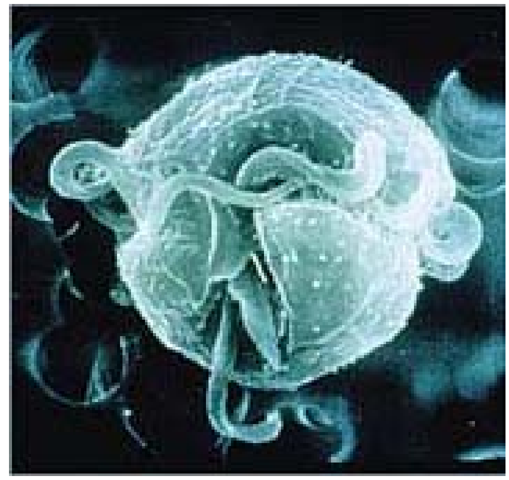
TIEE
Teaching Issues and Experiments in Ecology - Volume 1, January 2004

ISSUES – FIGURE SET



Pfiesteria piscicida
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Human Alteration of the Global Nitrogen Cycle

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Figure Set 2: What is the evidence for Nitrogen saturation of temperate forests?

Purpose: Help students understand the phenomenon called nitrogen saturation.
Teaching Approach: "support a statement"
Cognitive Skills: (see Bloom's Taxonomy) — comprehension, interpretation, evaluation
Student Assessment: justification essay

BACKGROUND

Nitrogen Saturation

Nitrogen saturation of forests occurs when the availability of inorganic nitrogen exceeds demand by plants and microbes (Aber et al. 1989). It is a response to human-caused increases in nitrogen deposition - specifically oxides of nitrogen (nitrate and NOx) mainly from fossil fuel emissions and also ammonium from production and use of fertilizers. With increasing recognition of this problem ecologists have focused more effort on the capacity of forests to retain high inputs of nitrogen and also effects of excess nitrogen on vegetation. In addition, some of these studies target effects of high nitrogen loading in receiving waters.

Two aspects of the Aber et al. paper are especially important to emphasize to students: 1) the non-linear response of key system phenomena (e.g. N cycling processes, N loss to ground and surface waters) to N inputs that is due to a "saturation" point beyond which fundamental changes take place and 2) a shift from positive fertilization effects of N to negative effects. The "good-bad" aspect of N loading to temperate forests may be confusing to students.

High rates of nitrogen deposition to forests lead to a cascade of effects (Vitousek et al. 1997). Increasing concentration of ammonium in soil stimulates nitrifiyers with an accompanying rise in hydrogen ions. Nitrate is mobile in soils and its leaching also results in loss of cations including calcium, magnesium, and potassium. Loss of these nutrients can lead to stunted tree growth and tree mortality as a result of nutrient imbalances in tree roots and leaves. Finally, with calcium depletion and soil acidification, aluminum ions become mobile and are a potential threat to tree roots or aquatic organisms.

Since the 1980's, numerous nitrogen saturation studies have documented: 1) increase in nitrate concentrations in streams and rivers, 2) increased loss of nutrient cations from soils, 3) nutrient imbalances, higher rates of insect and pathogen damage, and reduced frost hardiness, 4) declines in tree growth, especially of evergreens, and 5) higher rates of nitrous oxide emissions (Peterjohn et al. 1999).

The impacts of nitrogen saturation were first seem in Europe in the early 1980's with observations of increased nitrate in some streams and rivers and also yellowing plus needle loss in spruce and other conifers. The problem is most severe in parts of northern Europe compared to North America because nitrogen deposition rates are higher. Japanese watersheds are also experiencing N saturation in urbanized areas (Ohrui and Mitchell 1997). Effects in the U.S. are more limited to high elevations with high inputs and shallow, poorly buffered soils (Vitousek et al. 1997).

The Broader Context

As Jefferies and Maron (1997) point out, a century ago scientists debated whether atmospheric inputs of N were sufficient for plant growth. Today we recognize that more N is fixed each year by humanity than by natural processes in terrestrial ecosystems (see also Data Set 1 of this Issue). This shifts the ecological focus to fate of this anthropogenic N and its effects on systems.

