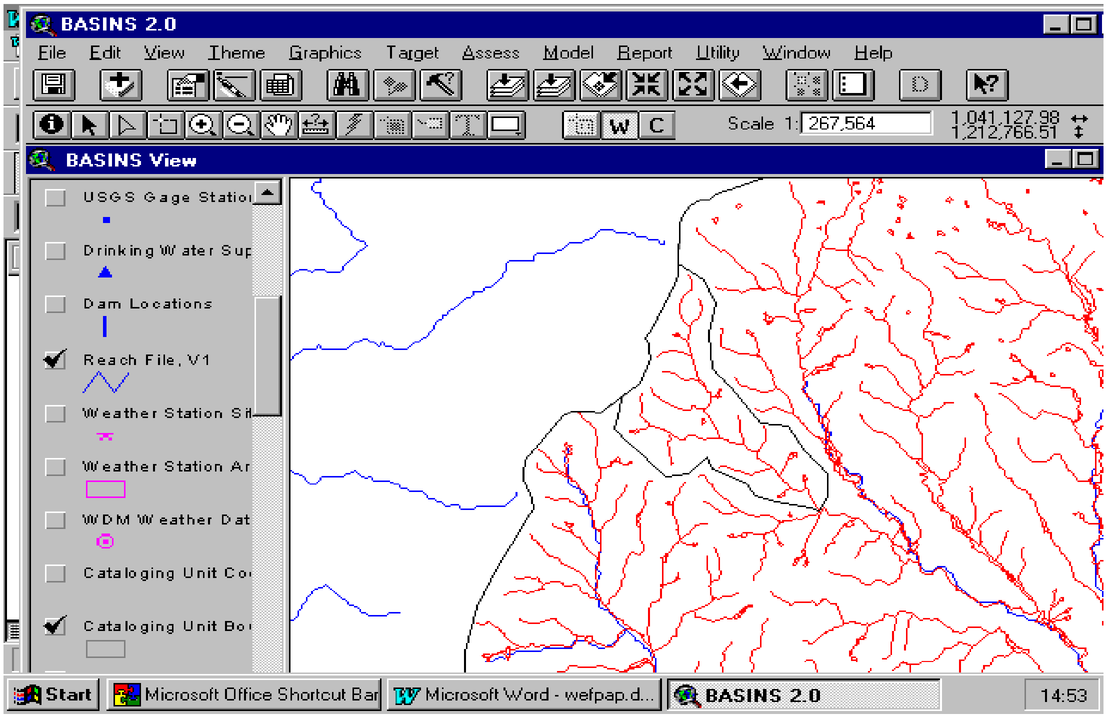

Figure 5 - BASINS2 Combines Easy Access to Data, Integrated Watershed Models, and a PC-Compatible Windows Environment

Habplan

Habplan is a landscape management and scheduling model developed by NCASI (http://www.ncasi-nerc.org/projects/habplan/). Habplan selects from management regimes that the user indicates are allowable for each polygon on a landscape. Simulations are based on the Metropolis Algorithm. Habplan is a random (within feasible criteria) schedule generator that continues to run and generates alterations to the previous schedule until the operator is satisfied. Habplan could be used to identify a harvest schedule that limits the amount of a watershed harvested in sensitive soils at any time or that constrains harvesting of first-order drainages to a targeted percent at any one time. It might also be used to maintain connectivity between streams to minimize isolation of amphibians during a shift mosaic of harvesting.

TAKE-HOME POINTS

- A program to effectively and efficiently address CWEs requires a careful balance between being so reductionist in the characterization of watershed processes that essential mechanisms and control options are missed and being so detailed so that it becomes too expensive and cumbersome to apply.

- Well-designed programs based on BMPs can find a high level of compliance, because BMPs work and there is some certainty for planning future forest management activities.

- BMP-based programs are often viewed with skepticism by those focused primarily on watershed concerns because BMPs may fail to recognize sensitive conditions, whether hazards on the landscape or risks in receiving streams.

- WA has melded many elements from BMP-based, conservation biology, and historic condition approaches and also provides a systematic, structured, reproducible, defensible, and adaptive procedure for analyzing watersheds and identifying appropriate management practices.

- WA has at least partially flopped because it was too complicated, too time consuming, too expensive, and failed to diffuse the debate about appropriate practices, only changing the scale where the debate occurred.

- Efforts to address cumulative effects should look at how to secure benefits for watershed conditions and the landowners that manage those watersheds, so that the process, as well as the health of the watershed, can continue to be sustainable.

