

# **Impact of Deforestation on Adjacent Small Stream Ecosystems**

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## Introduction

Deforestation, mainly the conversion of forests to agricultural land, occurs today at a rate of about 13 million hectares – an area nearly the size of Panama – per year, according to the 2005 Global Forest Resource Assessment. Forest planting, landscape restoration, and natural expansion reduce the net loss to an estimated 7.3 million hectares each year – about 0.18% of the remaining global forested area. Regions of Africa and South America experience the largest net loss of forests – 4.3 and 4.0 million hectares per year, respectively (Chopra, et al., 2005).

Forests play a vital role in the sequestration of carbon from the atmosphere and in the preservation of biodiversity (Woodwell, 2001). The Global Forest Resource Assessment reports that nearly half of all primary forests – the basic indicators of biological diversity – are found in South America. High levels of deforestation in this region, then, pose significant threats to the vitality of many unique plant and animal species. Indeed, the impact of forest habitat loss on terrestrial communities has captured the attention of biologists and environmentalists alike. Not until recently, however, has the role of forests in aquatic systems come to the fore (Couceiro et al., 2006). This paper summarizes the current body of knowledge regarding the impact of deforestation on adjacent small stream systems.

Understanding these changes requires a comprehension of basic stream anatomy. The majority of authors refer extensively to J. David Allan's thorough analysis of running waters, *Stream Ecology* (1995), which is the source from which the following information is derived unless otherwise stated. Streams are lotic ecosystems – they obtain their energy from in-stream primary production by plants and from both in-stream and externally produced non-living organic matter. The majority of studies conducted thus far have described deforestation

effects on small, headwater regions of streams where the connection to the terrestrial environment is most direct and most profound. Allan (1995) observes that in these areas, periphyton (diatoms, green algae, cyanobacteria, and a few other groups) are the prominent primary producers, occurring on virtually every surface in running waters. Nutrients, especially phosphorus, and light limit periphyton growth; it is also vulnerable to grazing by herbivores.

Coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), and dissolved organic matter (DOM) supply a great deal of energy to small streams. The majority of POM and DOM comes from terrestrial inputs. Leaf litter is an important source of CPOM, while microbial colonization, invertebrate feeding, and physical abrasion convert it to FPOM and DOM. FPOM and DOM are derived from many other sources as well, most of which are terrestrial.

Because stream food webs are so complex, with the majority of species feeding on both primary producers and POM, consumers are more often classified by their method of nutrient acquisition. Invertebrates – mainly insects, with some mollusks and crustaceans – can be shredders (scraping or chewing CPOM), filterers (collecting FPOM and microbes), collector-gatherers (actively searching for FPOM), grazers (rasping and browsing periphyton and detritus), or predators. Fish are planktivores, herbivore-detritivores, surface and water column feeders, or parasites. Many fish even occupy multiple guilds throughout their development.

The availability of nutrients is just one factor that influences the biotic composition of a stream community. Physical features, such as the degree of siltation and the presence of large woody debris, influence the abundance of pool and riffle zones (Wright and Flecker, 2004). Chemical features, particularly the levels of nitrogen, phosphorus, carbon dioxide, and dissolved oxygen, affect stream pH and nutrient saturation (Thomas et al., 2004). Studies

show that not one of these determinates of community composition is immune to the effects of deforestation. At the same time, debate still exists as to the nature and extent of certain effects. The following is a discussion of those results that are heretofore undisputed, followed by the examination of the more controversial topics. The chemical and physical impacts of deforestation are discussed first, as biological impacts are oftentimes a result of these changes.

### **Physical Impact of Deforestation**

The removal of riparian (streamside) vegetation disables the retention of sediments from the stream bank (Couceiro et al., 2006). This results in an influx of stream siltation. The siltation generally reduces the number of pool sites and increases habitat homogeneity (Bojsen and Barriga, 2002). The presence of woody debris also directly influences a stream's physical composition. Deforestation limits the availability of large woody debris to streams, which in turn increases the water velocity and decreases the number of safe oviposition sites available (Wright and Fletcher, 2004; Couceiro et al., 2006).