Galloway et al (2003) take the phenomenon of nitrogen saturation further with their "nitrogen cascade" idea. They divide N compounds into reactive and nonreactive, and they propose that in prehuman times, reactive N did not accumulate due to a balance of nitrogen fixation and denitrification. In contrast today reactive N is accumulating on all spatial scales.

Results from numerous studies done in the 1990's now allow more synthetic analysis of nitrogen saturation in terrestrial ecosystems. For example, in a return to the question "Is the N status of northeastern forests being altered by N deposition?" Aber et al. (2003) say: "… our analysis suggests that the answer to this question is yes, although the degree of response varied greatly across the three different categories of indicators we examined. The surface water data suggest a strong relationship between NO3- concentration and flux across the N deposition gradient. The soil data show strong relationships between N deposition, soil C:N ratio, and nitrification in several cases, but the strength and significance of these trends differed among forest types and soil horizons. Finally, in the foliar data set, significant relationships with N deposition did not emerge beyond the covarying effects of climate and elevation".

References

Aber, J. D., J. M. Melillo, K. J. Nadelhoffer, J. Pastor, and R. D. Boone. 1991. Factors controlling nitrogen cycling and nitrogen saturation in northern temperate forest ecosystems. 1991. Ecological Applications 1: 303-315.

Aber, J. D., et al. 2003. Is nitrogen deposition altering the nitrogen status of northeastern forests? BioScience 53: 3750389.

Galloway, J. N., et al. 2003. The nitrogen cascade. BioScience 53: 341-356.

Jefferies, R. L., and J. L. Maron. 1999. The embarrassment of riches: atmospheric deposition of nitrogen and community and ecosystem processes. Trends in Ecology and Evolution 12: 74-78.

Ohrui, K., and M. J. Mitchell. 1997. Nitrogen saturation in Japanese forested watersheds. Ecological Applications 7: 391-401.

Peterjohn, W. T., C. J. Foster, M. J. Christ, and M. B. Adams. 1999. Patterns of nitrogen availability within a forested watershed exhibiting symptoms of nitrogen saturation. Forest Ecology and Management 119: 247-257.

Vitoursek, P. M., J. D. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and D. G. Tilman, 1997. Human alteration of the global nitrogen cycle: causes and consequences. Issues in Ecology 1: 1-15.

STUDENT INSTRUCTIONS

Support a Statement

Read the explanation below about the newly recognized phenomenon called nitrogen saturation and a study by Peterjohn et al. (1999) on Virginia forests. Then, with this information plus evidence in and your interpretation of Figures 2A and 2B, write an essay in which you support the following statement from the Peterjohn study.

Not all forests in West Virginia are negatively affected by high concentrations of nitrogen in precipitation. Differences in symptoms of nitrogen saturation are related to aspect (e.g. south or east-facing slopes).

Develop your argument in support of this statement logically — in a logical order. This means that you should 1) introduce the focus and intent of your essay, 2) give the general ecology reader some background information about nitrogen saturation — what it is and why it is important to study, 3) describe Peterjohn et al.'s study — the question(s) they were asking and their overall approach, 4) describe their findings in Figures 2A and 2B, and 5) explain the significance of these findings to the overall issue of nitrogen saturation in forests. Word limit is 750 words.

Nitrogen Saturation

The phenomenon called nitrogen saturation of forests occurs when the availability of inorganic nitrogen (ammonium and nitrate) exceeds demand by plants and soil microbes. It is a response to human caused increases in nitrogen deposition — specifically oxides of nitrogen (nitrate and NO_x) mainly from fossil fuel emissions and also ammonium from production and use of fertilizers. With increasing recognition of this problem since the 1980's ecologists have focused more effort on the capacity of forests to retain high inputs of nitrogen and also effects of excess nitrogen on forest vegetation. In addition, some of these studies target effects of high nitrogen inputs to streams, rivers, and lakes draining the affected forests.

Study by Peterjohn et al. 1999.

The Figures 2A and 2B are from study by Peterjohn et al. (1999) that focuses on forests in the Appalachian mountains because high rates of nitrogen (N) deposition there makes these forests especially susceptible to N saturation. The effects have been well documented in Watershed 4 in the Fernow Experimental Forest, West Virginia. Some parts of this forest showed clear evidence of N saturation (e.g. high concentrations of nitrogen in streams). However, Peterjohn and colleagues were surprised to find that part of the watershed — specifically south facing slopes — were not saturated with N because they responded positively, not negatively, to experimental addition of nitrogen fertilizers. To better understand the phenomenon of N saturation, they investigated this N/S slope difference further.