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POSTER ABSTRACTS

A Method for Evaluating Potential Forested Riparian Restoration Sites in Heterogeneous New England Watersheds

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The close mix of urban/suburban/rural forested, privately owned, land uses typical of the six-state New England region poses difficult challenges for inventorying and assessing highly fragmented riparian areas. After evaluating remote sensing and existing methods, the USDA Natural Resources Conservation Service New England Interdisciplinary Resource Team (NEIRT) developed a Riparian Area Inventory Guide that is uniquely suited to fragmented riparian areas. The method is designed to be useable by nonprofessionals, especially volunteer landowner groups, working within a watershed coalition. It is designed for use in conjunction with in-stream assessment procedures and incorporates socioeconomic information, and landuse and ownership changeability, along with the potential for positive impacts on forested riparian ecosystems. By identifying the highest potential for both ecological input and receptivity for land use and management changes by current and future owners, a ranking of priority sites for restoration and enhancement can be developed. The procedure is designed to allow different groups to collect inventory information, and to make the assessment and watershed action plan in a subsequent step. Testing of the guide was conducted on the Salmon Brook, Dunstable, Massachusetts. This 14,000-acre watershed is mostly wooded with light to medium residential and light commercial areas. Inventory and assessment worksheets were then adjusted to meet the needs of the local volunteer group.

Method to Determine Effective Riparian Buffers for Atlantic Salmon Habitat Conservation

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The ecological integrity of rivers is dependent upon effective riparian buffer zone management. Natural resource managers, policy developers, foresters, local conservation groups, and others require science-based information concerning the width at which a given buffer will be effective for water quality maintenance and other desired functions. This poster summarizes a method developed in 1999 to determine effective riparian buffer widths for Atlantic salmon habitat protection as part of the Atlantic Salmon Conservation Plan to protect critical salmon spawning and rearing habitat, as identified by the U.S. Fish and Wildlife Service and the Maine Atlantic Salmon Commission, from potential land use impacts.

A major assumption of the method is that no two buffers are alike with respect to their effectiveness and that various buffer characteristics dictate the required width for a given level of effectiveness (Kleinschmidt, 1999). The method uses a predictive model that generates suggested riparian buffer widths as a function of specific, measurable buffer characteristics (such as slope, soil characteristics, and plant community structure and density) that affect buffer function. The method utilizes a variable-width, two-zone approach and specifies land uses that are consistent with desired buffer function within the two zones.

A forested cover type in the portion of the riparian buffer immediately adjacent to the watercourse is necessary for buffer functions such as shading and large woody debris inputs to reach their full potential for river and salmon habitat protection. A minimum undisturbed zone (no harvest zone called Zone 1) of 35’ is recommended immediately adjacent to the stream. Further, it is necessary to maintain minimum stocking levels in the larger riparian zone or Zone 2 (e.g., the portion of the riparian buffer more than 35’ from the stream edge) to ensure wind firm conditions. The total width of Zone 1 and Zone 2 combined ranges from a minimum of 70’ to a maximum of several hundred feet or more depending on buffer characteristics.

Land uses that result in impervious surfaces, removal of the duff layer, fertilization or chemical use, alterations to the infiltration capacity of the soils, or tree removal sufficient to jeopardize wind-firm conditions adjacent to the stream are not compatible with the desired functions of Zone 2. However, limited tree removal using BMPs in the Zone 2 portion of the buffer (*i.e.*, more than 35’ from the stream) is consistent with desired buffer functions such as shading, woody debris inputs, and water quality maintenance. Non-forested systems such as meadow have been shown to filter sediment from stormwater runoff as well or better than forested systems in some situations because the dense, low vegetation discourages concentrated runoff patterns and encourages diffuse flows and infiltration. Limited removal of timber in Zone 2 where proper BMPs are used can also result in vigorous re-growth (including rapid assimilation of nutrients) and no increase in erosion. Buffer widths should not be relaxed for smaller streams. Small 1st order streams are actually more vulnerable to impacts from sedimentation, solar heating, base flow alterations (e.g., water withdrawals) and other potential effects of logging, agriculture, and other land uses, because they are less able to dilute or buffer such impacts.

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Water Temperature Characteristics of 1st Through 4th Order Streams in Western Maine.

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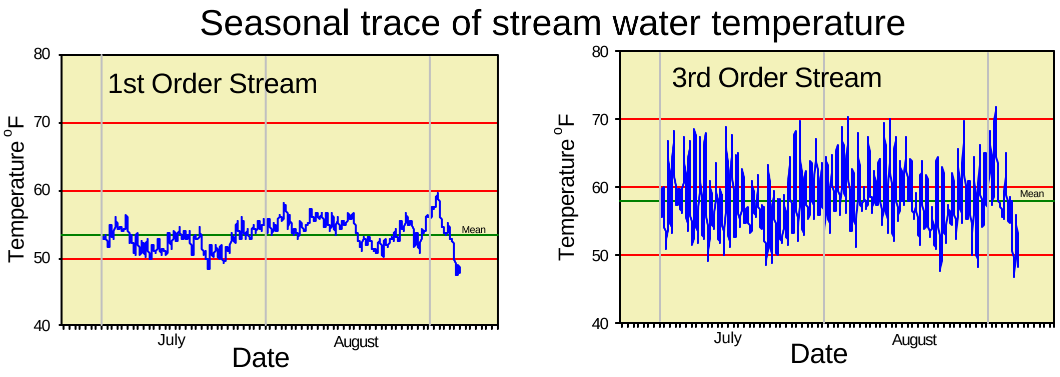
Water temperature is an important habitat parameter for streams, yet basic stream temperature information has been lacking in the region. In the summer of 2000 we placed 25 automatic temperature probes in 1st to 4th order streams in western Maine. Probes were place in 2 watersheds, one heavily cut over in the past 10 years, and one with very little harvesting in the past 40 years. The two watersheds joined at a 4th-order confluence. Streams in the harvested watershed were typically protected with 75' uncut or partial-cut buffers. Probes were synchronized to record water temperature at the same time each hour of the day between July 1 and August 31. Our objectives were to (1) understand basic temperature changes as water moves downstream from lower to higher orders, (2) understand whether water temperature exceeded the thermal maximum for brook trout in a heavily harvested watershed, and (3) understand the relationship between stream order and diurnal variation in stream water temperature.

