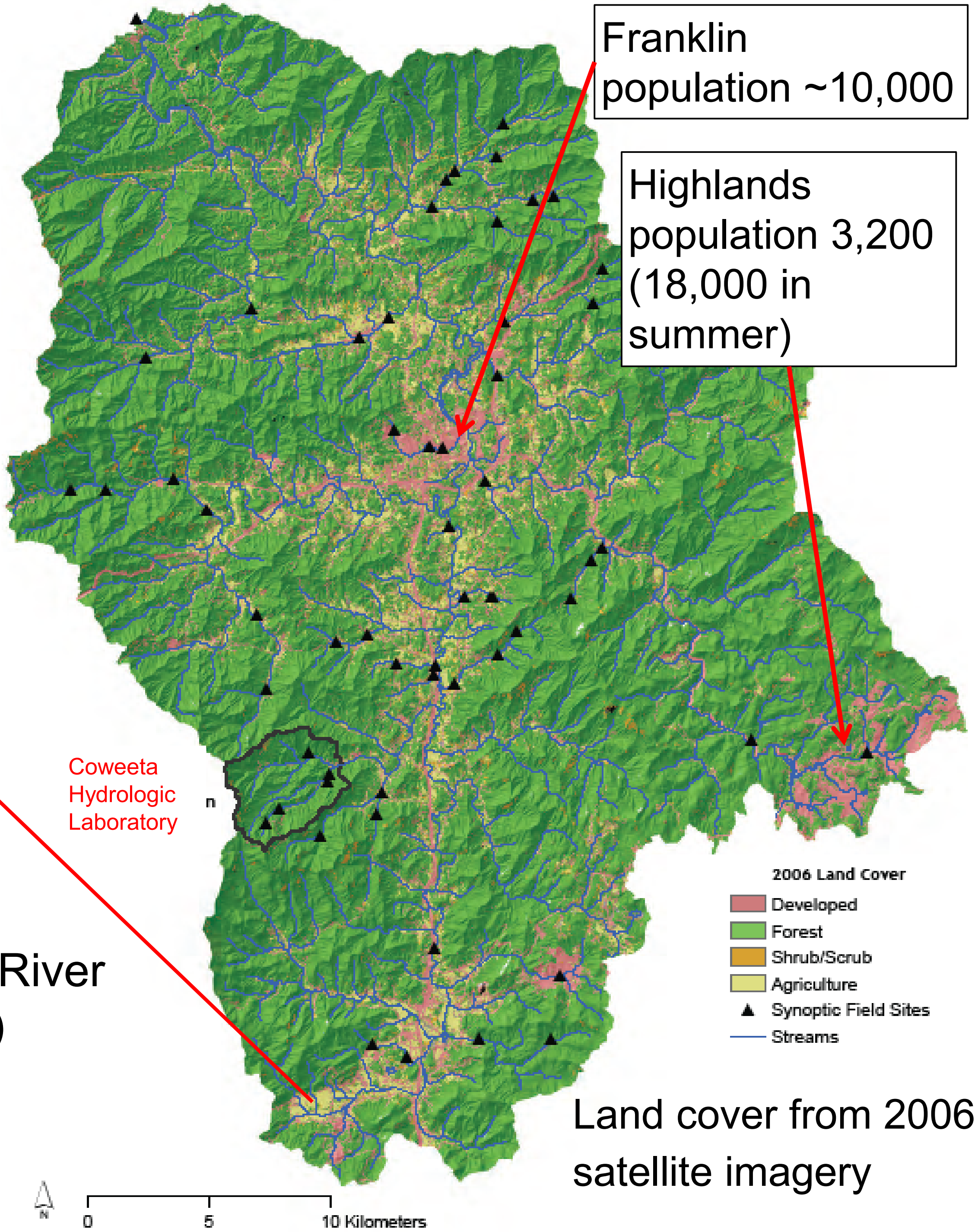
Low Density Rural Landscapes Don't Necessarily Support Clean Healthy Streams

C. Rhett Jackson,
John Porter Stevens Distinguished Professor of Water Resources
University of Georgia

Brook trout, NWF



Upper Little Tennessee River Basin (ULT)

Land cover from 2006 satellite imagery

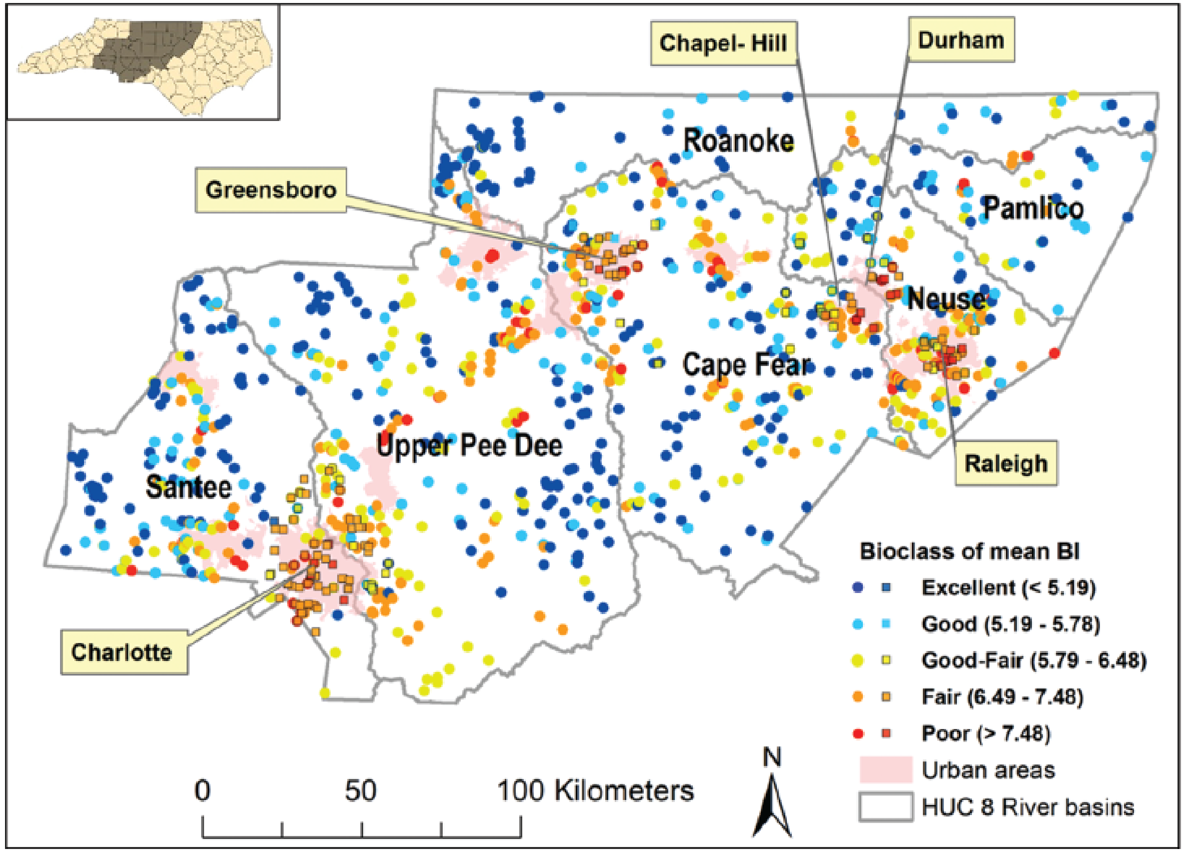
CWT LTER
Coweeta Long Term Ecological Research Program

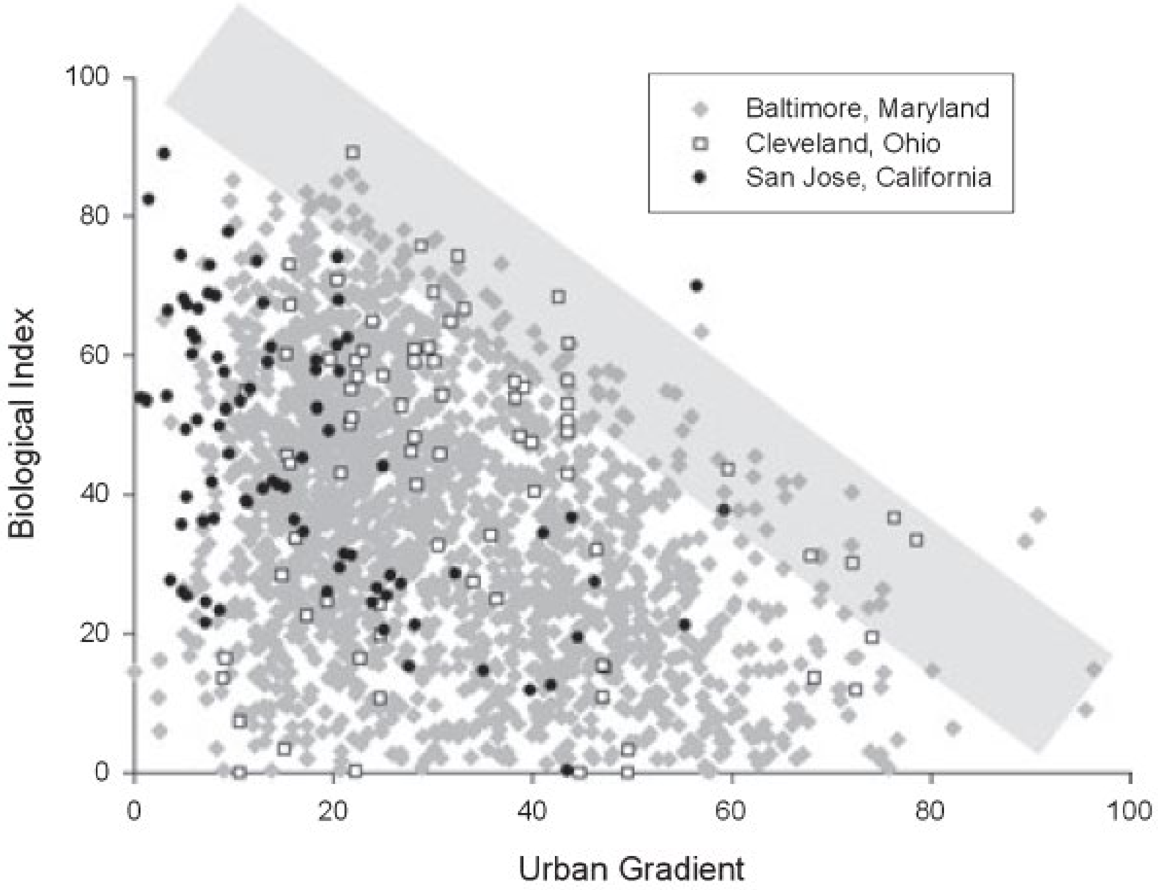
 

Why do people stay in the Southern Appalachians and move here? Environmental and lifestyle amenities.

“Exurbanization” – the movement of people to a region for reasons other than employment. E.g. second home development and retirement homes.

Aggregate forest cover in the ULT watershed is 80%. So… we might expect clean, healthy, forest streams.
What are the water quality and habitat effects of low levels of rural development and exurbanization?





Paul et al. 2009. JAWRA

Miller, Paul, & Obenour. 2019. Freshwater Science.

Basic Rule of Thumb: urban streams are bad, agricultural streams are bad, forested streams are good.

So, why would we have stream degradation in a landscape that is 80% forested?

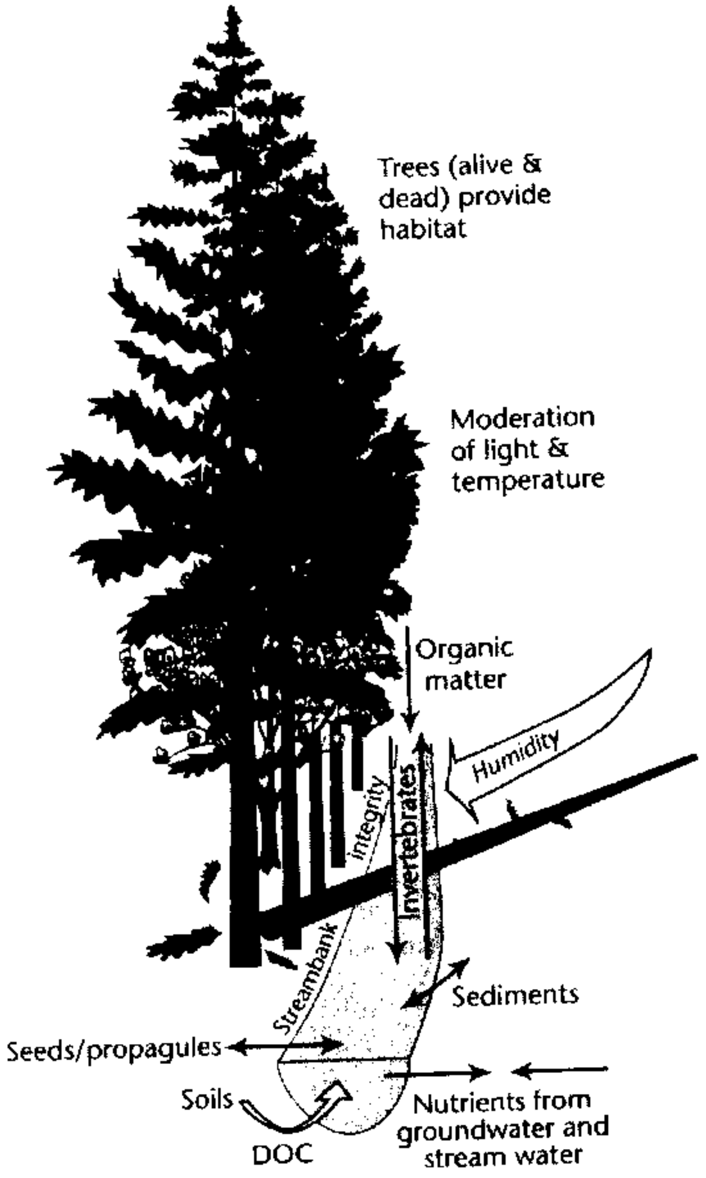


Figure 1. Schematic of the interactions between headwater streams with their riparian areas. Some flows go in two directions, for instance, invertebrates falling from the canopy into the stream and adult aquatic insects leaving the stream and being intercepted in the riparian area. Humidity tends to increase toward the channel due to the presence of water and the low point in the topography.

Ecology (Dr. Jackson's definition):

Ecology is the study of how light, H_2O, C, N, P, K, (carbon and nutrients) minerals, oxygen, and substrate space are apportioned among individual organisms, species, and guilds through space and time. Local ecosystem characteristics and processes are the byproduct of the interaction of natural selection (evolution), resource limitation (conservation of mass and energy), and topography.

The ecology of streams is intimately connected to the condition of the riparian zone.

In forested ecosystems, fish are essentially made out of leaves and sticks. In agricultural systems, fish are largely made of soil C and fertilizers.