Peterjohn et al. used root ingrowth to measure response of trees to N fertilization. They added ammonium and phosphate as fertilizer to soil cores which they put in the ground in four 35m transects. Every 5m they buried 3 cores (for 3 levels of treatment — high, medium, and low), and after 5 months they measured root growth into the cores. These are the data in Figure 2A.

They also used instruments called lysimeters to measure concentration of the ion nitrate (NO_3^-) leaching down into the soil. Lysimeters are thin tubes placed vertically into the ground with a porous cup on the bottom; water in the soil can move into the little cup through tiny pores and nitrate is dissolved in that water. These data are in Figure 2B.

Peterjohn et al. also found that tree species composition was different on the south and east facing slopes. *Acer saccharum* (sugar maple) and *Prunus serotina* (black cherry) dominated the east facing slopes while on the south slopes. *Nyssa sylvatica* (black tupelo) and *Fagus grandifolio* (beech) were the dominant trees.
The researchers conclude the paper with the following: "If future studies support the hypothesis that species composition is a good indicator of a forest's susceptibility to N saturation, then community composition may account for a significant portion of the unexplained variability in the response of forested watersheds to similar levels of elevated N deposition … It would also suggest that management practices, or natural changes, which favor certain species might delay or accelerate the onset of N saturation and the potentially negative changes associated with this process."

Literature Cited

Peterjohn, W. T., C. J. Foster, M. J. Christ, and M. B. Adams. 1999. Patterns of nitrogen availability within a forested watershed exhibiting symptoms of nitrogen saturation. Forest Ecology and Management 119: 247-257.

FIGURES

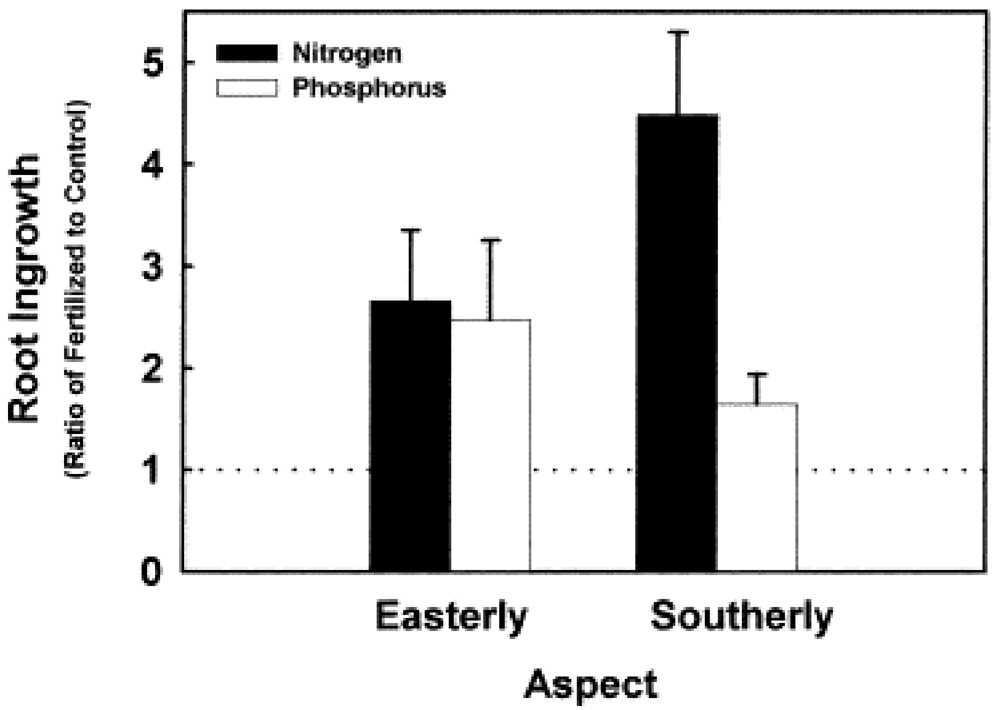

Figure 2A. Stimulation of root growth from nitrogen and phosphate addition on roots growing into soil cores on east and south-facing slopes in a West Virginia forest. Bars are 1 standard error. Dotted line indicates no stimulation by fertilization. W. T. Peterjohn, C. J. Foster, M. J. Christ, and M. B. Adams. 1999. Patterns of nitrogen availability within a forested watershed exhibiting symptoms of nitrogen saturation. Forest Ecology and Management 119: 247-257.