Stream temperature results based on stream order are shown below:

Order	# stations	Mean daily Max	Seasonal Max
1	8	58.3 °F (14.7°C)	63.9 °F (17.7°C)
2	12	61.7 °F (16.5°C)	66.9 °F (19.4°C)
3	3	66.5 °F (19.2°C)	70.3 °F (21.3°C)
4	2	67.6 °F (16.6°C)	69.2 °F (20.7°C)

As expected, stream water warmed as it moved into higher order stream channels. However, neither mean daily maximum temperature nor seasonal maximum temperature for any stream order exceeded the thermal maximum for brook trout (~75-80°F; 25-27°C). Moreover, the seasonal maximum temperature in the harvested watershed was slightly *lower* in 1st and in 2nd order streams than in the unharvested watershed. This could be explained by many factors unrelated to harvesting, but at least we demonstrated that the cut-over watershed did not cause excessive stream warming.

Finally, we were interested in characterizing the diurnal fluctuation in stream temperature in relation to stream order. We predicted that lower stream orders would display wider fluctuations in daily water temperature because smaller volumes of water respond more quickly to differences in air temperature, all else being equal. However, 1st order streams showed the *lowest* daily fluctuation in temperature (mean = 3.0 °F / day), followed by 2nd order streams (4.2 °F/day), and then by 3rd order streams (7.2 °F/day). Thus, some factor other than stream volume appears to influence diurnal water temperature fluctuation. The most likely explanation for this observation was stream exposure to sky. Higher order streams are more open to the sky, and thus are more responsive to radiational heating (during the day) and cooling (at night). Normal diurnal stream temperature fluctuation was maintained with the protective buffer strips used in the cutover watershed.



Rate of Stream Water Warming in Buffered-Clearcut and Intact-Forest Streams in Western Maine

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Water temperature is a fundamentally important parameter for stream health. Increases in water temperature can have undesirable effects on stream chemistry, aquatic insects, stream flora, and fish behavior and development. Consequently, maintaining water temperature within acceptable limits is a key goal of forest practices in the riparian zone. Small headwater streams are considered more vulnerable to changes in temperature than larger streams because small streams or normally shaded from solar radiation by the forest canopy.

To better understand whether forested buffer strips maintain stream temperatures, we studied the rate of water warming in 6 headwater streams in western Maine during the summer of 1999. Three streams were surrounded by extensive, intact mature forest (Control streams), and 3 streams were surrounded by clearcuts but protected with 75’ (each side) mature forest buffer strips (Buffer streams). In each stream we placed temperature probes at 100 m intervals over a 300 m stream reach (0, 100, 200, and 300 m). All probes were synchronized to record water temperature at the same time each hour.

Throughout the summer, water in 2 of the 3 Buffers streams was consistently colder than the Control streams. The remaining Buffer stream was consistently the warmest stream. Thus, the presence of adjacent clearcuts was poorly related to absolute stream temperature.

Normally, water warms as it flows downstream as a result of contact with air, the confluence with other streams, and accumulated solar radiation. However, water in 2 of the 6 streams we studied *cooled rather than warmed* over the 300 m study reaches (1 Control Stream and 1 Buffer Stream). For the remaining 4 streams, water temperature increased. Water in the 2 Buffer streams that exhibited warming, warmed at a rate 2 to 4 times that of the 2 Control streams that warmed. But despite the greater rate of warming in 2 of the Buffer streams, they still remained colder than all 3 Control streams.

It appears that 75’ buffer strips maintained water temperature at levels conducive to brook trout (*Salvelinus fontinalis*), a key indicator of stream health. Moreover, two key factors unrelated (or weakly related) to timber harvesting appeared to dominate stream water temperature behavior: (1) subsurface inflow, and (2) stream source (e.g., seep vs. pond). Only if streams are near the thermal limit for brook trout (75-80^{o}F; 25-27^{o}C) as they enter a harvest area, might 75’ buffer strips be insufficient to keep stream water temperature within an acceptable range. However, headwater streams small enough to be fully covered by canopy are often much colder than the brook trout thermal limit. Such streams are unlikely to breach this threshold when 75’ intact buffer strips are used, even if they warm at a faster rate than streams surrounded by extensive forest.