Forested mountain streams:

Are messy,

Have dense overhanging vegetation and overhead canopy,

Are well-shaded in summer,

Are cold and clear,

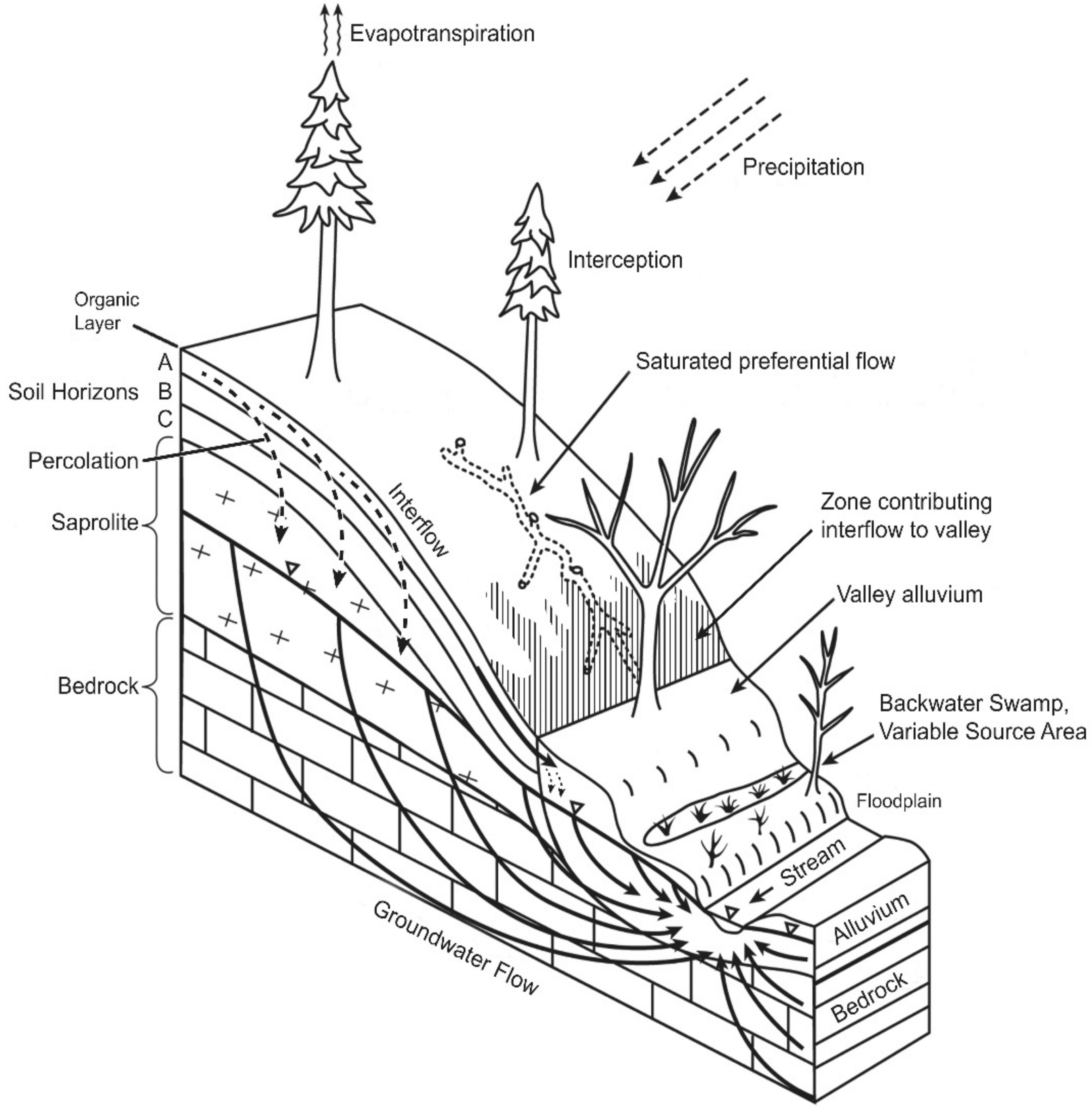
Receive a lot of organic input.

Have lots of wood in the channel,

And feature habitat complexity.

The Solution to Pollution Is Dilution

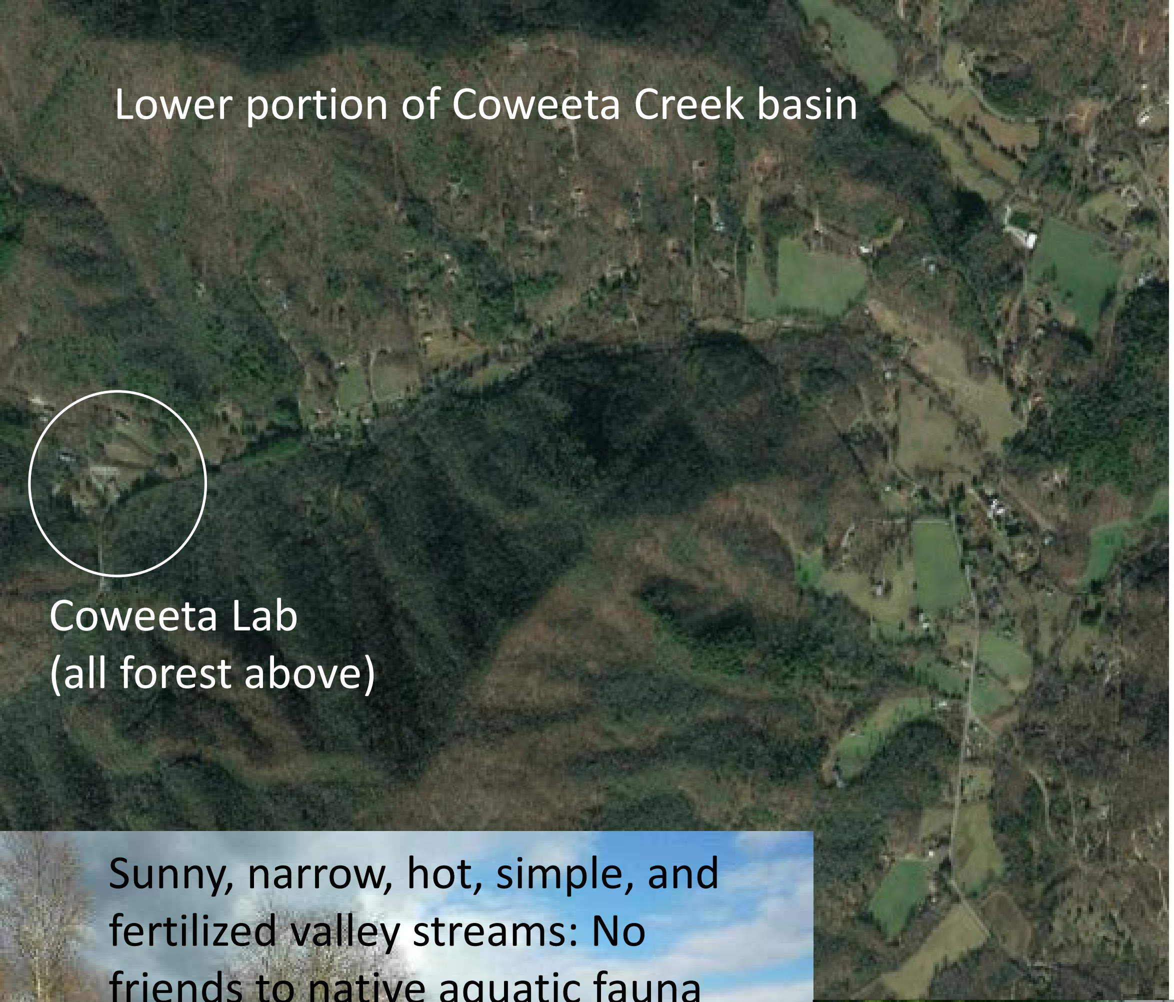
Note: except for two historical Appalachian photos, all photos in this presentation are from the ULT Basin.

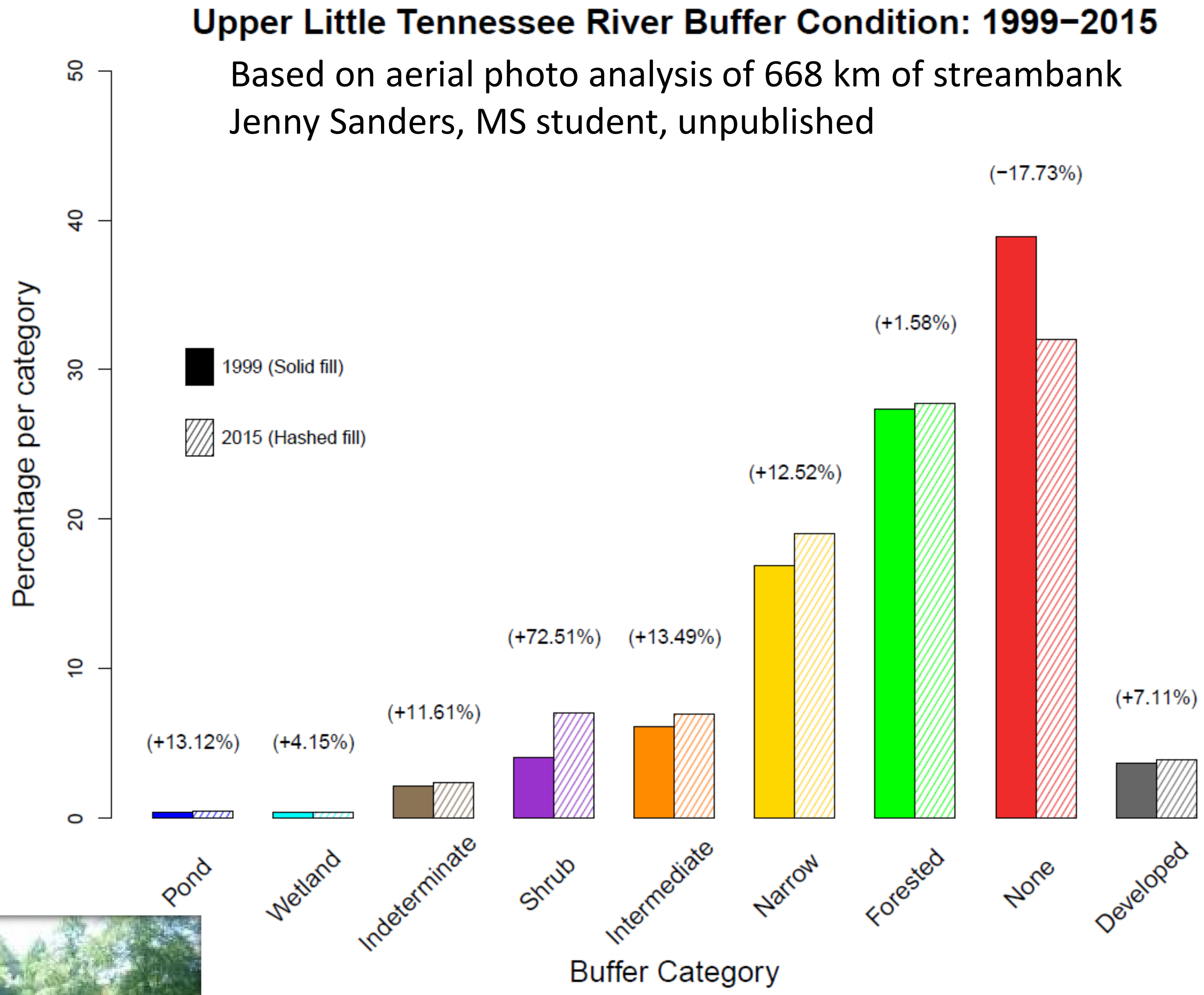


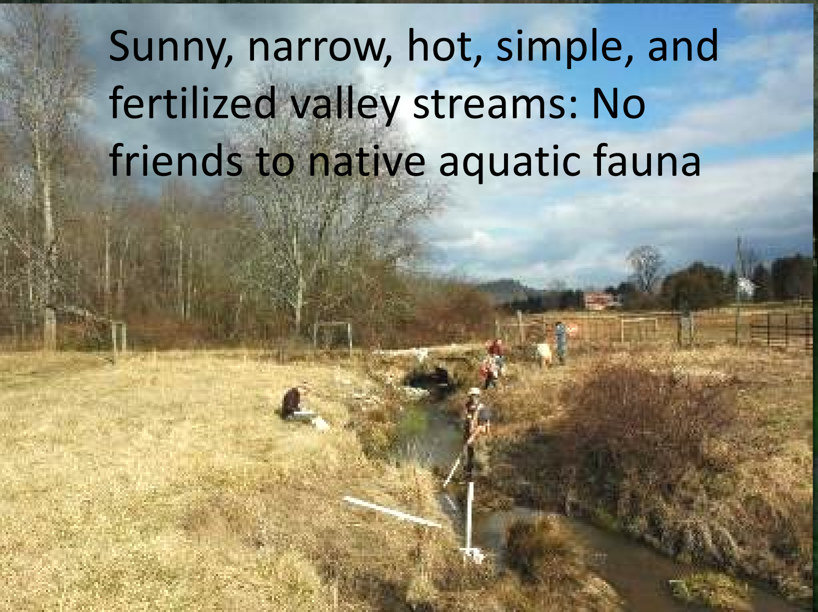
Hydrology

In undisturbed forests and grasslands, rainfall reaches streams mostly by slow subsurface pathways.

Nutrient and carbon contributions from the landscape to streams are minimal.





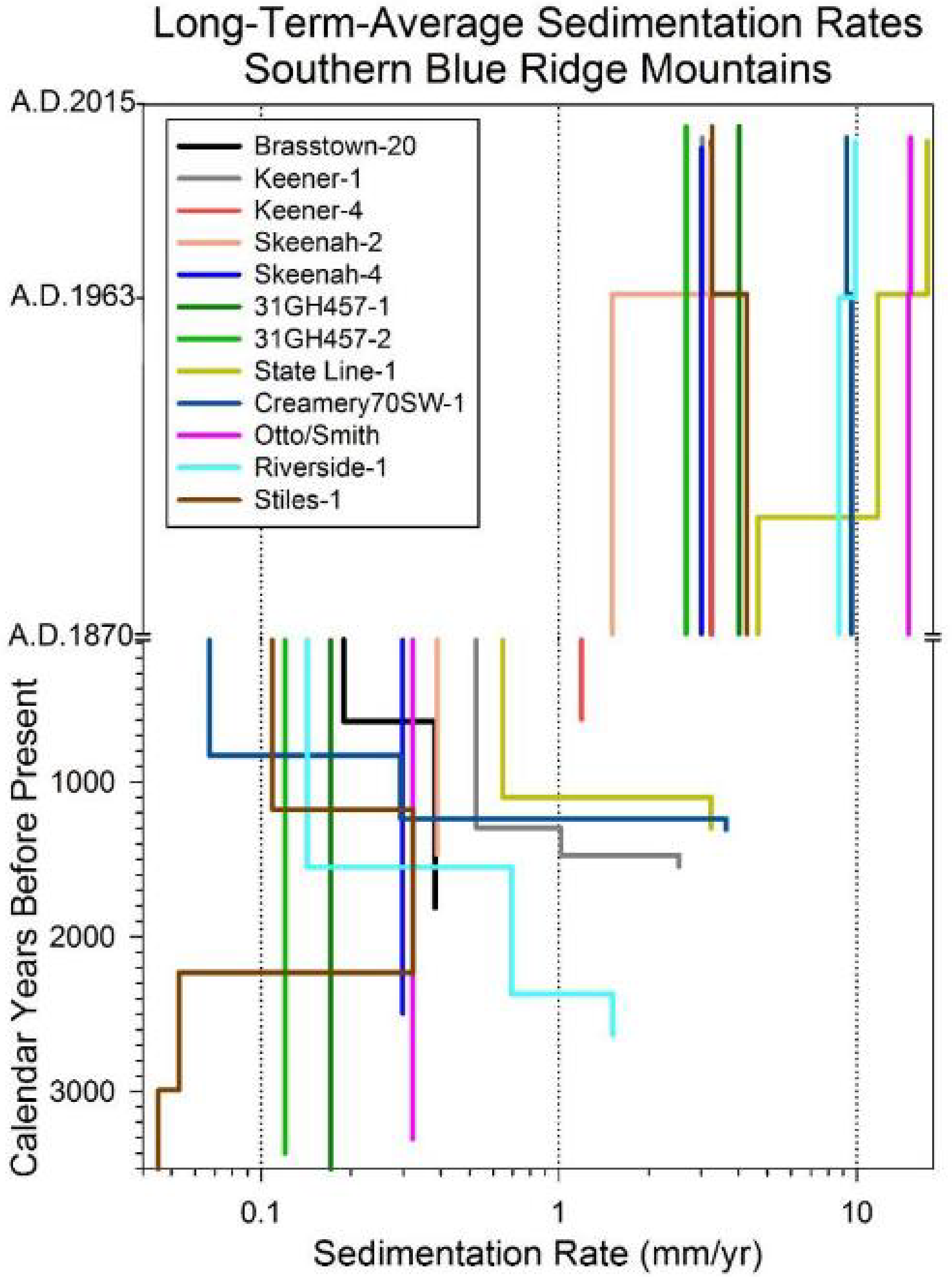


2/3rds of all valley stream banks feature either no, narrow, or shrub buffers or developed lands.