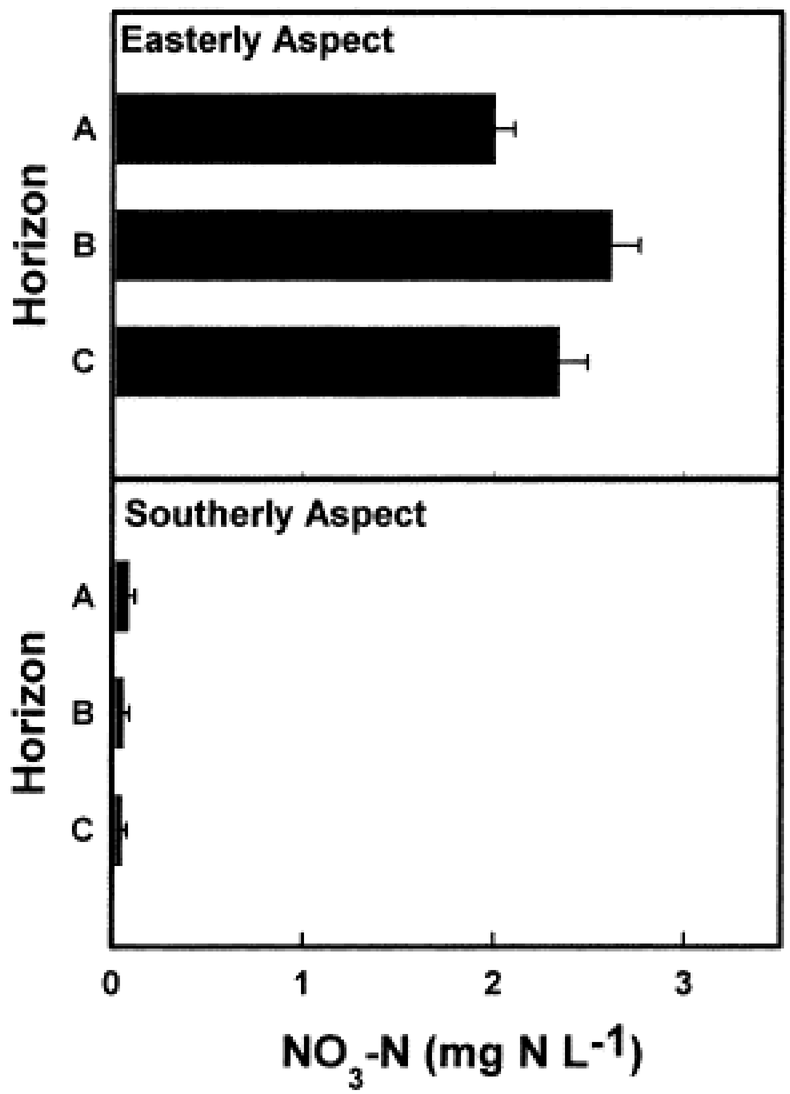

Figure 2B. Average concentrations of nitrate in water leaching down into the soil on east and south-facing slopes in a West Virginia forest. Bars represent 1 standard error of the mean. W. T. Peterjohn, C. J. Foster, M. J. Christ, and M. B. Adams. 1999. Patterns of nitrogen availability within a forested watershed exhibiting symptoms of nitrogen saturation. Forest Ecology and Management 119: 247-257.

FACULTY NOTES

Support a Statement

This activity will help your students build a logical argument in support of a statement. They are given the following: "Not all forests in West Virginia are negatively affected by high concentrations of nitrogen in precipitation. Differences in symptoms of nitrogen saturation are related to aspect (e.g. south or east-facing slopes; Peterjohn et al. 1999)."