Do Riparian Buffer Strips Maintain Interior-Forest Air Temperatures?

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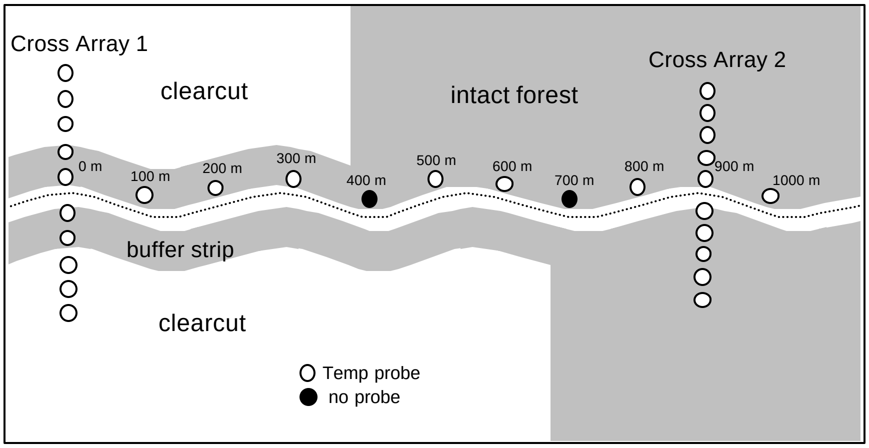
A key reason riparian buffer strips are retained along streams in forest management is to protect stream water temperature. If buffers are wide enough and cool enough, they also may maintain terrestrial components of biodiversity. In 1998, we studied air temperature within a 75' buffer strip, in the adjacent clearcuts, and in upstream intact forest. Our goal was to determine whether air temperature in 75' buffer strips was similar to air temperature in interior, intact riparian forest. If interior forest air temperature is maintained in buffer strips, then biodiversity components might also be maintained.

To understand air temperature in and around riparian zones, we established 2 perpendicular temperature sensor arrays and 1 longitudinal array along a 1st order headwater stream in western Maine (see. Fig.). The 2 perpendicular arrays extended 50 m away from the center of the stream, with probes at 10 m intervals. One array crossed the buffer strip and extended into the flanking clearcuts (Array 1). The other array was positioned well within flanking intact mature forest (Array 2). The longitudinal array was positioned at 100 m intervals along a 1000 m stream reach, and 10 m from the stream center. Probes were synchronized to record temperature every hour between July 1 and August 31, 1998.



We compared the daily maximum temperature for each probe in Cross Array 1 to the daily maximum temperature in the corresponding probe in Cross Array 2. The probes in the clearcut recorded average daily maxima 5 – 10 ^{o}F higher than daily maxima in the intact forest array. Air temperature can be greatly elevated just 10 m into a clearcut from the riparian buffer edge.

However, air temperature also rapidly dropped within the riparian buffer strip. The 2 probes closest to the stream in Array 1 recorded daily maxima that averaged only 0 – 2 °F warmer than corresponding intact forest probes.

The longitudinal array indicated that at some locations along the stream, the buffer strip did not maintain interior forest air temperature. For example, the probe at the 200 m station displayed an average daily maximum temperature approximately 4 °F warmer than the 800, 900, and 1000 m longitudinal probes in intact forest. This was a result of a more open canopy at 200 m temperature station.

In summary, uncut riparian buffer strips 75’ wide provide at least a narrow (10 m) strip of forest cover with a microclimate very similar to that of extensive mature forest cover.

The Effect of Nitrogen Loading on Estuarine Ecosystems: A Stable Isotope Approach to Food Web Analysis.