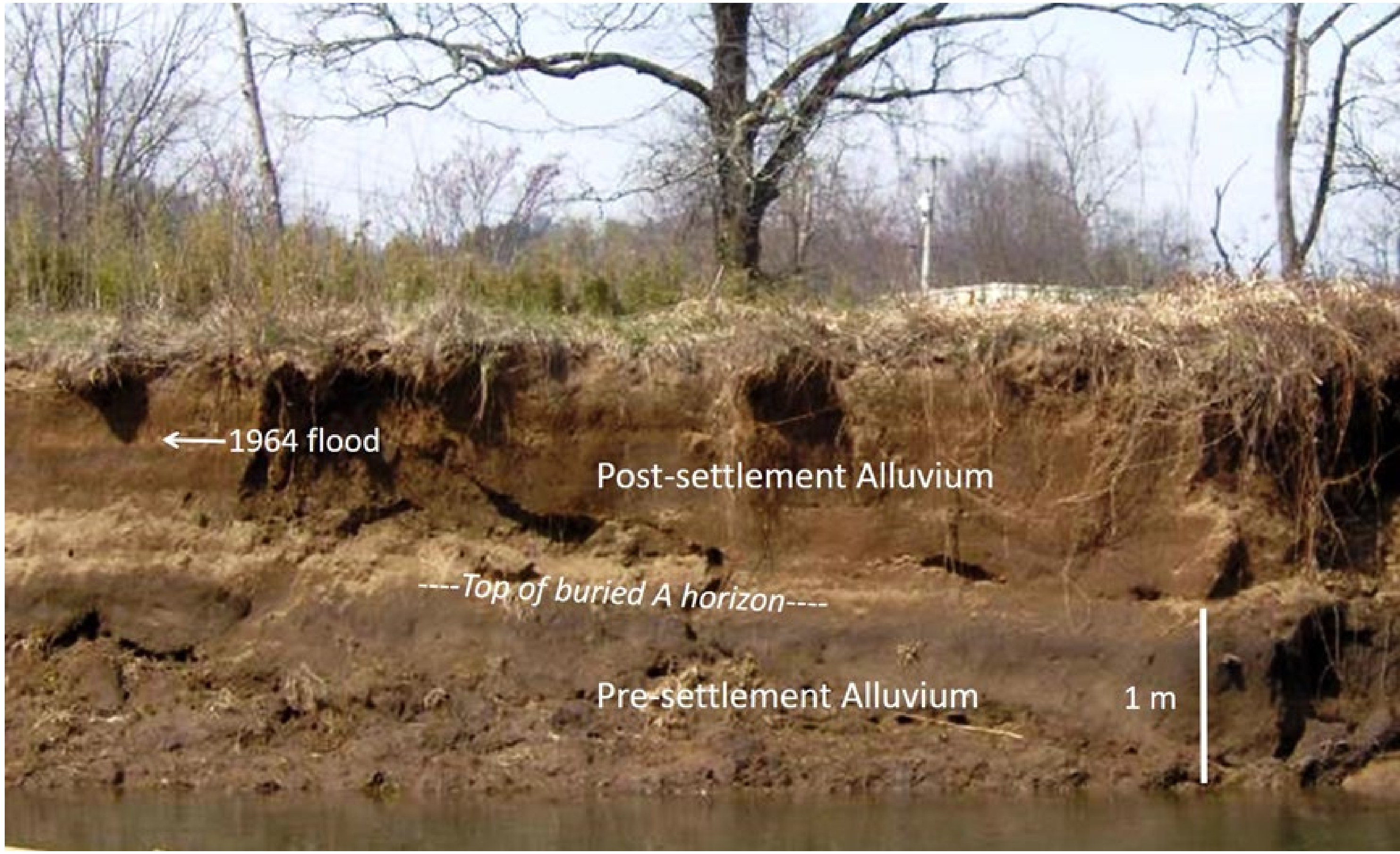

11

Senate Document 84. Message from the President of the United States Transmitting A Report of the Secretary of Agriculture in Relation to the Forests, Rivers, and Mountains of the Southern Appalachian Region.

Home of Fannie Corbin, Shenandoah National Park, October 1935 Library of Congress, # LC-USF33- 002167-M2

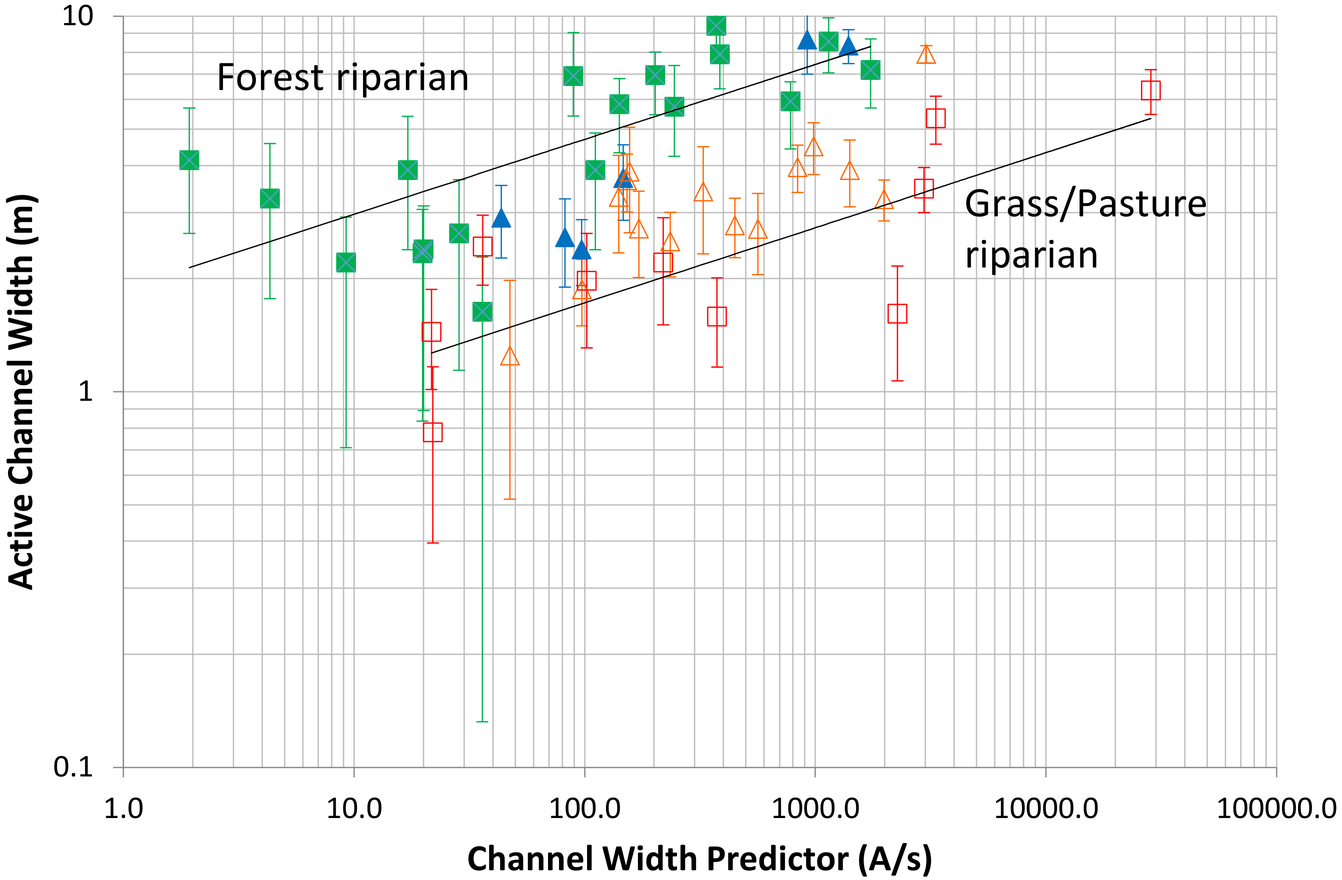


Valley sedimentation rates increased tenfold after European settlement and remain high, sometimes highest at the present.



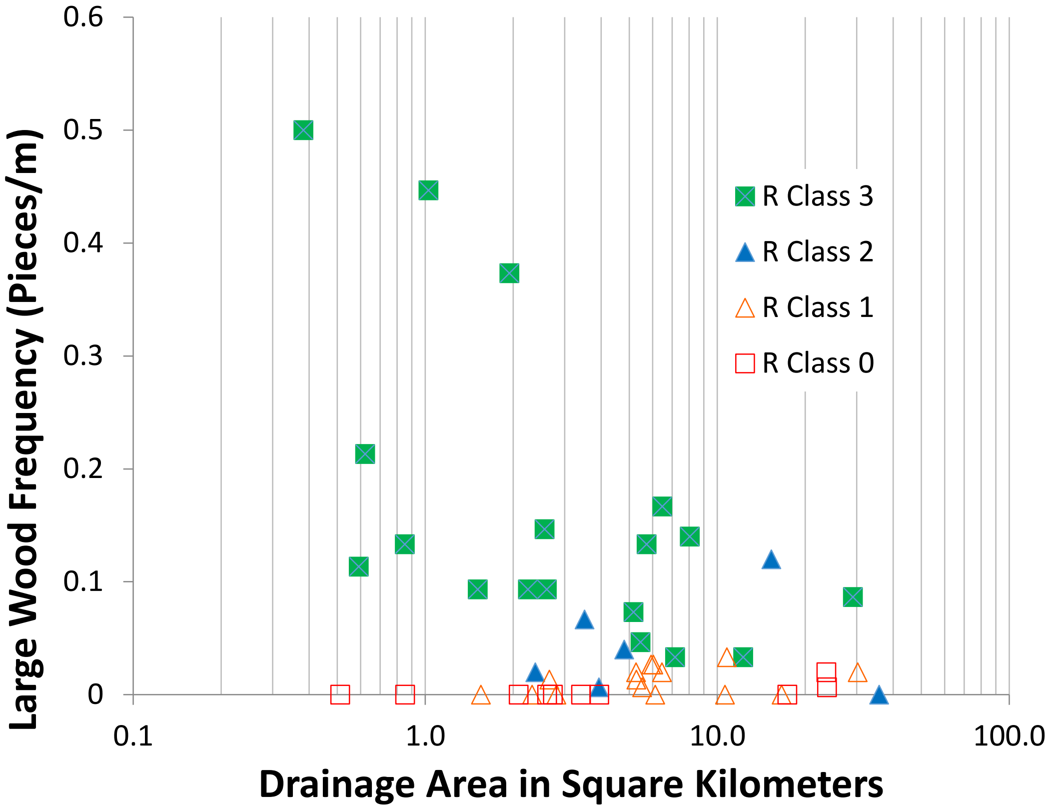
Leigh. 2015. Multi-millennial Record of Erosion and Fires in the Southern Blue Ridge Mountains, USA. In "Natural Disturbances and Range of Variation." Springer


Because of past sedimentation and
riparian forest removal, many lower valley
streams feature incised channels.



Channel widths of grass/pasture streams are 33% to 40% of those with full forest buffers. This difference was expected, but not the magnitude. Even narrow buffers improve channel conditions.

Jackson et al. 2015. River Research and Applications.



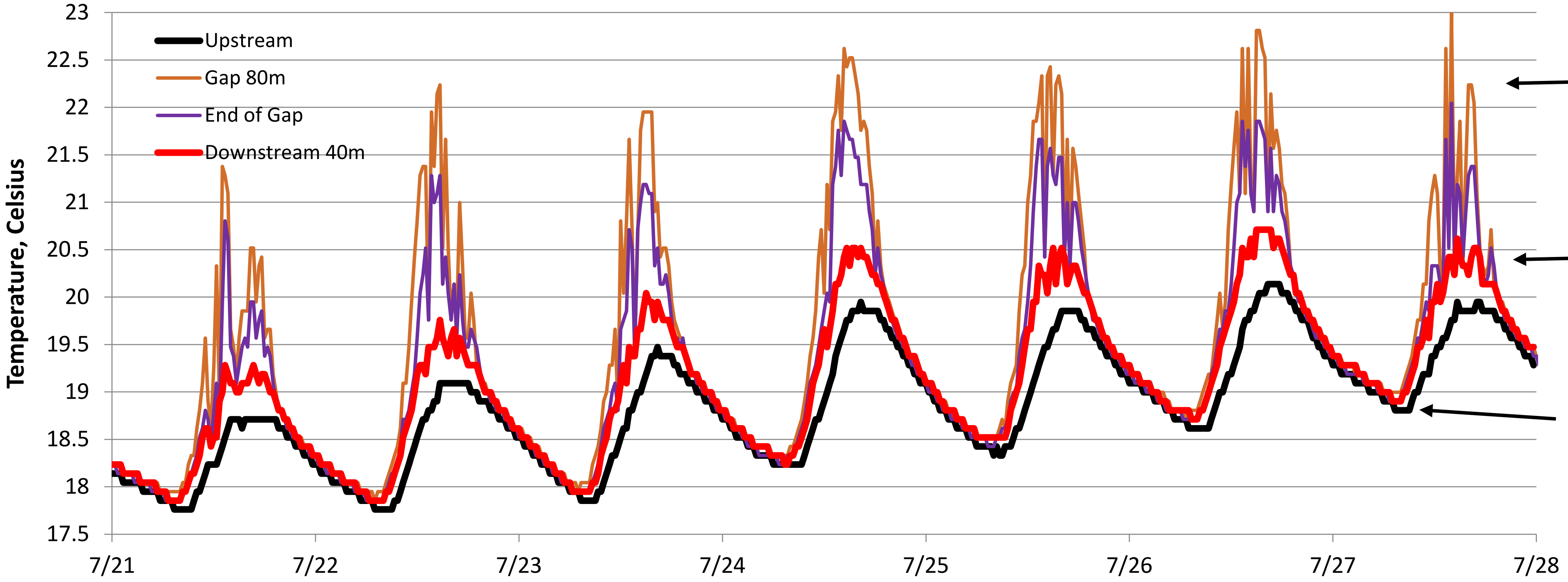
Wood frequencies in the forested streams are low relative to other ecoregions, but stream segments without forested buffers essentially have no wood at all.

Jensen et al. 2014. Phys. Geography.

Jackson et al. 2015. River Research and App.

Summer stream temperatures in small mountain streams are very sensitive to changes in riparian condition.

High maximum temperatures and diurnal variation under canopy gaps.