Many ecologists have documented the extensive reduction in stream canopy cover due to deforestation (Couceiro et al., 2006; Bernstead and Pringle, 2004; Bojsen and Barriga, 2002; Kishi et al., 2004). Couceiro et al. (2006) showed that this loss diminishes the protection of the fish and invertebrates from avian predation. Several studies also reveal the effect of canopy cover on stream temperature. Deforestation eliminates the shade provided by dense canopies, exposing streams to more sunlight and thereby increasing their temperatures (Couceiro et al., 2006; Kishi et al., 2004).

### **Chemical Impact of Deforestation**

Thomas et al. (2004) extensively researched the effects of deforestation on the chemical composition of adjacent streams. They found that greater siltation in deforested streams leads to a more fine-grained, organic-rich stream bed with increased infilling by aquatic vegetation. This results in higher quantities of chlorophyll, total suspended solids,

dissolved inorganic phosphate relative to inorganic nitrogen, and particulate organic carbon and nitrogen. The influx in organic matter promotes bacterial heterotrophy, thereby decreasing the amount of dissolved oxygen. Less dissolved oxygen in deforested streams is supported by several other studies, though is sometimes attributed to higher stream temperatures rather than increased respiration (Couceiro et al., 2006; Kishi et al., 2004).

Thomas et al. (2004) also showed that pasture streams can influence the dissolved oxygen, inorganic nitrogen, and inorganic phosphate levels of forested streams when the two meet. In addition, they reported significant fluctuations in percent chemical composition between dry and wet seasons – with predictably higher concentrations of chemicals during the dry season.

### **Biological Impact of Deforestation**

Biological impacts include all of the effects that deforestation has – directly or indirectly – upon living organisms within a stream community. Throughout streams deprived of riparian vegetation reverberate the effects of less leaf litter and woody debris, less habitat heterogeneity, increased light, increased temperature, and decreased oxygen levels.

The general trend in ecosystems' responses to these changes includes the following: an increase in the proliferation of periphyton and associated biofilms (Thomas et al., 2004; Bernstead and Pringle, 2004; Bojsen and Barriga, 2002, England and Rosemond, 2004), a decrease in the taxa richness of invertebrates with little change in the abundance of invertebrates (Bernstead and Pringle, 2004; Couceiro et al., 2006), and a decrease in the species diversity and abundance of fish (Bojsen and Barriga, 2002; Wright and Flecker, 2004; Kishi et al., 2004).

Autotrophic productivity increases in response to increased light availability. Invertebrate taxa dependent upon terrestrial CPOM and FPOM (shredders, filterers) are therefore at a loss, while biofilm-dependent taxa (some collector-gatherers, grazers) may

thrive (Bernstead and Pringle, 2004; England and Rosemond, 2004). Physical and chemical conditions also affect invertebrate diversity and abundance. The increased habitat homogeneity select against those taxa that colonize woody debris, and anoxic conditions disfavor many burrowing macroinvertebrates (Wright and Flecker, 2004; Couceiro et al., 2006). Most studies show that the diversity of invertebrates in forest streams enable certain taxa to withstand – even thrive in – streams with little or no riparian vegetation, which offsets the loss of those invertebrates that cannot. These patterns explain the general trend of decreased taxa richness and maintained invertebrate abundance.

Fish are impacted in a similar way as invertebrates, in that appropriately equipped species are selected for and species dependent upon terrestrial inputs (CPOM or terrestrial insects) are selected against. Homogeneous habitats and reduced protection from predatory birds are critical physical disturbances for many fish as well. Additional pressures may be accountable for the often observed net decline in fish species, however, such as top-of-the-chain vulnerability to the trophic cascade and the sensitivity of some species to heat (England and Rosemond, 2004; Kishi et al., 2004; Bojsen and Barriga, 2002). England and Rosemond (2004), for instance, linked the decline of invertebrate shredders to the reduction of terrestrial carbon support for insectivorous fish and crayfish. The physiologically optimal temperature was shown to have been exceeded in a deforested stream for the fish Dolly Varden in study conducted by Kishi et al. (2004).