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The estuaries of Acadia National Park are currently threatened by nutrient enrichment associated with sources outside park boundaries, such as increasing residential development and air pollution. Nutrient enrichment of these fragile ecosystems can lead to eutrophication and the resulting losses of biodiversity and habitat. Some of the ecosystem responses that have been documented in coastal systems include increased algal growth, increased community metabolism and decreases in dissolved oxygen (1). Most importantly, anthropogenic nitrogen loads to estuaries have been linked to shifts from seagrass to algal dominated communities, a shift which may have important ramifications for the entire food web. For instance, it has been found that nitrogen loading causes shifts in the diets of primary consumers (2). The United States Geological Survey (USGS) is currently undertaking a project to create a decision support system that will allow for the prediction of how changes in land use around the park will effect the estuaries (3). This project involves looking at current nutrient loading, land use, and ecological responses to increases in nutrients. Our research will assist in documenting the ecological response of the estuarine food web to nutrient enrichment. This project will have both laboratory and in situ components. The laboratory component will utilize aquarium sized microcosms (4) stocked with the dominant estuary macrophytes, and associated epiphyte and grazing community. Microcosms will be fertilized with varying levels of N (same as those proposed for the field experiment) and they will be run continuously for 2 months in the winter 2000-2001. At the end of the experiment, the ecosystem components will be removed and analyzed to determine the stable carbon and nitrogen isotope composition. This will allow us to determine the amount of fractionation of C and N between trophic levels in the food web as well as whether this fractionation changes with N additions. The in situ component will consist of enclosures placed in the submerged macrophyte zone of the Northeast Creek estuary. A range of nutrient loading conditions will be applied to replicate enclosures. We will conduct two, month-long experiments during each of two growing seasons. Food web components will be sampled from each enclosure at the end of each experiment and analyzed for C and N signatures. Using the results of the isotope analyses from both the laboratory and the in situ experiments, we will be able to determine 1) the impact of N loading on the relative importance of each primary producer in the diet of consumers, 2) the impact of N additions on trophic level isotopic fractionation of C and N, and 3) the impact of N loading on estuarine food web structure and function.

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Wildlife Use of Forested Riparian Areas in New England

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Although it is common to retain forested buffer strips along streams to protect stream water quality during and following forest harvest, the utilization and value of these remaining forested areas and the streams by wildlife are unclear. Riparian buffers protect stream water quality by minimizing sedimentation and water temperature fluctuations and maintaining a source of organic material to the stream (Naiman et al. 1998). Riparian areas also provide a variety of functions for wildlife, including habitat for obligate riparian species and those frequenting early succession communities and habitat edges, refugia from upland disturbances such as fire or harvest, and as topographic landmarks and travel corridors (Kelsey and West 1998). Although various effects of forest harvest practices on stream water quality have been examined and the literature examining biotic response to water pollution is extensive, few studies assess wildlife response to riparian forest manipulations. Much of the research examining effects of riparian forest harvest and the value of riparian forest buffers to wildlife has been conducted in northwestern North America and the southern United States. Although the basic paradigms of stream continuity and watershed functions apply throughout these regions, differences exist in the regional geomorphology, climate, stream conditions, stream-side and watershed land use activities, and biotic composition of riparian habitats across North America. Results of studies that examine wildlife response to riparian forest manipulations may be region-specific or may vary among watersheds within a region. The temporal and spatial variability of streams, adjacent riparian areas, and the watersheds in which they occur create a complex environment utilized by a variety of wildlife that is not uniformly tolerant of riparian disturbances due to their diverse life histories and mobilities (e.g., microbial communities to migrating birds). Additionally, biotic recovery from these disturbances may be immediate, or the effects may persist for decades (Harding 1998). The need for research examining wildlife responses to forest management activities across temporal, spatial, and taxonomic gradients continues.

To determine the extent of published research conducted in northeastern North America that examines the responses of wildlife (birds, mammals, amphibians, invertebrates, fish, reptiles) to riparian forest harvest, we searched 18 online databases with approximately 20 combinations of the following search words: riparian, forest, wildlife, invertebrates, stream, birds, amphibians, mammals, reptiles, biodiversity, buffer, management, insect, policy, exotic, hyporheos, groundwater, watershed, aquatic. The searches included literature published during 1967-June 2000, although not all databases indexed publications from the entire interval. Reference lists published in approximately 20 recent riparian ecology books were also compiled. Several thousand citations were reviewed, and databases were developed in EndNote citation management software with approximately 1500 citations from northeastern North America

(~500) and published literature from outside this region (~1000) that were considered important papers in riparian ecology research. Published studies of effects of riparian forest manipulations on riparian biota in northeastern North America represent <2% of the retrieved citations. Currently the databases are being edited and collated into a northeastern riparian ecology research database and a second general riparian ecology research database.

In addition to reviewing the available citations, we have used software developed by the University of Maine Forest Management Research Cooperative (Hansen 2000) to tally wildlife use of New England riparian forests complied by DeGraff et al. (1992) and DeGraff and Rudis (1987). Our summary of New England wildlife species utilization of riparian forests was prompted by our review of the literature: with the limited research of riparian harvest effects on New England wildlife (less than 30 papers published in the primary literature during 1967-2000), predictions of wildlife response to riparian habitat manipulation must be made based on descriptions of wildlife use of riparian areas rather than from results of studies applying controlled, riparian forest manipulations. Our poster summarizes these descriptions and predictions of wildlife use as well as our review of the published research on wildlife-forest management interactions in northeastern North America.

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Usage and Effectiveness of Forestry Best Management Practices in Maine: Interim Findings of Maine Forest Service's Statewide BMP Monitoring Project

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Possible impacts of forest management activities on water quality and aquatic habitat have received considerable attention in recent years. However, current information concerning rates of use and effectiveness of forestry Best Management Practices in Maine has been lacking. Most recently Briggs et. al. (1996) reported on a field study of 120 harvest sites. They noted that BMPs were effective when applied, but that rates of application varied widely among different BMP techniques.