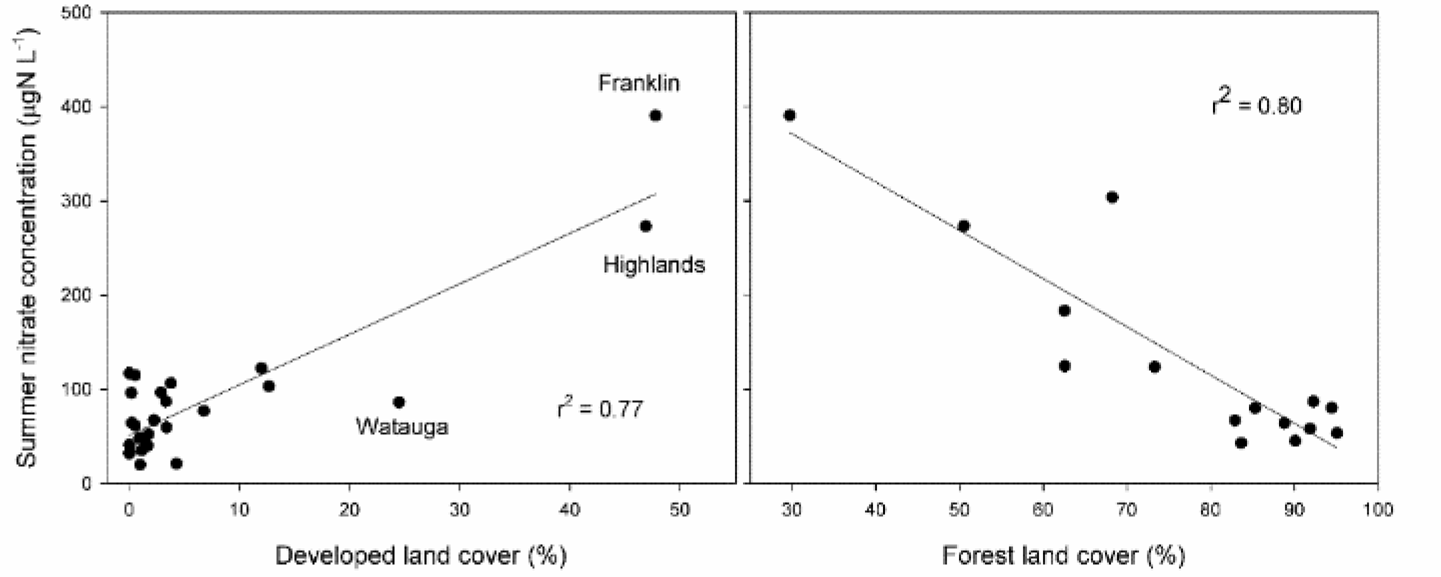


Rapid heating within gap

Rapid cooling below gap

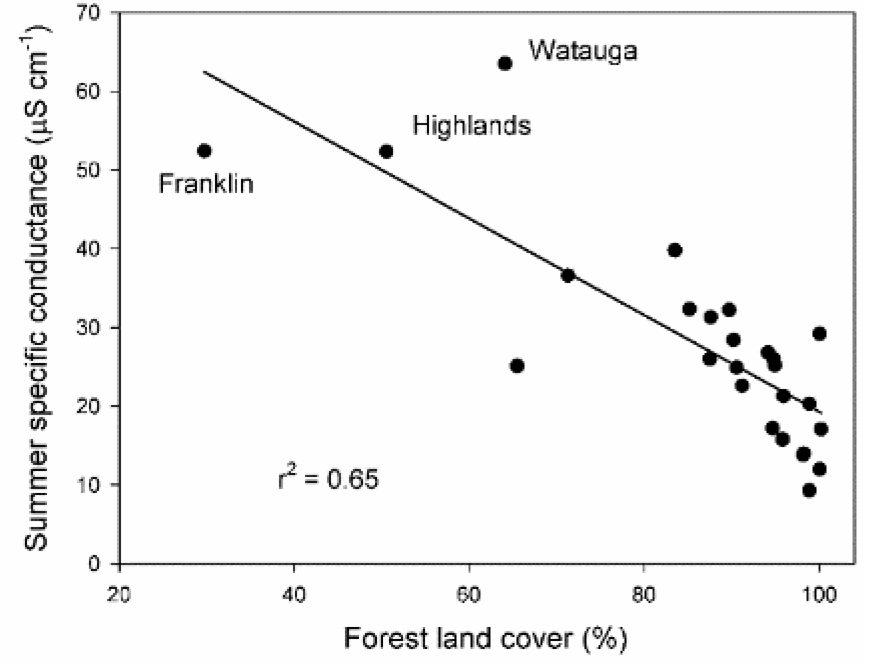
No differences in night-time temperatures.

Rural streams are subsidized by fertilizers and agricultural/horticultural chemicals.

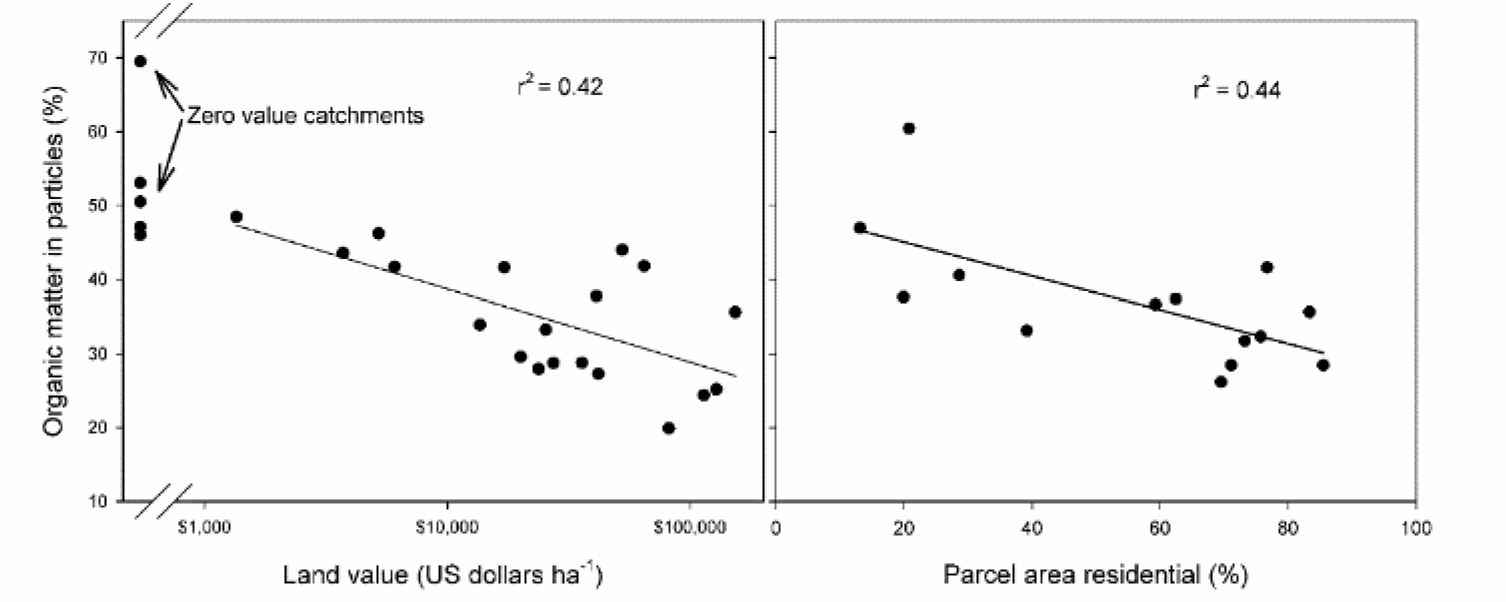


[NO_3^-] increases substantially with just 25% forest loss or 10% development. High variability in low-disturbance watersheds.

Webster, J.R., et al. 2012. Water quality and exurbanization in southern Appalachian streams.
in P.J. Boon and P.J. Raven, (Eds.)
River Conservation and Management.
Wiley-Blackwell, Chichester, UK.



Specific conductance responds to very low levels of forest conversion. Lots of noise in more developed watersheds.



Smaller proportion of organic matter in particles as land value increases!

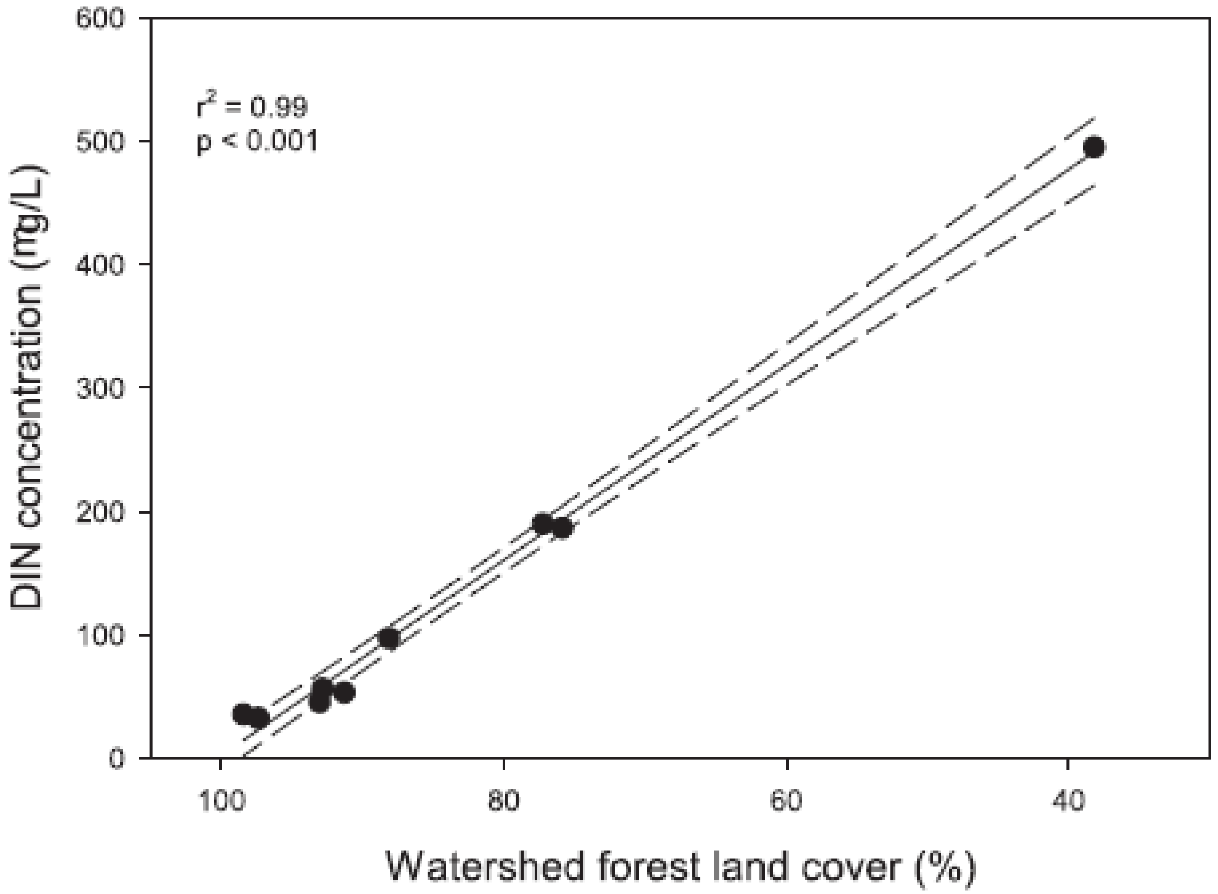


Figure 7. Stream dissolved inorganic nitrogen (DIN) concentrations across a gradient of forest cover. Basin forest cover explains 99% of the variation in stream DIN. Source: Adapted with permission from Webster and colleagues (2019).

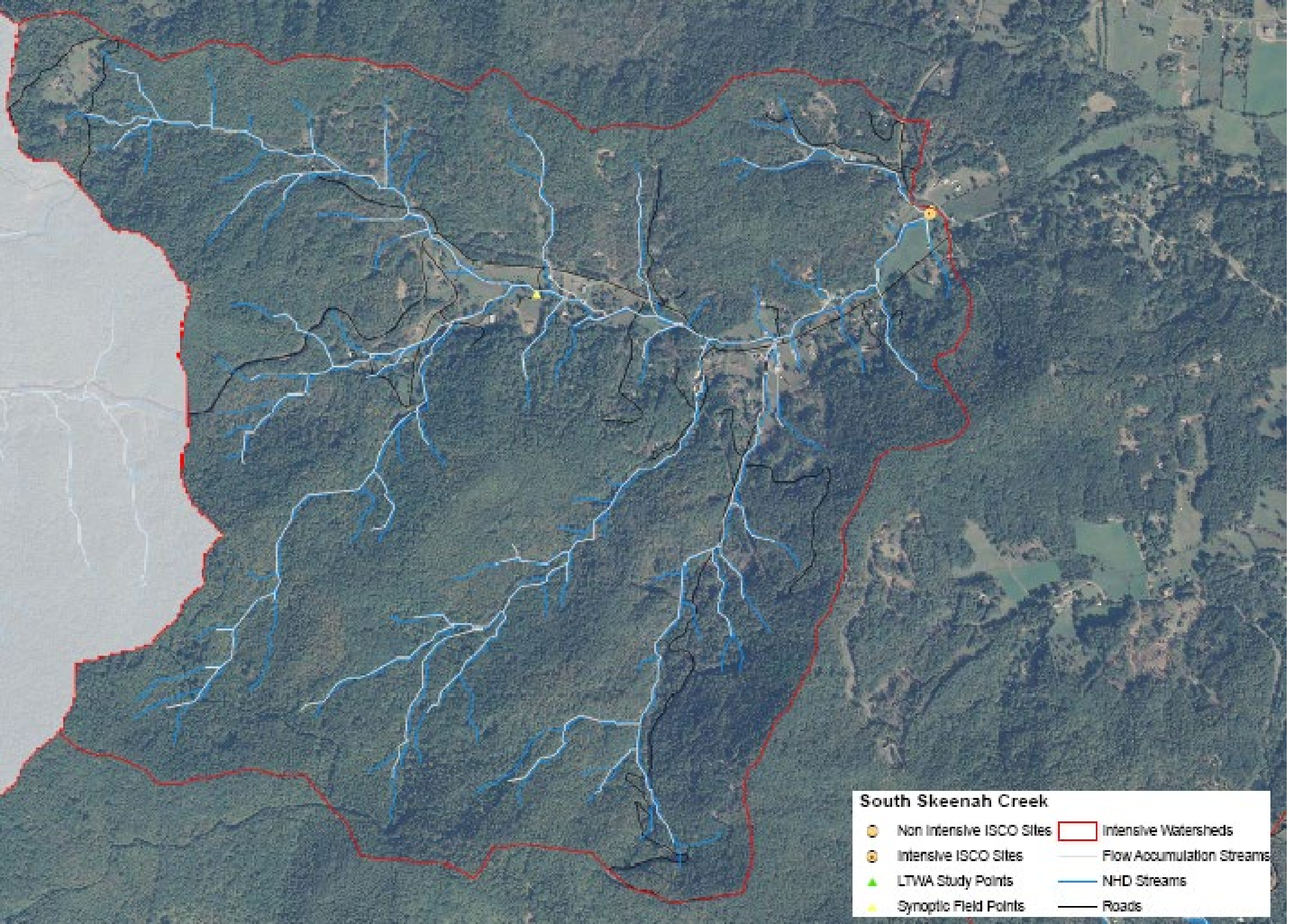
In all datasets we've analyzed, we have found a VERY strong relationship between forest conversion and concentrations of dissolved inorganic nitrogen, including nitrate nitrogen.

These are bioavailable forms of nitrogen that accelerate growth of algae and other aquatic organisms.

So, if riparian forest removal puts more sunlight on streams and forest conversion puts more bioavailable nitrogen in streams, then the streams are going to become warmer and more productive and they are going to grow more algae.

This changes aquatic food webs. Appalachian streams shift from detrital-based (leaves and twigs) to algal-based.

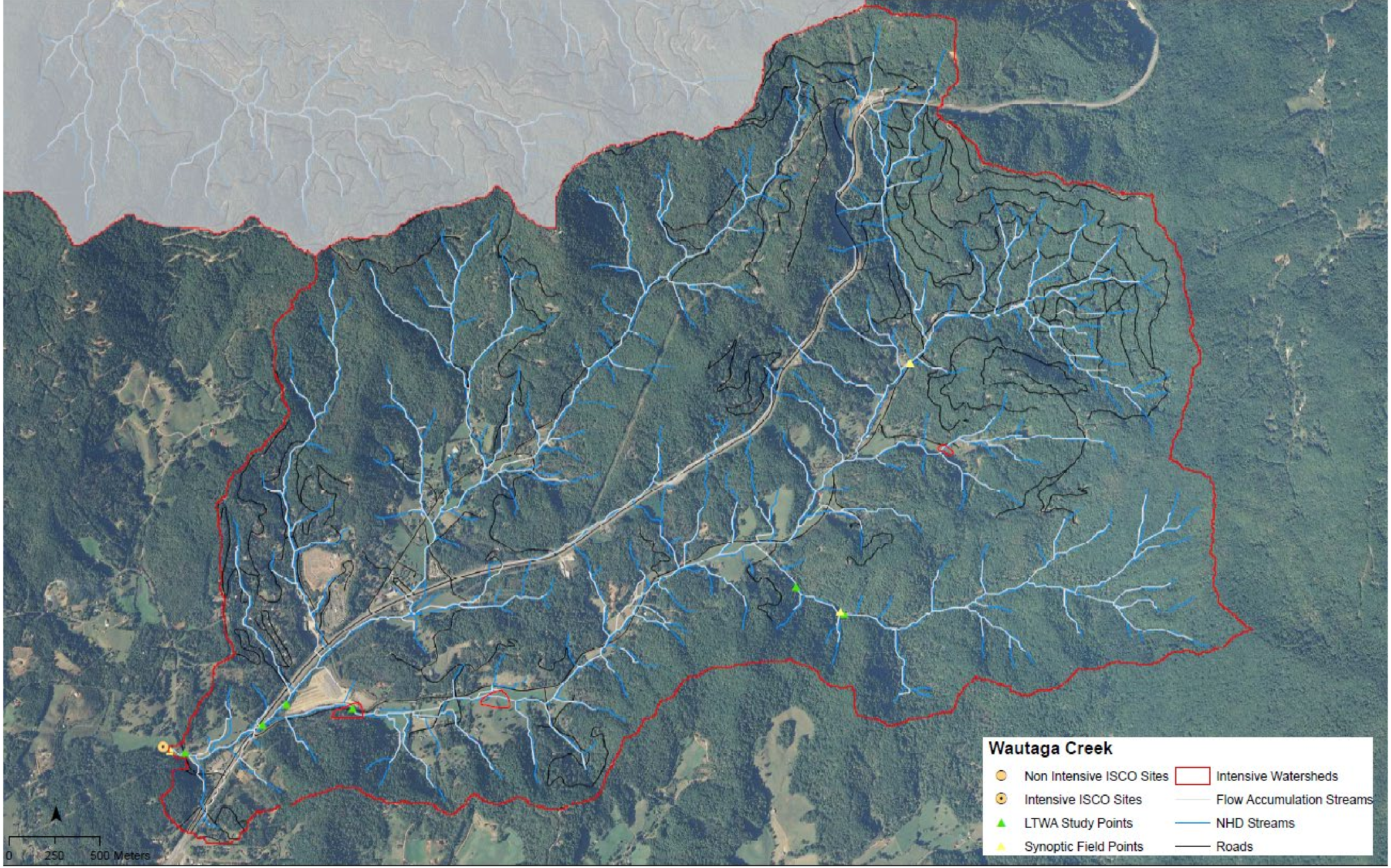
Furthermore, the increased N primes the pump for decomposition, so leaves in the stream decompose faster, sometimes creating late summer food scarcity.