The students' goal is to logically develop an argument in support of this statement using the data in Figures 2A and 2B. They are directed to "Develop your argument in support of this statement logically — in a logical order. This means that you should 1) introduce the focus and intent of your essay, 2) give the general ecology reader some background information about nitrogen saturation — what it is and why it is important to study, 3) describe Peterjohn et al.'s study — the question(s) they were asking and their overall approach, 4) describe their findings in Figures 2A and 2B, and 5) explain the significance of these findings to the overall issue of nitrogen saturation in forests." The stated word limit is 750 words although this is clearly up to you. (If you have access to the paper, you can give it to your students; this will of course increase their understanding of the study and improve their argument, but it will take more time).

Developing a logical argument based on questions and data is clearly an important skill for students. However, it requires more sophisticated thinking for undergraduates than most of us realize, and consequently we spend too little time helping students improve their abilities to think and write logical arguments. Students need to practice this ability, get feedback, and see good examples of good logical arguments (and poor ones).

You can do this as homework before class or an in-class activity done by students on their own or in groups.

Peterjohn et al. Study

N saturation is a relatively new phenomenon and for this reason alone potentially interesting to students. However it is not an easy topic to teach because its study requires knowledge of N cycling (e.g. mineralization and nitrification), movement of cations and anions in soil, and effects of changes in nutrient ratios (e.g. foliar Ca:Al) on tree growth.

I selected the Peterjohn et al. study for this Issue because the data are readily accessible to basic ecology students. Understanding why high rates of nitrate leaching are seen in N saturated forests is a good introduction to the process of N saturation and is probably enough detail for most students. (For figures your can use in class on C/N ratios and other topics, see suggestions below.)

The Peterjohn et al. study is also useful because it helps students better appreciate variability in ecosystem responses to pollution. The questions below will stimulate discussion about topics such as the need for long-term and multi-site studies.

The study by Peterjohn et al. (1999) focuses on forests in the Appalachia because high rates of N deposition there make these forests especially susceptible to N saturation. The effects have been well documented in Watershed 4 in the Fernow Experimental Forest, West Virginia. Findings include a 20x increase in stream nitrate concentrations, high rates of soil nitrification, low retention of inorganic N loading, high percentage of mineralized N being nitrified, and little seasonal change in stream nitrate concentrations.

Despite this clear evidence of N saturation, Peterjohn and colleagues were surprised to find that part of the watershed — specifically south facing slopes — were N limited in N addition experiments. They conducted this study to determine if some slopes but not others were N saturated.

Peterjohn et al. used root ingrowth to measure response of trees to N fertilization. They added ammonium and phosphate to soil cores which they put in the ground in four 35m transects. Every 5m they buried 3 cores (for 3 degrees of treatment), and after 5 months they measured root growth into the cores. These data are seen in Figure 2A of this Issue. Using ANOVA they demonstrated significant effects of N or P addition ($p=0.0005$) and a significant treatment x aspect interaction ($p=0.0048$). The test also showed a significantly greater response to N on the south-facing slopes ($p=0.037$).

They also used lysimeters to measure nitrate leachate. As Figure 2B shows, the differences in nitrate in the leachate were dramatic.

Tree species composition was different on the south and east facing slopes. Peterjohn et al. calculated importance values of living tree stems as averages of relative density, basal area, and frequency. The largest difference in importance values were seen in *Acer saccharum* (sugar maple) and *Prunus serotina* (black cherry) with values of 26.7 and 14.1% respectively on east slopes in contrast to 2.1 and 2.2% on the south slopes. *Nyssa sylvatica* (black tupelo) and *Fagus grandifolio* (beech) were the dominant trees on the south facing slopes.

The authors propose that some factor related to differences in species composition accounts for the different response of the 2 slopes to N inputs. They discount differences in temperature, moisture, and pH because these were similar on both south and east facing slopes.

They conclude the paper with the following: "If future studies support the hypothesis that species composition is a good indicator of a forest's susceptibility to N saturation, then community composition may account for a significant portion of the unexplained variability in the response of forested watersheds to similar levels of elevated N deposition … It would also suggest that management practices, or natural changes, which favor certain species might delay or accelerate the onset of N saturation and the potentially negative changes associated with this process."