Maine Forest Service was directed by the legislature to develop a methodology to assess BMP implementation in 1998. MFS, with the assistance of FORAT (an advisory group) developed a methodology for assessing use and effectiveness of key BMP issues, based on random selection of Forest Operations Notifications received. MFS District Foresters and Forest Rangers began applying the methodology in March, 2000. Sites are selected randomly on a monthly basis, in each of 9 districts. Most large landowners, and many smaller landowners, have agreed to participate.

As of September 1, over 140 sites have been visited by MFS staff. Preliminary analysis shows that approximately one third (52 sites) of harvested sites surveyed thus far have no surface water present. Further analyses will examine rates of usage of broad BMP types, including skid trail channeling of water, temporary and haul road stream crossings, filter strips, and residual shade on surface waters. Information will be used to help focus attention on training needs, as well as to establish a baseline from which to evaluate trends. MFS BMP monitoring will be ongoing, and is expected to continue indefinitely. Findings will be reported annually.

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Soil Cation Distribution in the Near-Stream Zone of New England Forested Watersheds

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The distribution of exchangeable soil cations, including the metals Al and Be, are being studied across a range of forested watersheds in Maine during 1998-1999. A pilot study was conducted in a hillslope and near-stream zone at two forested watersheds in eastern Maine. Organic and mineral soil samples were collected along transects perpendicular to the stream and analyzed for exchangeable soil cations, pH, percent organic matter, and exchangeable acidity. Results showed that Ca was the dominant exchangeable cation in the organic horizon (mean throughout = 9.1 cmol(+)/kg), while exchangeable Al dominated in the mineral soils (mean throughout = 4.9 cmol(+)/kg). The concentration of exchangeable soil cations differs between the near-stream zone and the hillslope. The highest values of exchangeable Al (mean = 7.1 cmol(+)/kg) and Be (mean = 36.1 μmol(+)/kg) occur in the organic horizon immediately adjacent to the stream, while Ca is significantly lower in this area (6.0 cmol(+)/kg). During hydrologic events, the major flow pathway shifts from high pH baseflow to acidic, Al-rich rapid water flow in the upper mineral horizons. As ground water approaches the stream laterally, it encounters less acidic soils with lower percentages of organic matter. Additionally, higher pH groundwater may mix with lower pH water near the soil surface as it emerges near the stream. These spatial patterns result in significantly higher Al and Be saturation and lower base saturation in the near-stream zone relative to upslope soils. This is in contrast to the traditional idea of increased base accumulation towards the shore zone. Therefore, stream water chemistry may be most strongly influenced by the soils within a short distance of the stream. These trends will be further evaluated in the full study data to determine the distribution of exchangeable soil cations across a range of forested watersheds in Maine.

Aquatic Goals and Stream Buffering Practices for The Nature Conservancy's St. John River Property

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This poster explains our aquatic goals for the Upper St. John River and our current stream buffering guidelines for those areas where we are managing forests.

The Maine Chapter of The Nature Conservancy's purchase of 185,000 acres along the Upper St. John River began a conservation effort for the St. John River watershed upstream of the Allagash. We now have unprecedented opportunities to protect over 150 miles of the East's longest, undammed, wilderness river amid a system of preserves ranging from individual fens to twenty-thousand-acre landscapes that include entire watersheds for multiple first and second order streams. Within the Upper St. John River watershed are lakes that support some of the northeast's most diverse native minnow communities as well as the largest, intact, native brook trout fishery in the east. The Conservancy has identified the following research goals for aquatic systems in the upper St. John River watershed.

Goal One: identify both lotic and lentic habitats that we suspect are intact and host native species with minimal evidence of human impacts. Goal Two: compare such habitats with those more impacted by human activities and characterize the effects of human impacts. Goal Three: characterize and begin monitoring chemical and physical parameters of main stem river and tributary stream-stretches that are likely to be fairly intact or non-impacted from past land uses. Goal Four: identify specific practices that threaten aquatic health.

Draft buffer recommendations for riparian areas of tributaries and the main stem of the upper St John were established to protect aquatic ecosystems and the riparian zone in all areas on The Nature Conservancy's St. John River (IP) Property currently designated as forest management areas. Comments on how these goals, methods recommended to help attain these goals, or how they can be modified to better meet our needs are all welcome. Note that these guidelines are meant to complement, not replace forest reserves and apply only to those areas in active forest management. Forest reserves are being designed to include multiple watersheds of first and second order streams and frontage on the main stem of the St. John.

DRAFT BUFFER RECOMMENDATION SUMMARY

Water Quality Buffer: Variable Width from 50 to 250 feet (~16 to ~75 meters) wide

Goal: to protect water quality from excess heat, sediments, nutrients and other pollutants and to ensure adequate/appropriate input of organic carbon to support the aquatic system. This is also intended to provide a minimum level of habitat for species associated with the water's edge (e.g. riverbank plants and aquatic invertebrates).