Typical “valley development” land use pattern of the S. Appalachians

South Fork Skeenah Creek southeast of Franklin, NC.

Image by John Chamblee

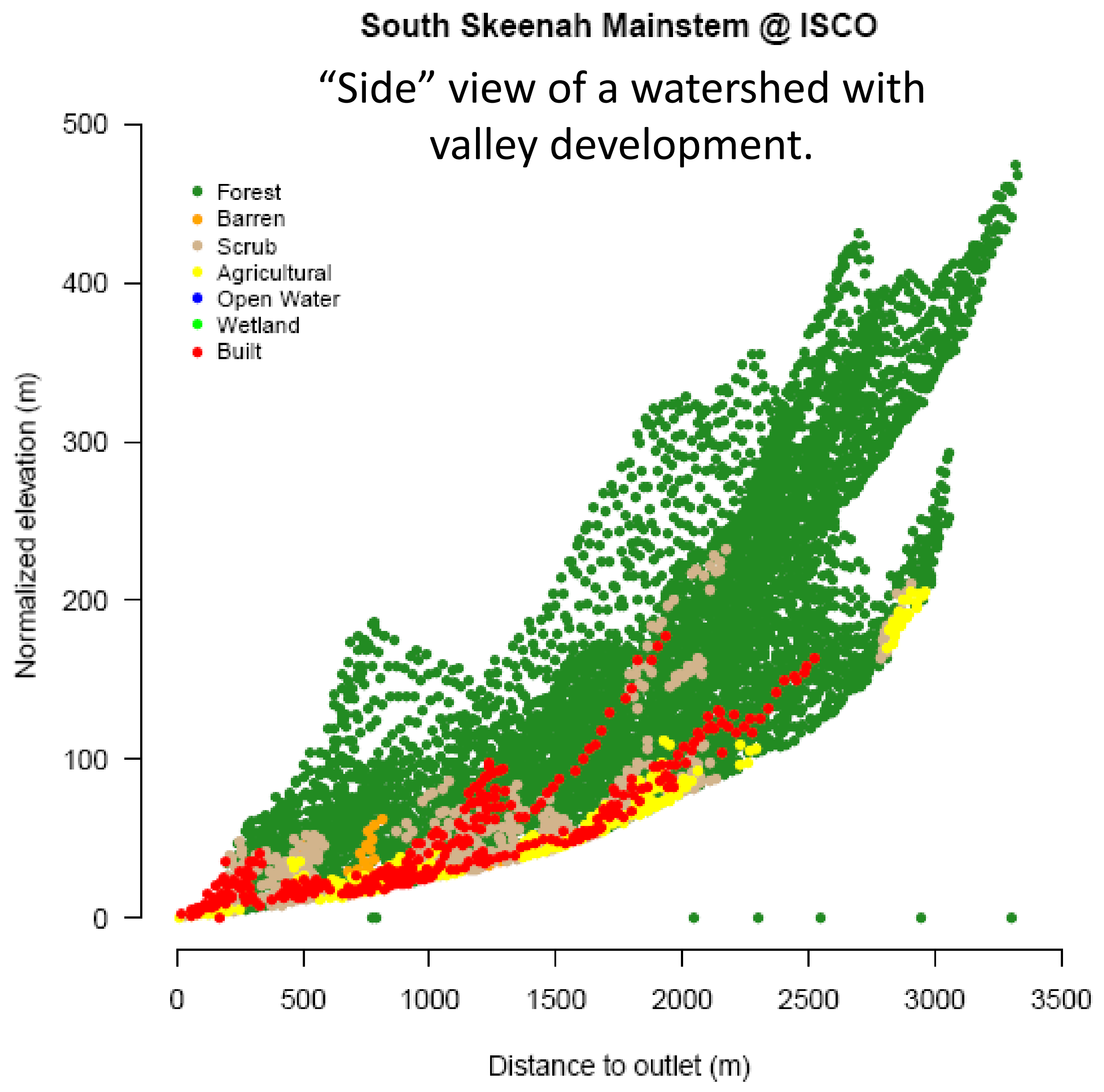


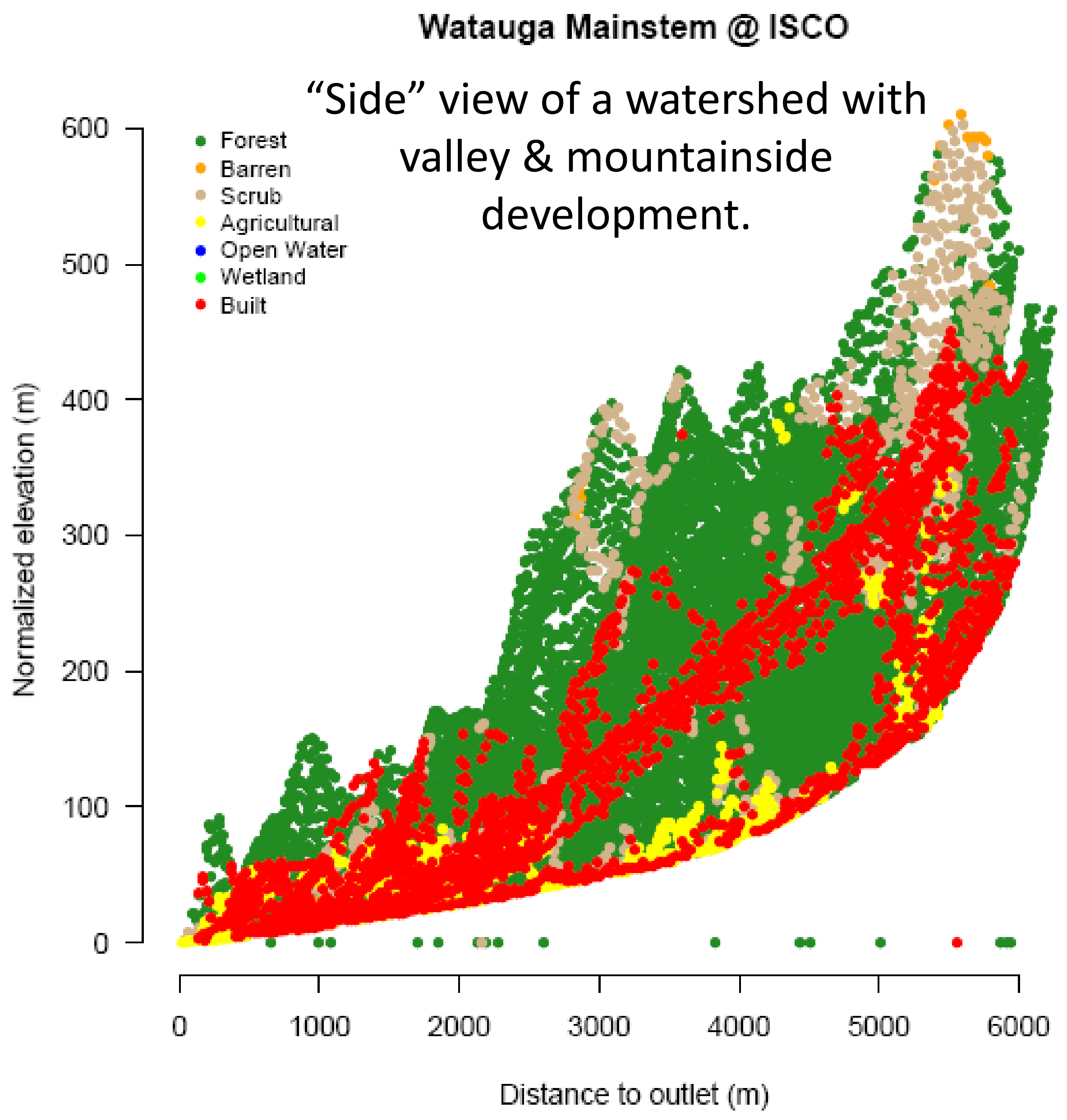
"Mountainside development" land use pattern.

Watauga Creek, northeast of Franklin, NC.

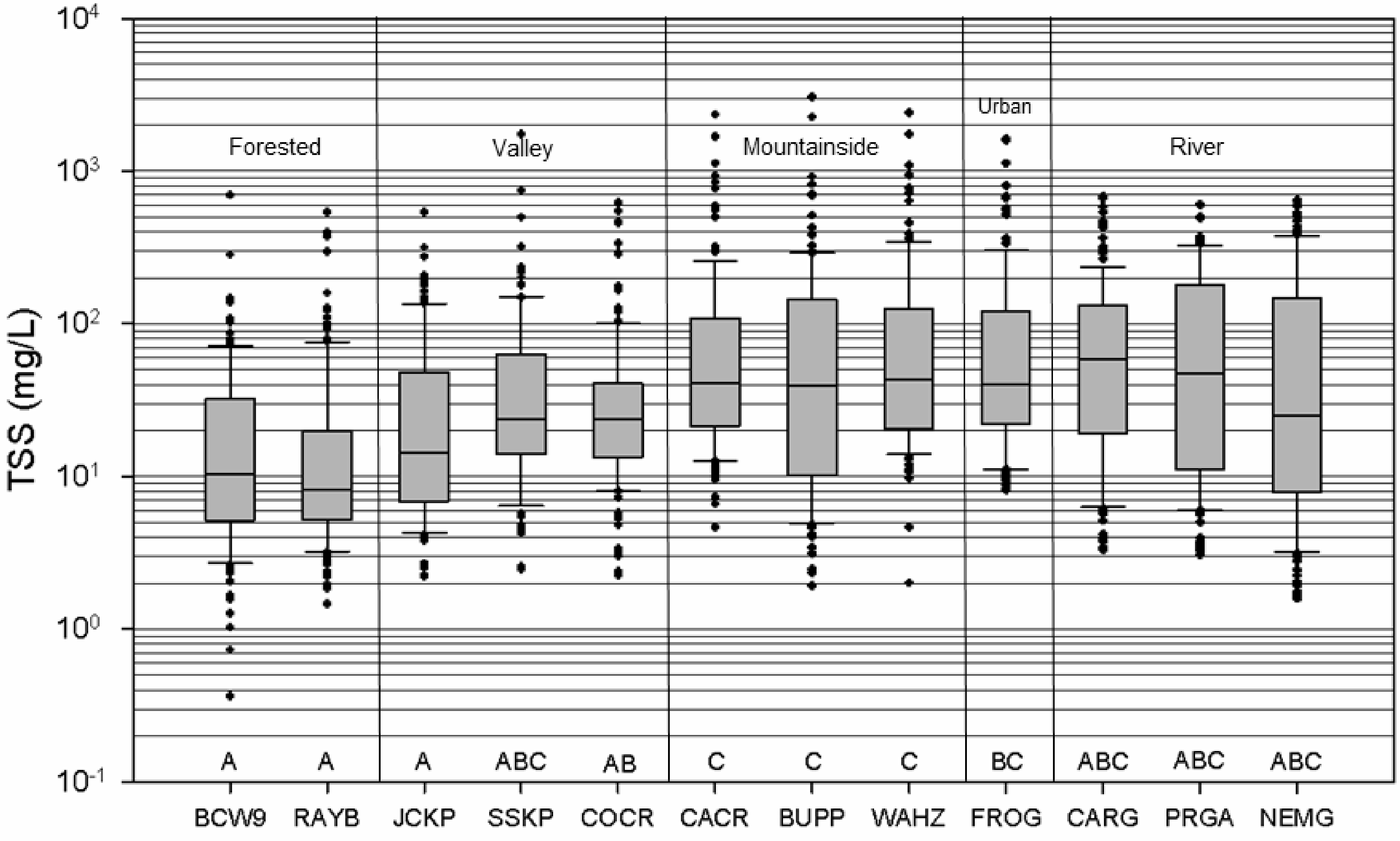
Image by John Chamblee

Traditional Valley Development Pattern Versus Modern Mountainside Development Pattern (houses on hills)





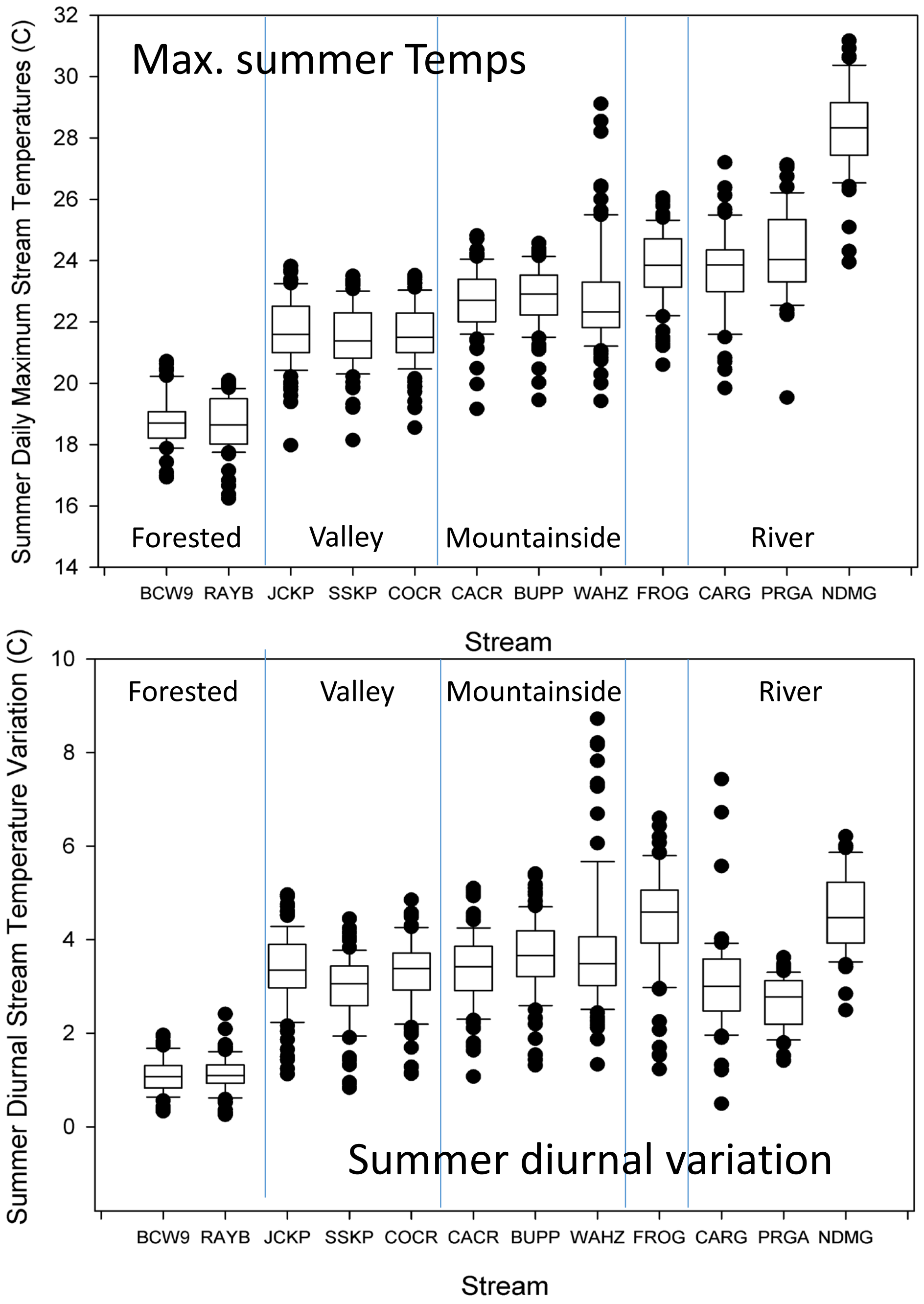
Analysis by J. Chamblee & colleagues



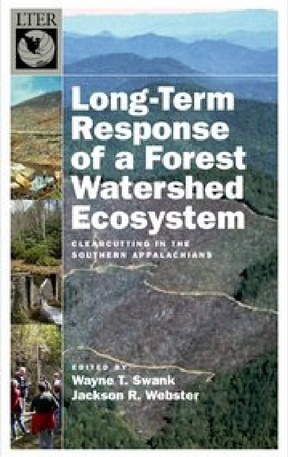
Suspended sediment concentrations elevated 2–6 X above forested streams.