Other Figures/Tables for Discussion

For a figure on C/N ratios in regard to N saturation see Fig. 5a in the Aber et al. 2003 BioScience paper (www.metrocast.net/~dougmac/papers/2003_Bioscience_Aber_et_al.pdf): the data are foliar C/N ratios of hardwoods vs. conifers.

For a table showing high N deposition and low soil C/N and root biomass growth and therefore relatively high N leaching in the Smoky Mountains compared to other forests see Table 3 in Fenn et al. 1998. Nitrogen Excess in North American Ecosystems: Predisposing factors, Ecosystem Responses, and Management Practices. Ecological Applications 8: 706-733 (www.sgcp.ncsu.edu/products/pubs/docs/ecolapplications.pdf).

Discussion Questions

1. Peterjohn et al. measured nitrogen limitation by adding ammonium (NH_4^+) and phosphate (PO_4^{-3}) to soil cores which they put in the ground in four 35m transects. Every 5m they buried 3 cores (for 3 levels of treatment — high, medium, and low addition), and after 5 months they measured root growth into the cores. What is nitrogen limitation and how does this method allow researchers to study this phenomenon? What are some of the advantages and limitations of this particular technique?
2. In the discussion section of their paper Peterjohn et al. say that "…community composition may account for a significant portion of the unexplained variability in the response of forested watersheds to similar levels of elevated N deposition." What do they mean by this statement and why do they focus on "unexplained variability"?
3. Nitrogen saturation of forests is the ecosystem response to human-caused increases in nitrogen falling on the forests as rain, snow, and dry deposition (e.g. gases and small particles). Fossil fuel burning is a major cause of this excess nitrogen. Why do fossil fuels such as oil contain nitrogen — where did they come from? Forests in the northeast U.S. are especially susceptible to nitrogen saturation. Why might that be?
4. Peterjohn et al. found that sugar maple and black cherry were the dominant trees on the east slope in their study while black tupelo and beech dominated the south facing slopes. They conclude that differences in tree species composition most likely accounted for the differences in response of the two tree communities to nitrogen deposition. What other factors did they need to take into account in order to reach this conclusion? (They discount differences in temperature, moisture, and pH because these were similar on both south and east facing slopes). They do not list reasons why trees differ in their response to nitrogen saturation. How does this influence your confidence in their conclusion?
5. It is very challenging to convince policymakers that nitrogen saturation in eastern forests of the U.S. is a serious environmental problem. Why might this be?

WWW Sites

See the Resources section of this Issue for sites on N Saturation from an LTER site, power point slides, and an EPA and power company site.

Student Assessment: Justification Essay

Write a brief essay (300-400 words) explaining the phenomenon of nitrogen saturation and why it is an environmental problem. Your audience is the general public.

Evaluating an Issue: How do you know whether it is working?

On-going (also called formative) evaluation of the approaches your are using is critical to the success of student-active teaching. Why try out new ideas if you don't know whether or not they are working? This is a brief overview of formative evaluation. For more information, go to the Formative Evaluation essay in the Teaching Section.

Course Goals:

Formative evaluation only works if you have clearly described your course goals - because the purpose of the evaluation is to assess whether a particular technique is helping students reach these goals. For instance, most of us have "learn important ecological concepts and information" as a course goal. If I reviewed the nitrogen cycle in a class, for evaluation I might ask students to sketch out a nitrogen cycle for a particular habitat or system. Each student could work alone in class. Alternatively, I might ask students to work in groups of 3 and give each group a different situation (e.g. a pond receiving nitrate from septic systems, an organic agricultural field, an agricultural field receiving synthetic fertilizer). The students could draw their flows on a large sheet of paper (or an overhead transparency) and present this to the rest of the class.

The Minute Paper:

Minute papers are very useful evaluative tools. If done well they give you good feedback quickly. Minute papers are done at the end of a class. The students are asked to respond anonymously to a short question that you ask. They take a minute or so to write their response in a 3x5 card or a piece of paper. You collect these and learn from common themes. In the next class it is important that you refer to one or two of these points so that students recognize that their input matters to you. The UW - FLAG site (www.wcer.wisc.edu/nise/cl1/flag/) gives a good deal of information about using minute papers including their limitations, how to phrase your question, step-by-step instructions, modifications, and the theory and research behind their use.