Application: to any and all identifiable streams and associated headwaters and flanking non-forested wetlands not protected by reserves or other buffers. The buffer is 100 to 150 feet wide around source (headwater and seepage) areas, and up to 250 feet wide in areas that are prone to erosion or windthrow, around Great Ponds, and around areas with special recreational or historical values. If harvests adjacent to a riparian area (cuts extending more than 250 feet from the riparian area) are designed to leave an intact forest canopy (>60%) without channelization or diversion of surface and near surface water, and there are no other hazards to erosion or windthrow then the no-cut aquatic buffer can be reduced to 50-feet measured perpendicular from the edge of tree-line bordering the aquatic resource.

Riparian Habitat Buffer: 250 feet wide minimum no-cut zone plus 250' restricted forestry zone with regularly spaced 300-600 acre expansion areas

Goal: to provide riparian habitat for species including forest interior breeding birds, amphibians, reptiles, and mammals (most noteabley pine marten), to provide additional removal of sediments and nutrient pollution from overland runoff, and to maintain an unimpeded source of organic matter to streams.

Application: Third order and higher order streams - with the exception of the St. John and Baker Branch which have a wider buffer intended to protect recreation and wilderness values in addition to recharge areas for rare rivershore natural communities dependant on seeps. On third and higher order streams, no timber harvesting within 250 feet of the stream, light (<30% removal) infrequent (>20 year) harvests 250 to 500 feet from the stream. There would be no year-round roads, or culverts in the 500' buffer zone. Expansion areas will consist of round or square-ish blocks of forest land 300- to 600-acres in size located no more than four miles apart along the ribbon of Riparian Habitat Buffer. These areas can be harvested in the same fashion as the outer band of the habitat buffer with an emphasis on the retention of current and future supplies of coarse woody debris, native tree species diversity, and minimizing canopy opening size.

The Nature Conservancy is currently seeking partners to develop an aquatic research and monitoring program as part of its conservation efforts in the Upper St. John River Watershed. We are seeking multi-year funding to support our research efforts and are interested in developing a cooperative relationship with scientists knowledgeable in aquatic systems and interested in establish methodologies.

A new study to test the effectiveness of different buffer widths for protecting stream physical, chemical, and biotic integrity in managed forests.

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This poster describes a new study initiated this past summer (2000) to understand the effectiveness of different buffer widths for protecting various riparian values on small headwater streams in managed forest. The purpose of this poster is to inform interested stakeholders of this project and forthcoming data.

We have selected 15 1st or 2nd order headwater streams in the western mountains of Maine for a Before-and-After-Control experiment. Each of the streams is presently surrounded by extensive mature forest. In 2001, we will collect baseline (pre-harvest) data on all streams, thus providing us with baseline information on natural variation in an array of stream parameters. Between 2001 and 2002 field seasons, each stream will be subjected to 1 of 5 treatments:

(1) clearcut to stream edge,
(2) 10 m (33') buffer,
(3) 23 m (75') buffer,
(4) 200 m (660') buffer
(5) Control (no harvesting)

Thus, there will be 3 replicate streams in each treatment. All buffers will be partially harvested to a common residual basal area. For 1 year before, and for 2 years after harvest, we will collect data on the following parameters:

Physical	pH conductivity turbidity dissolved oxygen
Aquatic Habitat	water temperature stream substrate in-stream woody debris stream shade
Aquatic Biodiversity	macroinvertebrates salamanders fish *
Terrestrial Habitat and Biodiversity	forest structure herbaceous plants * salamanders

* pending additional funding

This study is a cooperative project between Manomet Center for Conservation Sciences and the University of Maine. We invite additional collaborators to participate in this project that might be able add additional parameters of interest to the experiment, or that might be interested in combining data from other studies in the region. The study is being funded by the NCASI, the Cooperative Forest Research Unit at the University of Maine, and Plum Creek Timber Company.

Landscape Factors and Riparian Zones: Modification of Atmospheric Inputs in a Paired Watershed Study at Acadia National Park, Maine

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Preliminary data show site-specific differences in atmospheric deposition of major anions (NO_3^-, SO_4^{2-}, and Cl^-) as measured in throughfall solution chemistry in paired watersheds at Acadia National Park, Maine. Significant differences are also present in outfluxes of the same anions in weekly samples of streamwater chemistry. Contrasting vegetation and soil characteristics have been provided for this study by a severe wildfire that burned one of the two watersheds in 1947. The natural experimental design also includes topographic and aspect variations across watersheds, and within each watershed.