Why? - Road runoff (see photo), dirt roads and driveways, continued effects of past sedimentation, riparian disturbance.


ALLISON
Shade your Stream
cool water,
clean water
www.shadeyourstream.org
MIKE'S BODY SHOP


Max. summer Temps
Summer Daily Maximum Stream Temperatures (C)
32
30
28
26
24
22
20
18
16
14
Forested
Valley
Mountainside
River
BCW9 RAYB JCKP SSKP COCR CACR BUPP WAHZ FROG CARG PRGA NDMG
Stream
Summer Diurnal Stream Temperature Variation (C)
10
8
6
4
2
0
Forested
Valley
Mountainside
River
Summer diurnal variation
BCW9 RAYB JCKP SSKP COCR CACR BUPP WAHZ FROG CARG PRGA NDMG
Stream

Long-term affects of forest disturbance on nutrient cycling and export.



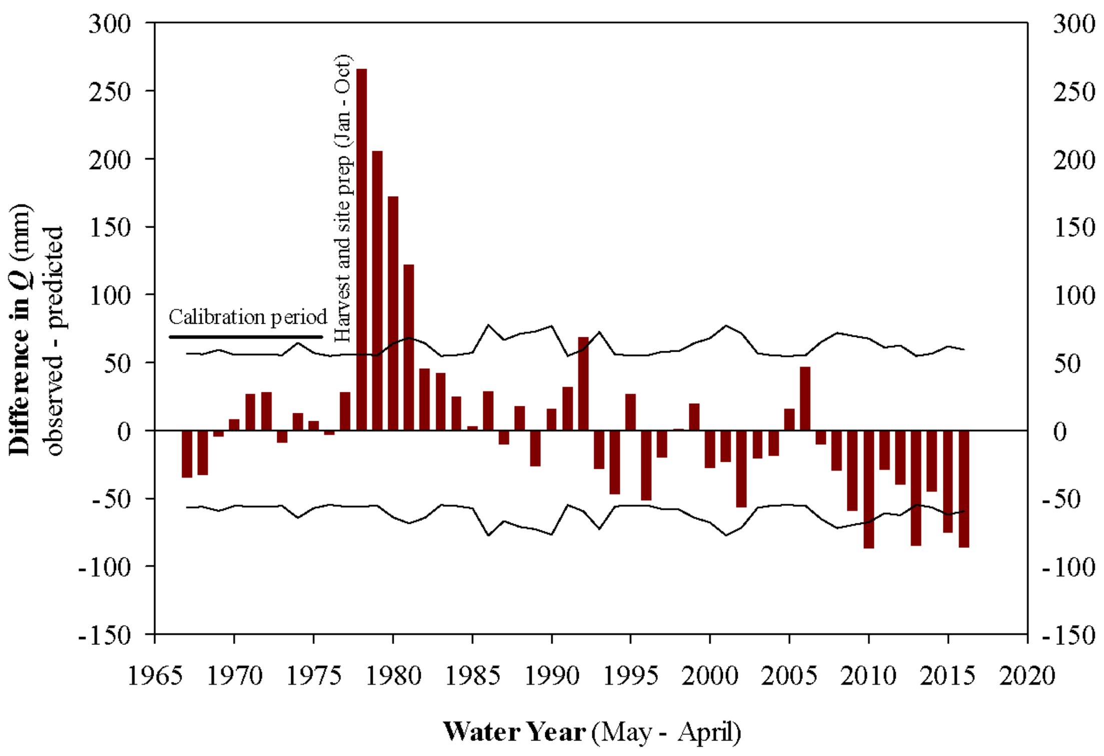
Context: highly diverse forest with high rainfall falling all year.
Basin area = 59 ha.

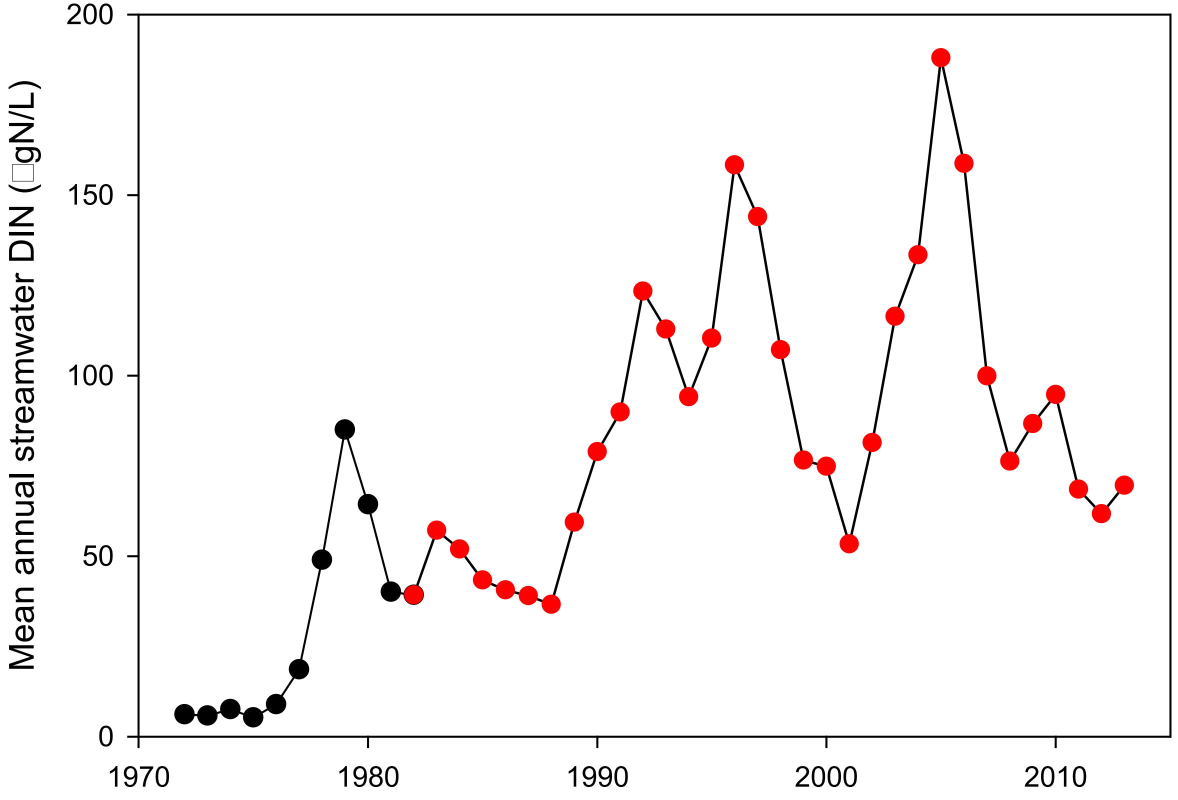
Swank and Webster 2014

Mixed-hardwood forest of Watershed 7 was clearcut-harvested in 1977 and allowed to regenerate naturally.

- new roads
- cable-yarding
- no riparian buffers

Experiment designed to test “ecosystem resistance and resilience” ideas.





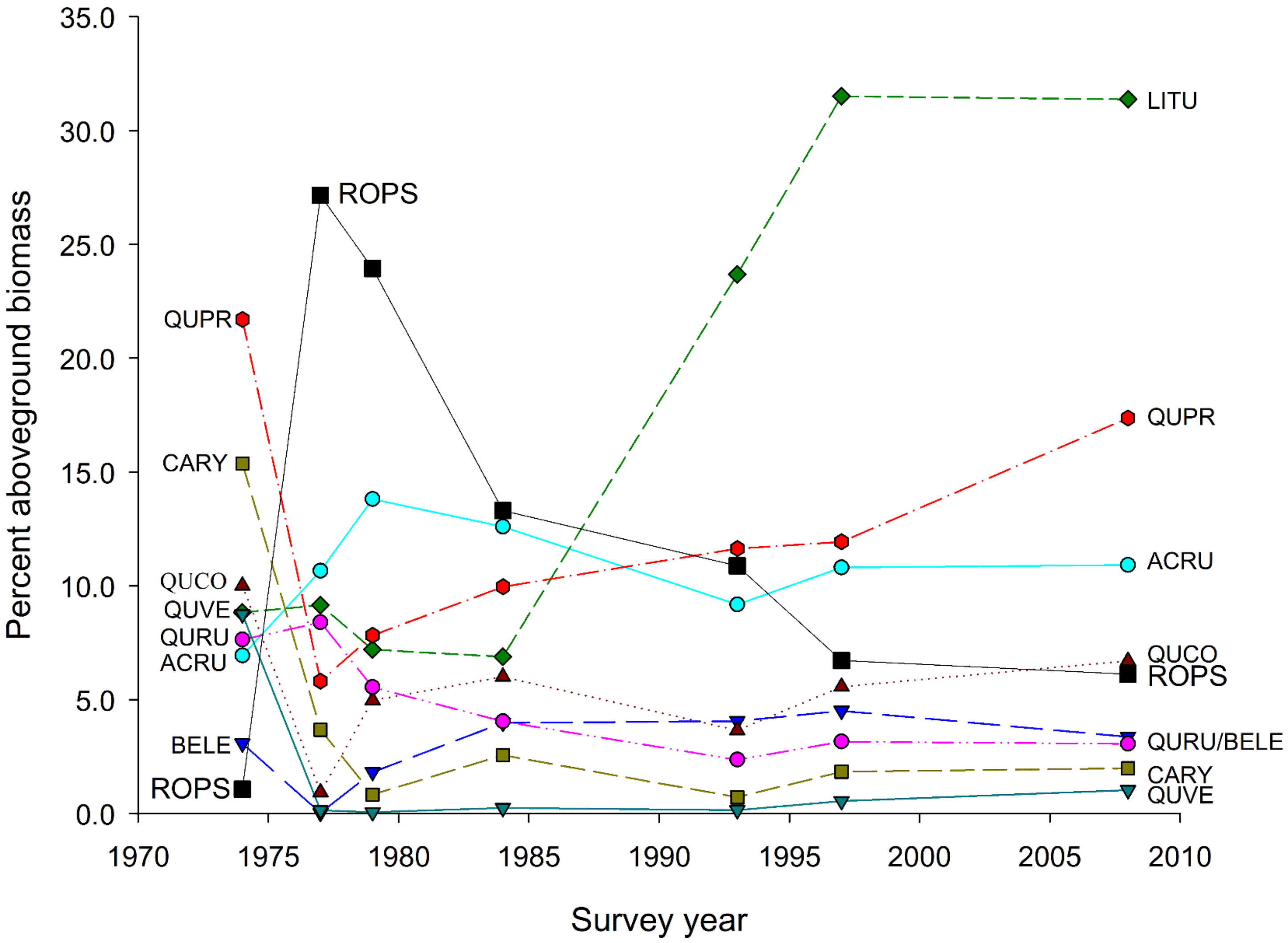
Discharge increased substantially for four years following harvest, then remained similar to the reference watershed for the next 25 years. At that time, discharge became consistently and sometimes significantly lower than in the reference watershed.

Dissolved inorganic nitrogen (DIN) was released after harvest due to lack of plant uptake of continuing soil mineralization, and the system appeared to start moving back towards pre-harvest condition until stream DIN increased again 12 years after harvest. What was going on?

Some ecological processes are slow, and responses to past disturbances can be long-lived.

Webster et al. 2016. Ecosystems.

Jackson et al. 2018. WIREs Water



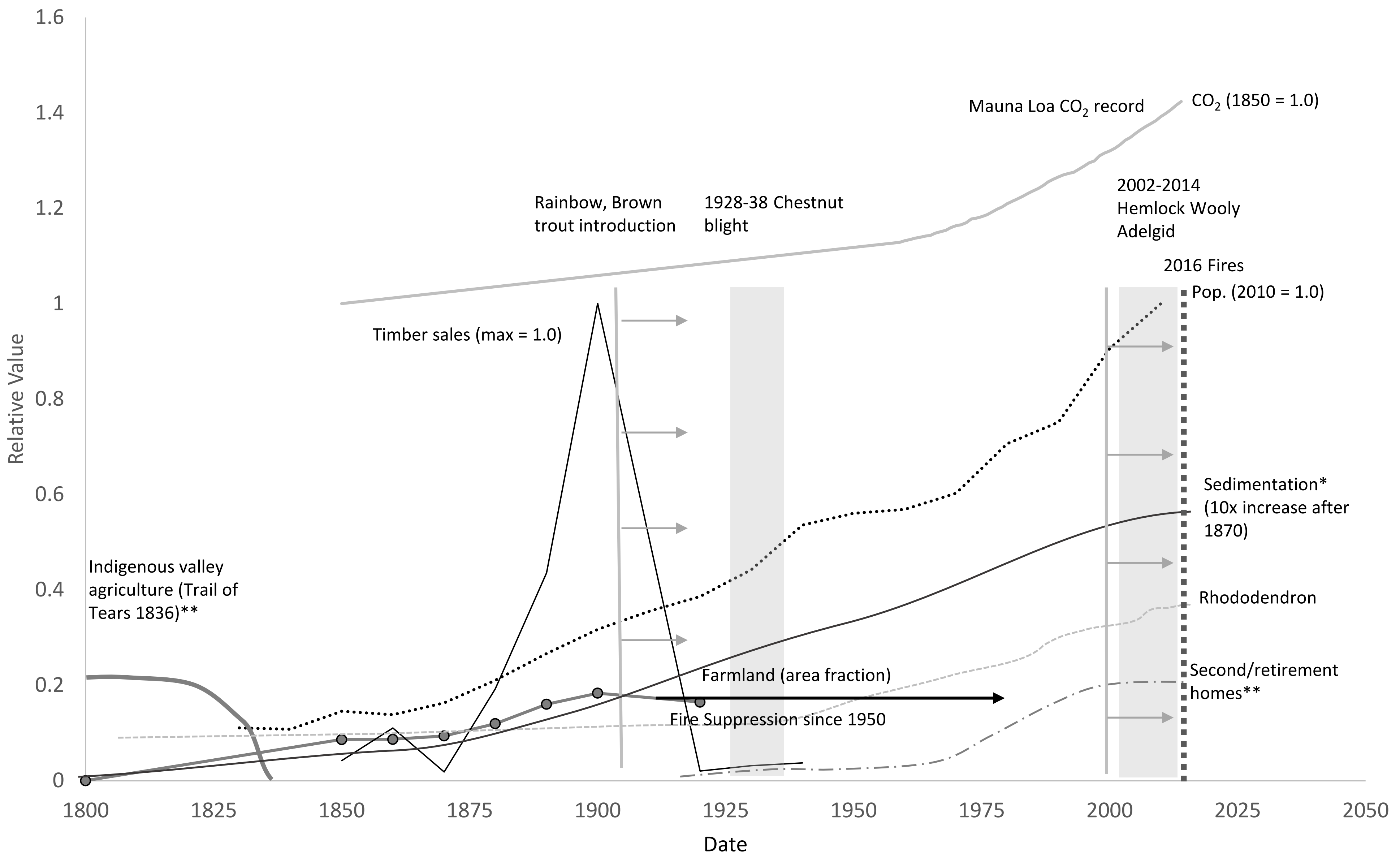
Time series of percent above ground biomass of dominant forest plant species.