Not all studies agree with these trends, of course. A study by Lyons et al. (1995) found an increased abundance of fish in deforested streams. It has been proposed that in this case, however, a higher density of periphyton-feeding fish in the original forested stream allowed for fewer casualties upon deforestation (Bojsen and Barriga, 2002). A decrease in the abundance of invertebrates was observed in a study by Bernstead et al. (2003). Couceiro et al. (2006) suggested that the great extent of terrestrial carbon depletion within the stream in this

instance was responsible for this aberration. Finally, Kishi et al. (2004) found increased algal growth to actually restrict grazing, but this they attributed to the inpalatability of red algae.

Ultimately, what these differences reveal are just a few of the many more variables upon which the reactions of streams to riparian deforestation depend. The extent of deforestation, the location of the stream relative to the site of disturbance, and the nature of the original stream community all affect the quality of a given stream's response.

Nonetheless, the aforementioned trends do span several locations, somewhat variable degrees of disturbance, and multiple unique stream communities, and they provide a solid foundation upon which to build understanding of the complex relationship between terrestrial and small stream ecosystems.

### **Common Data Accumulation and Analysis Procedures**

Because of the prevalence of deforestation and the high concentration of endemic species, tropical forests provided the sites for many of the studies on affected small stream communities, though studies in temperate forest zones revealed similar trends. A general framework for analyzing deforestation effects also persisted.

Regardless of the geographic location of the study, data was collected from multiple catchments of both forest streams and pasture/agriculture streams. Depending upon the nature of the study, various measurements were obtained. Some basic physical parameters were measured at every site, including canopy cover, wood volume, flow rates, mean depth, number of pool, run, and riffle sites, light penetration, stream temperature, and stream pH. Studies heavily focused on the chemical effects of deforestation included measurements of total suspended solids, particulate organic carbon and nitrogen, nitrate, ammonium, phosphate, total dissolved phosphorus and nitrogen, dissolved oxygen, and chlorophyll.

A sampling of the biota was also taken to determine levels of organismal abundance and diversity, and methods varied greatly. Seines, gill nets, minnow traps, point counts, and

electrofishing were commonly employed tools and techniques. Stable isotope analyses and gut-content analyses were performed in experiments designed to explore the origins of food sources for aquatic organisms – as terrestrial and aquatic nutrients each carry unique  $^{13}\text{C}$  signatures.

Finally, in order to establish patterns of correspondence among variables, a variety of programs and analytical methods were used. Linear regression and analysis of variance (ANOVA) were most common to determine relationships between the physical, chemical, and biological variables. Species Indicator Analysis, Whiteaker's Beta, and Fisher's Alpha were generally employed as techniques to determine species richness and species diversity.

### **Conclusion**

Recent studies show that deforestation – on both small and large scales – has a significant impact upon the physical, chemical, and biological characteristics of adjacent small streams. In general, aquatic habitats lose heterogeneity, and this effect is mirrored among invertebrate and fish populations. This loss of biological diversity is not only tragic in and of itself, but it increases the vulnerability of the community to disease and catastrophe, such as global warming (Allan, 1995).

The 2005 Millennium Ecosystem Assessment even reports that the degradation of ecosystem services exacerbates poverty in developing countries and that “in most countries, the marketed value of ecosystems associated with timber and fuelwood production are less than one third of the total economic value, including nonmarketed values such as carbon sequestration, watershed protection, and recreation... The total economic value associated with managing ecosystems more sustainably is often higher than the value associated with the conversion of the ecosystem through farming, clear-cut logging, or other intensive use.” For the sake of environmental, social, and economic health, then, the rehabilitation of forests and



their associated streams must become a priority. A better understanding of terrestrial and aquatic links enhances the ability of conservationists to work efficiently and effectively.

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