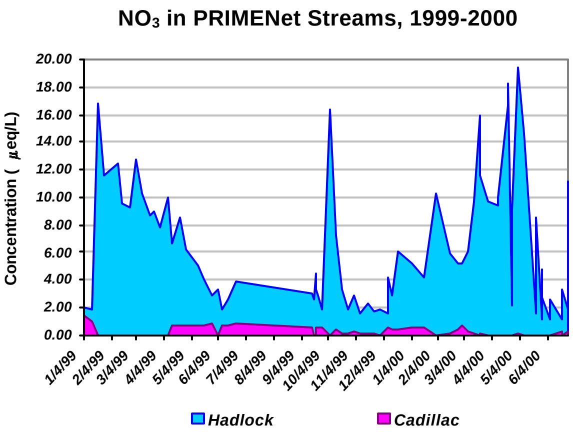
Differences in deposition rates are usually attributed to the influence of landscape factors on precipitation patterns and scavenging efficiency of vegetation. Differences in outflux amounts can be attributed to biomass uptake or leaching, soil processes, or in-stream processes; landscape controls may also drive biological and soil processes. A mass balance approach on the catchment and sub-catchment scale will be used to determine the retention of NO_3^-, SO_4^{2-}, and Cl^- in each watershed.

The objectives are: (1) determine which compartments in each watershed contribute to different rates of anion processing; and (2) relate these differences to landscape factors determined to be driving deposition and outflow rates.

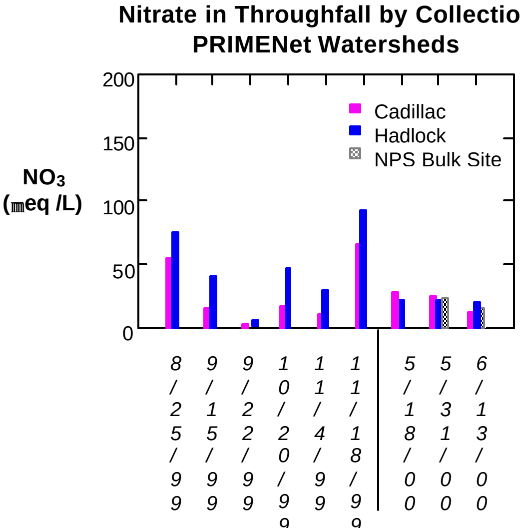
BACKGROUND

This thesis draws on ongoing study of a pair of watersheds with similar physical characteristics, but with very different vegetation types, in part due to disturbance by fire. Research is part of a long-term ecological investigation begun in 1998. The experimental design utilizes two gauged-watersheds instrumented at Acadia National Park through collaborative funding by the Senator George J. Mitchell Center for Environmental and Watershed Research at the University of Maine, USGS BRD and EPA PRIMENet. The reference watershed, Hadlock Brook Watershed, drains the west slope of Sargent Mountain in Acadia National Park, ME. The "experimental" watershed is Cadillac Brook Watershed, located on the steep eastern slope of Cadillac Mountain, much of which was burned in severe wildfire in 1947.

The focus of the PRIMENet project is atmospheric deposition of N and Hg, and their ecological consequences. Both elements are of major concern, both regionally and to the Park Service at Acadia. This project offers the advantages of a natural experimental design because of the major forest fire in part of the Park in 1947, as well as parallel design with the acidic deposition experiment on paired-watersheds at the nearby Bear Brook Watershed, Maine (BBWM).



Streamwater samples from Hadlock Brook have consistently higher concentrations of nitrate than do Cadillac Brook samples for 1999 and early 2000. Streamwater chemistry finishing by the immediate riparian zone should be investigated.



Autumn 1999 throughfall samples - NO_3 at Hadlock > Cadillac; spring / summer 2000 samples - similar NO_3 concentrations . Seasonal differences may be attributed to leaf off, reducing canopy cover at Cadillac.

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Predicting Leaching and in Stream Nutrient Concentrations in Small Watershed Before and After Clear Cut

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A forest biomass and nutrient cycling model was developed and tested. The model consists of six major modules namely forest hydrology, biomass growth, hydrogen balance, nitrogen balance, sulfur balance and base cation balance (Ca, Mg, and K). In the model, soil moisture, temperature and soil nutrient availability drive nutrient fluxes in forest ecosystems and controls biomass growth. Simple site specifications and initial stand conditions are required to run the model. Model outputs include dynamic changes in term of total biomass of foliage, wood, root, and forest floor; biomass nutrient contents; litter fall, organic matter decomposition, mineralization, nitrification, and immobilization; soil pH, cation exchanges capacity. The model can also be used to predict nutrient leaching, nutrient concentrations in soil solution and nutrient concentrations stream water and corresponding nutrient leaching fluxes.

The model was tested and applied in two paired small watersheds in Nashwaak in central New Brunswick. The results indicated that model predictions biomass, associated nutrient contents, foliage fall, nutrient concentrations in soil solution, leaching, nutrient concentrations and fluxes in stream water are closely agree with measured data. Compared with before harvesting, nitrate leaching increased about 5 times for the second and third years after harvesting.