"ROPS" is *Robinia pseudoacacia* L., aka Black locust, a tree species that facultatively produces nitrogen-fixing nodules in the soil when soil N levels are low and limiting plant growth.

Robinia became dominant early in succession, but most died off quickly. Still, 30 years after harvest, Robinia was a much bigger part of the forest than it was pre-harvest.

Why have elevated DIN levels persisted so long?

Jackson et al. 2018. WIREs Water



Select large-scale disturbance history of the Southern Appalachian Mountains

*semi-quantitative timeline – based on sedimentation data with poor time resolution.
**Best guess timeline – County parcel data cannot be used to definitively identify second homes or retirement homes.

esa ECOSPHERE

Multiple drivers, scales, and interactions influence southern Appalachian stream salamander occupancy

Kristen K. Cecala,[1,8,†] John C. Maerz,[1] Brian J. Halstead,[2] John R. Frisch,[3]
Ted L. Gragson,[4] Jeffrey Hepinstall-Cymerman,[1] David S. Leigh,[5] C. Rhett Jackson[1]

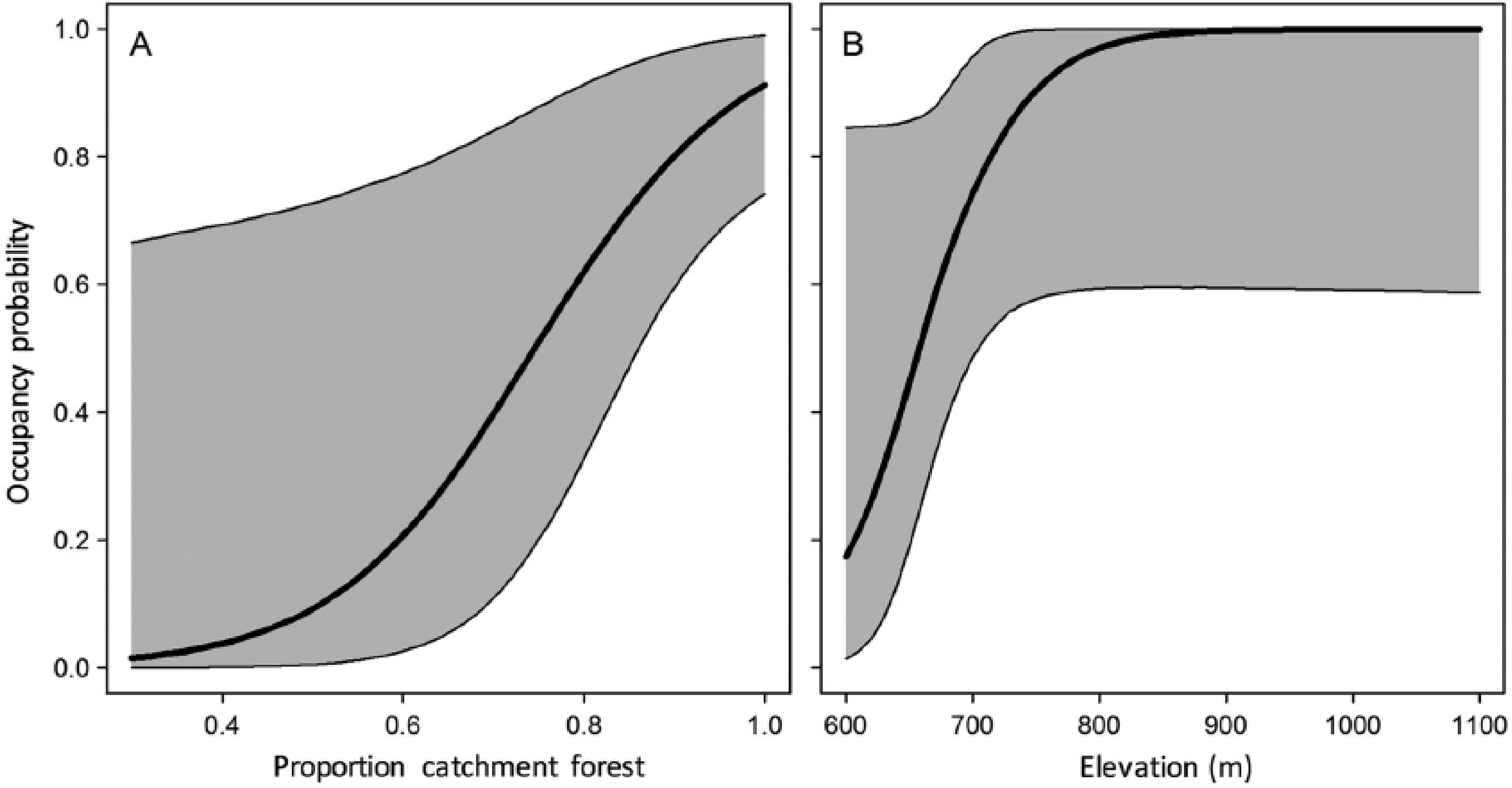


Fig. 3. Model-averaged effects of (A) proportion catchment forest land cover and (B) elevation on larval *Desmognathus quadramaculatus* reach-level occupancy. Bold lines indicate posterior medians, and gray-shaded areas and light lines represent the 95% credible intervals.

"small-to-moderate regional declines in forest cover cause corresponding declines in salamander abundance."

"Few reach-level metrics were included in our final multi-scale models suggesting that variation in salamander occupancy was largely driven by large-scale interactions such as forest cover and elevation or stream network structure."

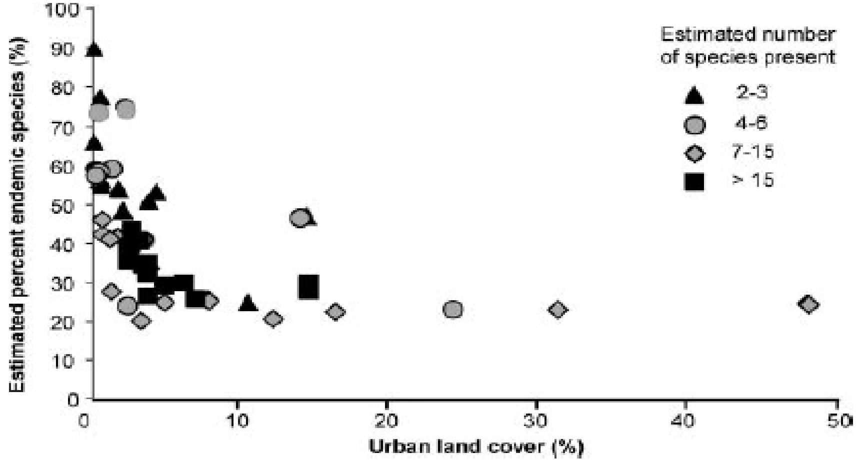


FIGURE 3. Average proportion of all species in a study reach that were endemic to the southern Appalachian highlands versus urban cover in wadeable streams the Little Tennessee River basin. The proportion of species was estimated using the best approximating multispecies, multiscale occupancy model and assuming summer season.

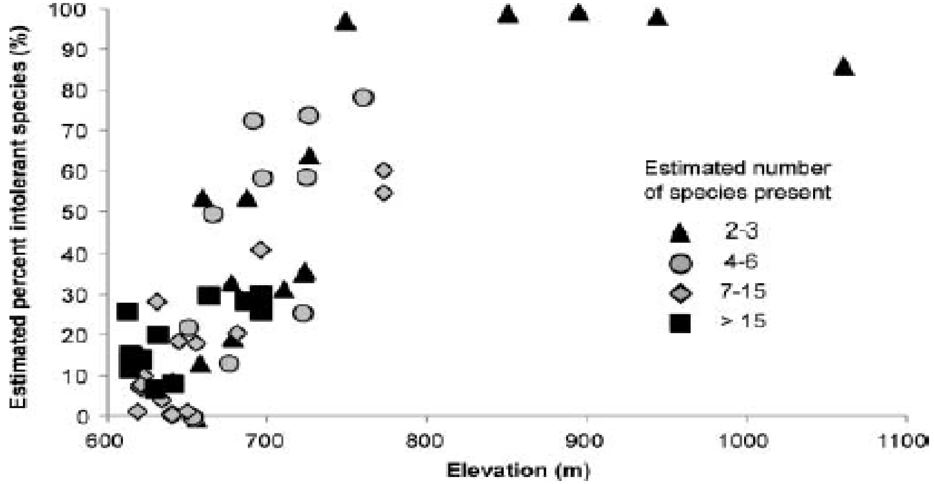


FIGURE 4. Average proportion of all species at a study reach that were warmwater intolerant versus study reach elevation in wadeable streams the Little Tennessee River basin. The proportion of species was estimated using the best approximating multispecies, multiscale occupancy model and assuming summer season.

Kirsch, J.E. and J.T. Peterson. 2014. M Multi-scaled Approach to evaluating the fish assemblage structure within southern Appalachian streams. Trans. Amer. Fish Soc. 143:1358-1371.

Study involved 525 channel units in 48 reaches sample in 2 consecutive years

Stream topography, channel units types, and urban land cover were important factors in determining fish occupancy

Habitat quality and thermal regime were most important factors among stream reaches.

Hydrogeomorphology affected occupancy within stream reaches.

Hydrobiologia (2016) 773:163–175
DOI 10.1007/s10750-016-2695-9

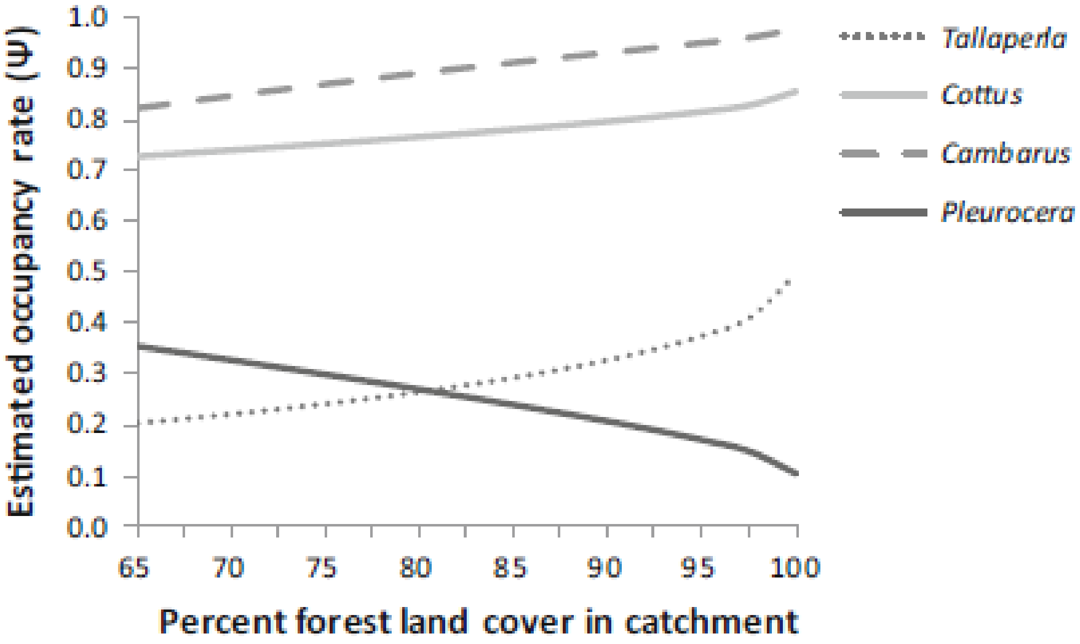
PRIMARY RESEARCH PAPER

Patch occupancy of stream fauna across a land cover gradient in the southern Appalachians, USA

John R. Frisch · James T. Peterson · Kristen K. Cecala · John C. Maerz · C. Rhett Jackson · Ted L. Gragson · Catherine M. Pringle

Best occupancy models for focal taxa

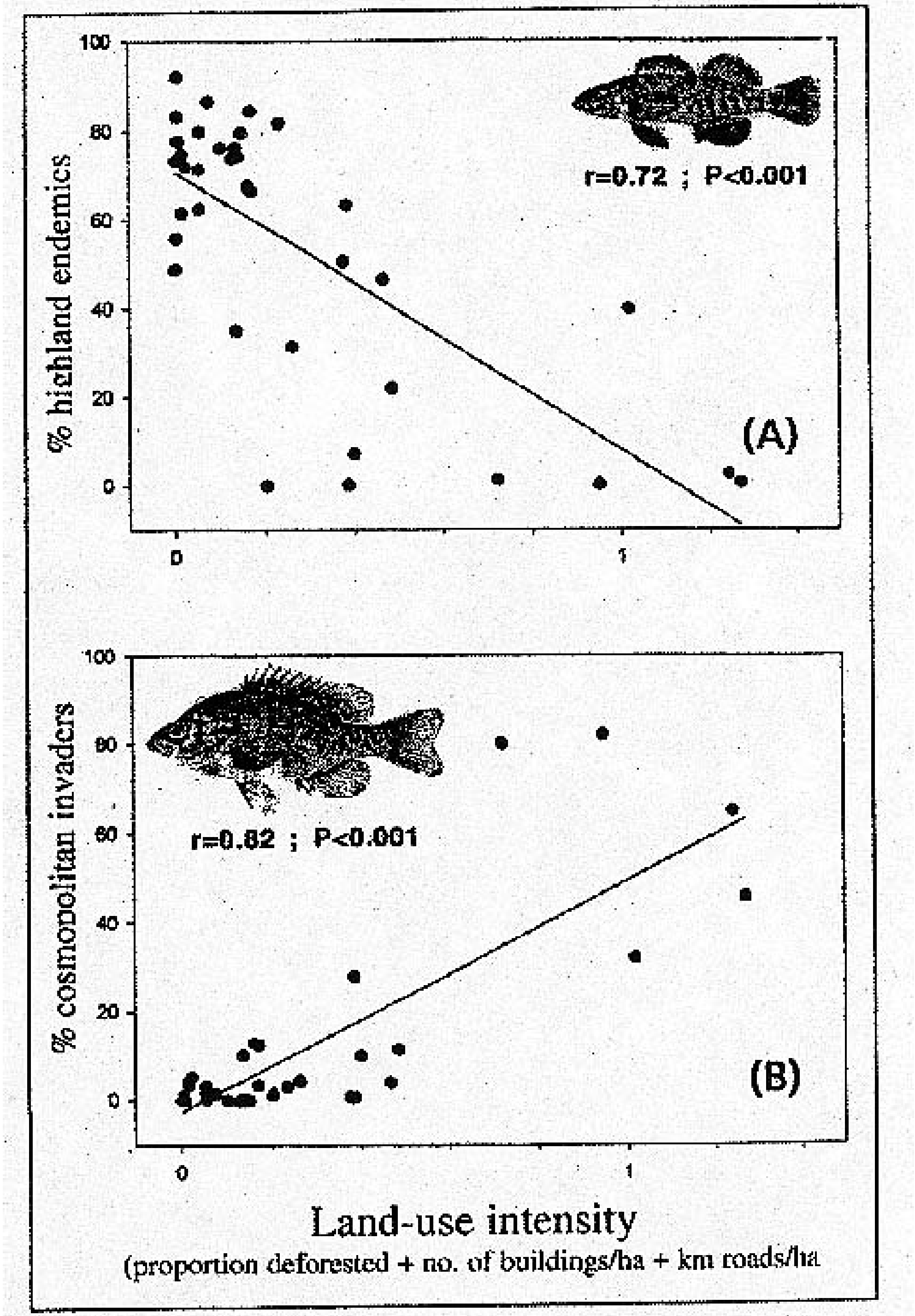
Tallaperla	forest (+)	TDN (-)
Cambarus	ag. (-)	LWD (+)
Cottus	forest (+)	D_{50} (+)
Pleurocera	[Ca] (+)	forest (-)



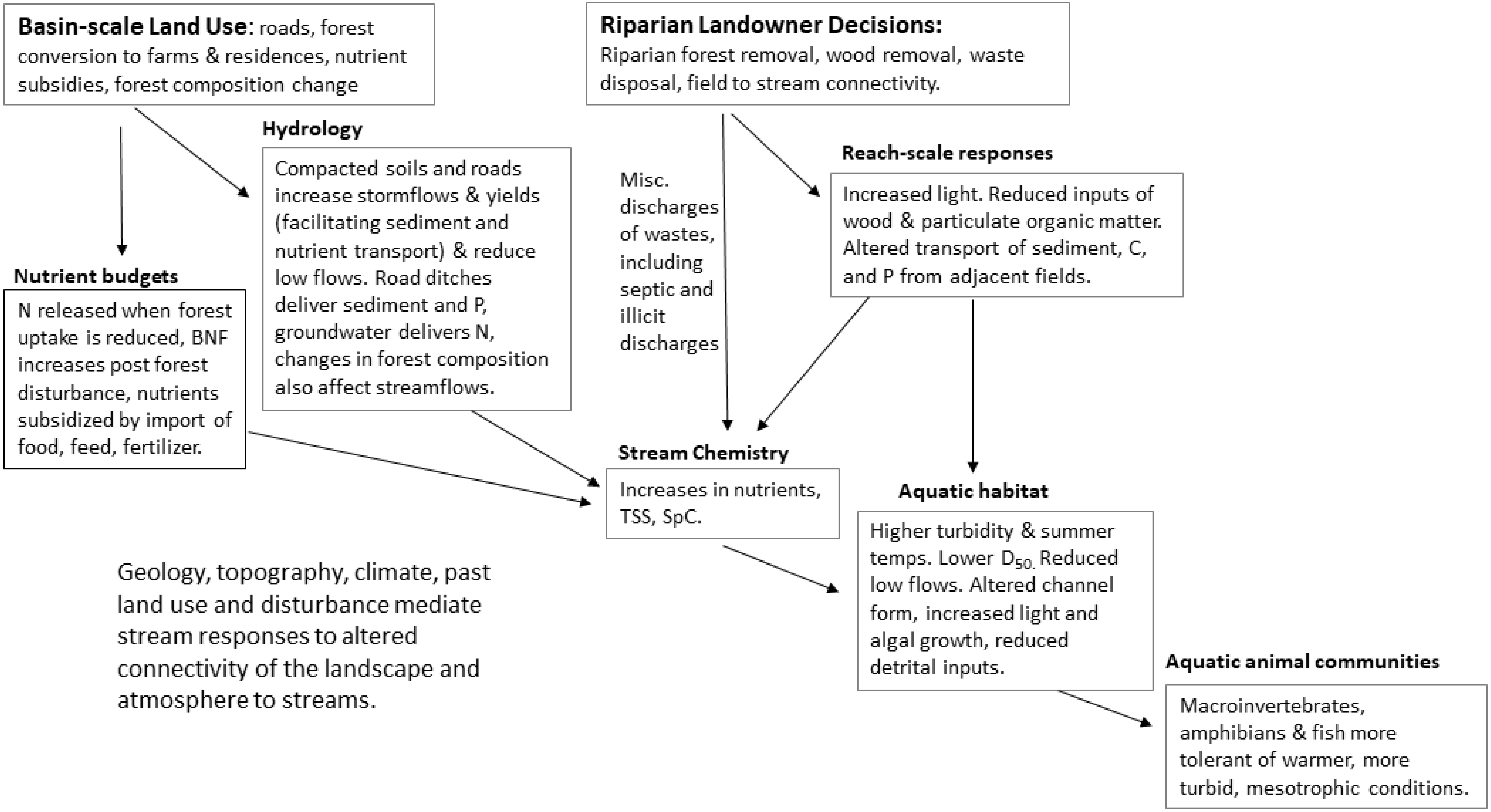
(shredding stonefly)
(insectivorous sculpin)
(omnivorous crayfish)
(shred/grazing snail)

Note x-axis starts at 65%

"Our results show the abundance of stream organisms was determined by the taxon-dependent interplay between catchment and reach-level factors"



Scott and Helfman, 2001


Basin-scale Land Use: roads, forest conversion to farms & residences, nutrient subsidies, forest composition change
Riparian Landowner Decisions: Riparian forest removal, wood removal, waste disposal, field to stream connectivity.
Hydrology
Compacted soils and roads increase stormflows & yields (facilitating sediment and nutrient transport) & reduce low flows. Road ditches deliver sediment and P, groundwater delivers N, changes in forest composition also affect streamflows.
Misc. discharges of wastes, including septic and illicit discharges
Reach-scale responses
Increased light. Reduced inputs of wood & particulate organic matter. Altered transport of sediment, C, and P from adjacent fields.
Nutrient budgets
N released when forest uptake is reduced, BNF increases post forest disturbance, nutrients subsidized by import of food, feed, fertilizer.
Stream Chemistry
Increases in nutrients, TSS, SpC.
Aquatic habitat
Higher turbidity & summer temps. Lower D_{50}. Reduced low flows. Altered channel form, increased light and algal growth, reduced detrital inputs.
Aquatic animal communities
Macroinvertebrates, amphibians & fish more tolerant of warmer, more turbid, mesotrophic conditions.
Geology, topography, climate, past land use and disturbance mediate stream responses to altered connectivity of the landscape and atmosphere to streams.

1. Stream diverted to clean a large dog kennel.
2. Streams diverted to ornamental ponds and other landscaping features.
3. Trash disposal on steep hillslopes on public lands.
4. Use of the yard for trash disposal.
5. Application of cow manure to stream banks.
6. Disposal of kitchen and yard waste in the stream (compost pile in stream).
7. Mysterious discharges from pipes on the streambanks.
8. Removal of wood to "clean the stream".
9. People cutting out coarse wood for canoe/kayak traffic down the river.
10. Harvest of rocks for landscaping purposes.
11. Backhoeing the channel to "clean it up".
12. Feeding of fish in the stream.
13. Animal carcass disposal in streams.
14. Recreational damming to create favorable hydraulics for tubing.
15. Hauling and depositing sand on the streambank to create "beaches".
16. Sluicing the flows for gem mining.

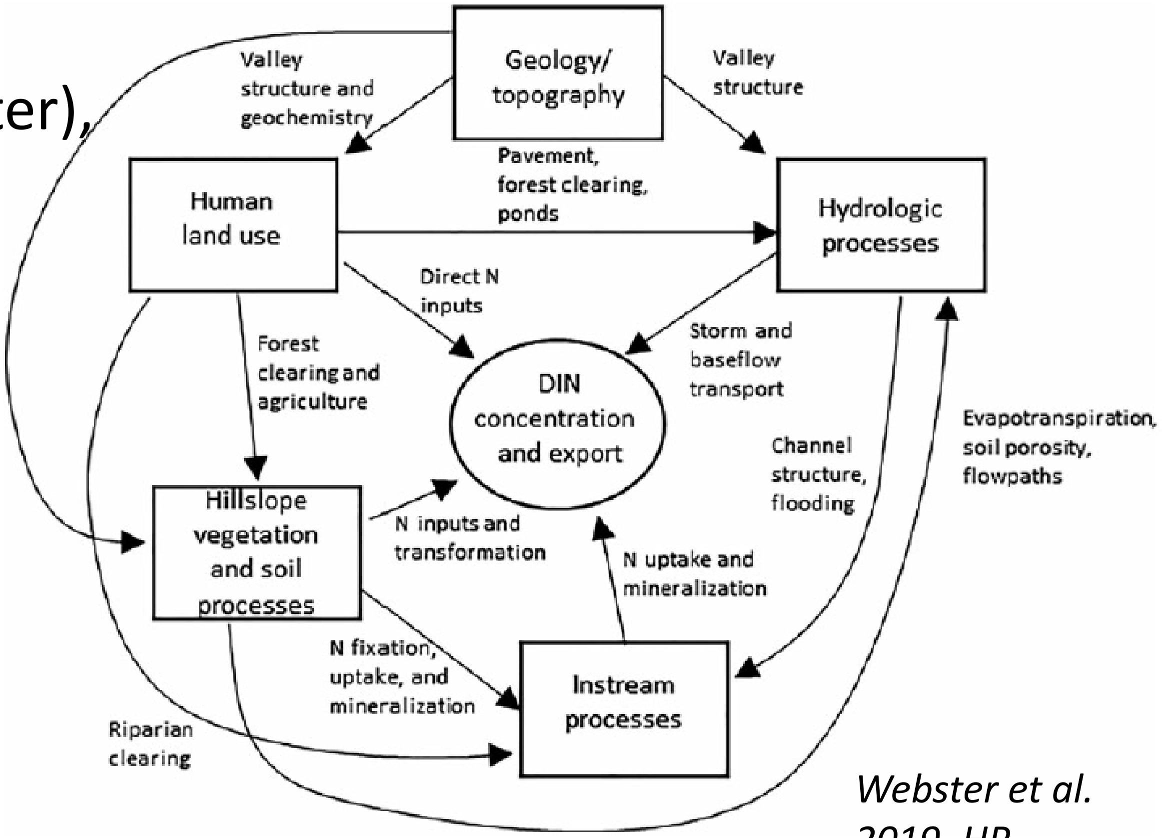
Individual landowner decisions matter!

Riparian activities we have observed in the ULT.

Moderate amounts of forest conversion (less than 35%) to small valley farms and rural residential lands, along with riparian forest removal, results in streams with:

Narrow and simple channels without wood,
Summer stream temperatures too warm for cold water taxa,
Ecologically high levels of bioavailable nitrogen,
Elevated specific conductivity (more ions in the water),
High levels of algal growth,
Higher sediment concentrations,
Poor trout habitat,
Simpler, less diverse aquatic ecosystems,
Streams that are more like Piedmont streams.

Most of these problems are solvable.



Webster et al. 2019. HP.

Conclusions

What can landowners and mountain Counties do to improve stream health?

Let the riparian forest regrow – use gaps for stream access and fishing

Reduce sediment delivery from unpaved roads and roadside ditches

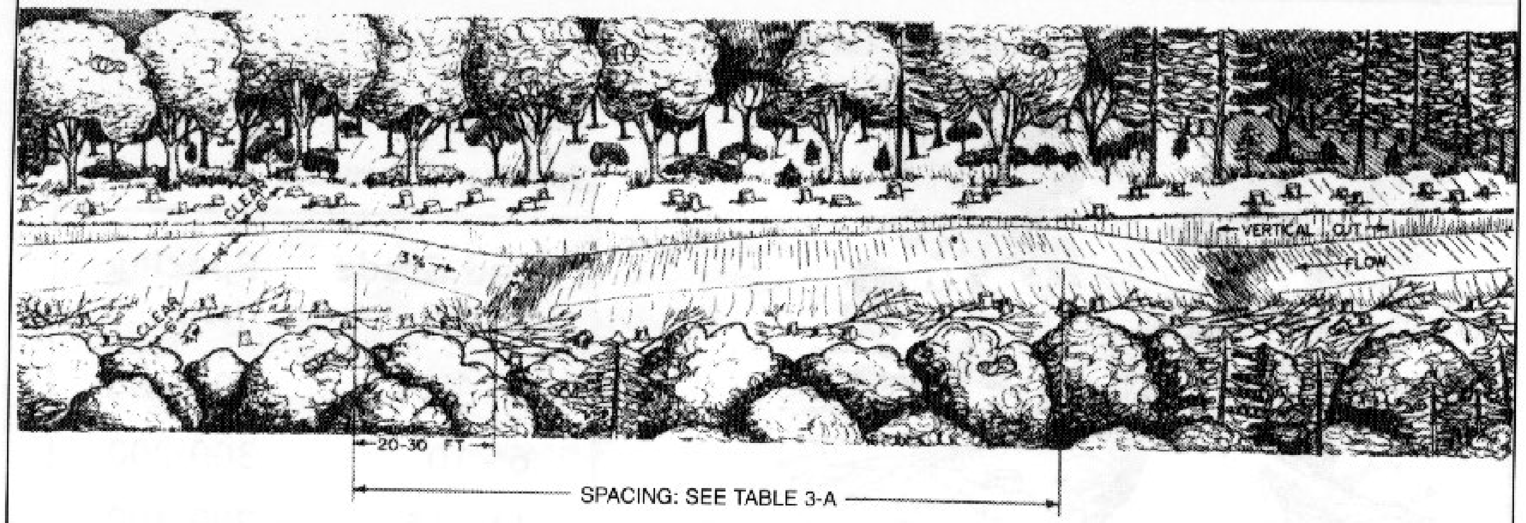
Minimize fertilizer application

Fence the livestock out of streams

Eliminate illicit discharges

Maintain/improve septic systems

Figure 3-A. Broad-based Dip Road



Guidelines for reducing sediment transport from unpaved roads to streams are well-developed in forestry best management practices (BMPs).

Figure 3-C. Design and Installation of Turnouts

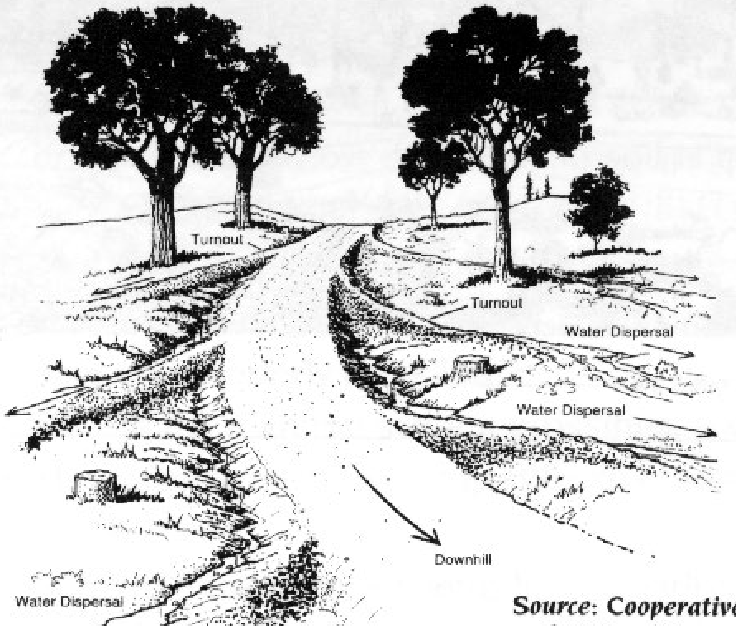


Table 3-B.
Spacing of Turnouts

Road Grade (percent)	Spacing (feet)
2 - 5	500-300
6 - 10	300-200
11 - 15	200-100
16-20	100

Source: Cooperative Extension Service Division of Agricultural Sciences and Natural Resources, Oklahoma State University

Funding: National Science Foundation LTER Program
United States Forest Service
University of Georgia

Collaborating Institutions in the Coweeta LTER:
University of Georgia, Virginia Tech University, University of Minnesota, University of Illinois, Indiana University, University of Wisconsin, University of Virginia, University of North Carolina, Mars Hill College, Duke University

Some Notable Macon County Locals Involved in These Projects:

Jason Love
Jennifer Knoepp
Pete Caldwell
Chris Oishi
Patsy Clinton
Katie Bower
Randy Fowler
Cindi Brown
Sheila Gregory
Jason Meador
Kitty Elliott
Stephanie Laseter
Barry Clinton
Chris Sobek
Joel Scott
Michelle Ruigrok
Carol Harper

The University of Georgia

UNIVERSITY OF GEORGIA
Institute for Resilient Infrastructure Systems

NATIONAL SCIENCE FOUNDATION
LTER NETWORK
LONG TERM ECOLOGICAL RESEARCH

CWT LTER
Coweeta Long Term Ecological Research Program

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE