MINUTES OF THE
CAPE COD WATER PROTECTION COLLABORATIVE
Governing Board Committee
February 12, 2014

A meeting of the Cape Cod Water Protection Collaborative was held in the Innovation Room of the Barnstable County Strategic Information Office on February 12, 2014 at 9:00 a.m.

Members:

Barnstable	Mark Ells	Present
Bourne	Linda Zuern	Present
Brewster	Sue Leven	Present
Chatham	Florence Seldin	Present
Dennis	Vacant	Vacant
Eastham	Jane Crowley	Absent
Falmouth	Rebecca Moffitt	Present
Harwich	Larry Ballantine	Present
Mashpee	Michael Richardson	Present
Orleans	Sims McGrath	Present
Provincetown	Elaine Anderson	Absent
Sandwich	Linell Grundman	Present
Truro	Patricia Pajaron	Present
Wellfleet	Curt Felix	Absent
Yarmouth	William Hinchey	Present
County Appointee	Sheila Lyons	Absent
County Appointee	Vacant	Vacant
Ex-officio member	George Heufelder	Absent
Ex-officio member	Paul Niedzwiecki	Absent

Staff Present:

Andrew Gottlieb	Executive Director
Gail Hanley	Cape Cod Commission
Patty Daley	Cape Cod Commission

1. Minutes of January 8, 2014

Florence Seldin moved to approve the minutes of January 8, 2014. Sims McGrath seconded the motion. The motion passed with 10 votes in favor and one abstention.

2. 208 Update

Patty Daley, Deputy Director at the Cape Cod Commission, provided an update on the 208 planning process. She said there were about 300 people in attendance at the February 6 Stakeholder Summit. She said a summary of the key findings/principles derived from the first six months of the watershed stakeholder process was discussed at the summit. She they also discussed the number of meetings that were held during that time and said they have received good input from those meetings. She said going forward in the next six months they will be getting into more policy discussions and the focus will be on scenario planning findings and principles; regulatory, legal, and institutional findings and principles; and implementation findings and principles. She said Beth Card of the DEP was in attendance and said the DEP will be getting more involved in the discussions. She said they are willing to have a discussion and they see a value in that. Ms. Daley said Commissioner Kimmell believes that this will be a model for not just the State; it will be a model for the whole country. Ms. Daley distributed to board members a schedule of upcoming sub-regional stakeholder meetings.

3. Town Reports

• **Town of Orleans** – Sims McGrath: They are still working on the investigative process. They received a proposal from Mike Domenica that is being considered for bundling and scoping of RFPs. They hope to have responses by mid-March.

• **Town of Brewster** – Sue Leven: A decision was just made to not ask for additional funds at Town Meeting. They have sufficient funds to complete their current scope/phase. They plan to hold another pond meeting on either the 8th or 15th of March. They are trying to put together a meeting with Pleasant Bay Watershed individuals to discuss aquaculture. At the first pond meeting they had 120 people in attendance and approximately 20 who watched it live-stream and a lot of people were interested in doing the work.

• **Town of Truro** – Pat Pajaron: They are looking at a few culvert replacements and the one in the Beach Point area needs to be replaced soon. They hired a Woods Hole group to look at options and it involves partnership with the National Seashore and Provincetown. The next step if looking at a new culvert is to look at sediment transport.

• **Town of Barnstable** – Mark Ells: They continue to participate in the 208 planning process. They have been working with Cape Cod Community College in regard to hooking up to the treatment plant.

• **Town of Mashpee** – Michael Richardson: Their plan is pretty much completed and it will be going to MEPA. It's a comprehensive plan although there are some glitches in the language. The Water District is willing to look at what has been put together and they are having good luck with the oyster project. A lot is going on that is positive.

• **Town of Yarmouth** – William Hinchey: They continue to work on bridge widening and upgrades to septic. They do have a completed plan but they were asked to go back to the drawing board. Paul Niedzwiecki and Andrew Gottlieb went to a Selectmen's meeting to discuss the 208 plan and it was a very good meeting. They are putting the finishing touches on their capital facilities plan.

• **Town of Bourne** – Linda Zuern: Tonight the Wastewater Advisory Committee is having a meeting at 5:00 p.m. There has been a lot of feedback from Curt Felix's presentation at the Board of Selectmen meeting. She attended the 208 watershed meeting and said she had some concerns about the AECOM model that they are putting together. She looked over the Senate's Docket No. 1947 and said for the record she is not in favor of it.

• **Town of Chatham** – Florence Seldin: They are proceeding with the extension of the sewer in the Stage Harbor area. They received a $4 million grant for the Muddy Creek culvert restoration project and another $1 million grant was received as well. They are going to move ahead on that.

• **Town of Falmouth** – Rebecca Moffitt: They received acceptance by the State to start their wastewater design plan. Falmouth is very pleased as they can now move ahead with the wastewater plan. The oyster project in Falmouth is going well and there is a lot going on in Falmouth currently.

• **Town of Sandwich** – Linell Grundman: Sandwich has completed its draft plan but it hasn't gone before the Board of Selectmen or the community yet. The sale of the 55 acres at the Golden Triangle site fell through and a wastewater treatment facility had been tied into that. She said even though the sale fell through, the benchmarks for that has helped the town with wastewater. The town has applied for a $10 million grant for beach nourishment.

Rebecca Moffitt and Linell Grundman inquired about using the facility at the Massachusetts Military Reservation (MMR) and a study that had been done by Mass Development.

Patty Daley, Deputy Director at the Cape Cod Commission, said the Commission just finished a study on joint land use at MMR. She said they are in the process of pursuing a feasibility study to look at additional issues in regard to Upper Cape towns using that. She said Mike Domenica did a study on excess capacity with Mass Development.

Linda Zuern said a few years ago Bourne looked at the MMR facility and said it was too expensive. Ms. Daley said those are all considerations that are being looked at.

• **Town of Harwich** – Larry Ballantine: They are working on Muddy Creek. They submitted their draft CWMP to the Cape Cod Commission. They are looking at cost allocation policies and continue to move on.

4. Executive Director's Report

Andrew Gottlieb gave the following update:

- Mr. Gottlieb said there is nothing new on the wastewater legislation in the Senate.
- The CCWPC budget is being discussed by the Assembly of Delegate's Environmental Committee on February 26 at 5:00 p.m.
- Rock Harbor is countering with a different approach with a variance in the town. He said they are working on the parameters for that. Sims McGrath said the problem with his board is the $50,000 and they are still trying to find a counter for the argument. He said perhaps they should wait a year to see what happens.
- He said in regard to the Policy for Awarding Municipal Support Funds for RFPs that was voted on by the board last month, he received two from Falmouth. He said Falmouth is committing a quarter of a million dollars to a PRB pilot study and they have requested funding from the CCWPC for $25,000. He the second one from Falmouth is in regard to shellfishing and credit for TMDL compliance for nitrogen removal in oystering. He said the CCWPC has agreed to give them $50,000 over a two-year period to do this.

5. Discussion of Falmouth MEPA Certificate

Patty Daley said Falmouth received a finding of adequacy/approval by MEPA for its Comprehensive Wastewater Management Plan (CWMP). Mr. Gottlieb discussed the MEPA process and said it's a high level environmental review process. He said other things are necessary and have yet to be done such as individual agency permitting. He said this sets the bar for how other towns can expect their CWMPs to be looked at. He said their approval is not a permit to do anything Falmouth still needs to go through the permitting process. Ms. Daley said the Secretary's certificate starts the Development of Regional Impact (DRI) process with the Cape Cod Commission and said a public hearing on the Falmouth CWMP DRI was held last night in Falmouth. Mr. Gottlieb said the procedural aspect of the Commission's review process has been narrowed down to move the project forward to go to Town Meeting in April. Ms. Daley said the certificate recognizes an adaptive management plan and she explained that any Notice of Project Change would need to be filed with MEPA. She highlighted elements of the certificate and said the Commission is talking to MEPA about changes in the regulatory review process. Mr. Gottlieb said it would allow a way for certain projects to move forward as it creates a framework to deal with this. He said a project is done when water quality measures have been completed not just because a project has received MEPA approval.

Rebecca Moffitt said there has been a positive shift among people and they can have a positive discussion about it. Linda Zuern asked about the 0% funding and Ms. Moffitt said the town has retired a debt at 0%. She said it does not increase the tax rate.

6. Monitoring RFP Process Discussion

Mr. Gottlieb said an RFP on south side monitoring has been sent out and the RFP closes on Friday. He said as was done in the past the CCWPC Steering Committee was used to review the RFPs and he asked the board if they wish to do the same here.

Sims McGrath moved to have the CCWPC Steering Committee review the RFPs. Florence Seldin seconded the motion. The motion passed with a unanimous vote.

7. Discussion on Potential Partnership with MBL on Analysis of Nitrogen Atmospheric Deposition

Mr. Gottlieb said he invited Ivan Valiela, Senior Research Scientist at the MBL, to discuss the potential partnership with the County and the MBL regarding analysis of nitrogen atmospheric deposition.

Mr. Valiela explained how global conditions are changing, rain and snow from the atmosphere has been reduced by half, the role the forested area plays—delivery of water to the forest area versus the ocean area, and how efforts to reduce nitrogen loading in wastewater should continue.

Mr. Gottlieb said it's complicated and the question is what this means to Cape Cod and what to do about future land use planning. He said he would prepare and bring to the next CCWPC meeting a summary of the scope. He said it's an applied science exercise.

Bob Duncanson, Director of Health & Environment in Chatham, suggested that this is something the Technical Advisory Committee should work on.

8. Adjourn

Upon a request by Mr. Ballantine the meeting adjourned at 10:50 a.m.

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Research review

The potential effects of nitrogen deposition on fine-root production in forest ecosystems

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SUMMARY

Temperate forests are recipients of anthropogenic nitrogen (N) deposition. Because growth in these ecosystems is often limited by N availability, elevated N inputs from the atmosphere can influence above- and belowground production in forests. Although fine-root production is the largest component of belowground production in forests, it is unclear whether or how increases in N availability to forest trees accompanying increased N deposition might influence fine-root growth. Uncertainties as to how fine-root dynamics (i.e. production and turnover) vary in relation to soil N availability contribute to this problem. Although fine-root biomass typically decreases along soil N availability gradients in forests, it is unclear whether fine-root production and turnover also decrease along these gradients. Here, four possible relationships between fine-root turnover, fine-root production, and forest soil N availability are evaluated to develop a general hypothesis about changes in rooting dynamics that might accompany increases in N deposition. The four possible relationships are as follows. (1) Fine-root turnover rates do not systematically change with N availability in forest soils. If this is true, then fine-root production rates decrease with fine-root biomass in relation to soil N availability, and increased N deposition could lead to decreased fine-root production in forests. (2) Decreases in photosynthate allocation belowground along N availability gradients will function to slow fine-root turnover (or increase life span) as N availability increases with N deposition, thereby dramatically decreasing fine-root production. (3) Fine-root production might increase with N availability even though fine-root biomass typically decreases with N availability. This could occur if fine-root metabolism and turnover increase (life span decreases) with soil N supply. Increases in fine-root production accompanying increases in N availability, if large enough, could result in constant proportions of forest production being allocated to fine roots as soil N availability increases with N deposition. (4) Although fine-root turnover and production might both increase as N becomes more available to tree roots, the proportional allocation of total primary production to fine roots could decrease. Identifying the most likely of these four possibilities requires intersite comparisons of forest root dynamics along gradients of soil N availability and N deposition. Collective results of studies that use sequential sampling of fine-root biomass to estimate production suggest that fine-root turnover and production either; do not vary systematically, or that they decrease as N availability increases. By contrast, studies using ecosystem C or N budgets suggest that fine-root turnover and production both increase with N availability and that similar increases might be expected with elevated N deposition. It is argued here that assumptions underlying most biomass-based estimates of fine-root production are more suspect than are assumptions underlying element budget-based estimates. If so, it is likely that N deposition will function to decrease forest fine-root biomass but to stimulate fine-root turnover and production. However, increases in fine-root turnover and production could eventually decrease if chronically elevated N deposition leads to forest stand mortality.

Key words: fine roots, nitrogen deposition, root turnover, belowground production, N saturation, forest ecosystems.

INTRODUCTION

'*In questions of science the authority of a thousand is not worth the humble reasoning of a single individual.*' Galileo Galilei (1564–1642)

Before the twentieth century, rates of nitrogen (N) deposition on the Earth's surface were low (Logan, 1983), and annual N inputs to forests from the atmosphere were miniscule compared with rates of N uptake by tree roots. However, atmospheric deposition of biologically available N (mainly NH_x and NO_y) on landscapes is increasing together with use of fossil fuel and N fertilizer (Galloway *et al.*, 1995). Although N deposition is highest in temperate industrialized regions of eastern North America and Europe, rates are likely to increase dramatically in other regions as industrial development and agricultural activities increase N emissions to the atmosphere in lower latitudes (Galloway *et al.*, 1994).

Recognition that high rates of N deposition could damage forest trees (Friedland *et al.*, 1984; Nihlgård, 1985; Schulze, 1989) led to the development of various 'N saturation' hypotheses (Ågren & Bosatta, 1988; Skeffington & Wilson, 1988; Aber *et al.*, 1989). These hypotheses describe forest responses to chronically elevated N deposition as a progression from 'pristine' conditions in which growth is N-limited and ecosystem N losses are small, to a 'saturated' stage characterized by nutrient imbalances in plant tissues and high rates of tree mortality and nitrate leaching. N saturation hypotheses have been tested in a number of multiple-site experiments (Burton *et al.*, 1993; Wright *et al.*, 1994; Emmett *et al.*, 1998; Tietema *et al.*, 1998) and decade or longer manipulations of N inputs (Magill *et al.*, 1997; Chappell *et al.*, 1999; Fernandez *et al.*, 1999). Studies of the effects of N deposition on forests have focused mainly on aboveground plant responses, soil N dynamics and ecosystem N losses. As a result, much has been learned about how aboveground plant growth, plant species competition, nutrient cycling and nutrient input and/or output balances respond to N deposition (Stoddard, 1994; Aber *et al.*, 1998; Gundersen *et al.*, 1998).

Responses of belowground plant processes, such as fine-root growth and mortality, have been less extensively studied than have soil microbial and aboveground processes (but see Pregitzer *et al.*, 1995). As a result, there is a great deal of uncertainty regarding the possible effects of N deposition on fine-root production and turnover (the inverse of life span). In this review, I evaluate hypotheses about how fine-root dynamics might vary in relation to changes in N uptake by forest trees that will be likely to accompany increased N deposition. The possible implications of chronically elevated N deposition on fine-root dynamics in forest ecosystems are then explored.

IS THERE A RELATIONSHIP BETWEEN FINE-ROOT PRODUCTION AND ABOVEGROUND PRIMARY PRODUCTION?

Aboveground primary production and N cycling rates are often correlated both within and across ecosystem types and regions (Reich *et al.*, 1997). This is because plant growth is often limited by N availability. Moreover, annual rates of foliar production, N inputs to soils in litterfall and N uptake into aboveground plant tissues are correlated in many forests worldwide (Vitousek, 1982; Vogt *et al.*, 1986), presumably reflecting the importance of N limitation in regulating aboveground growth. Foliage turnover increases with N availability, both because of changes in functional group composition and changes within functional groups. Deciduous species often dominate over evergreen species in temperate forests that have higher N-cycling rates (Gower *et al.*, 1993). Also, foliar turnover times in evergreen trees are typically shorter on nutrient-rich than on nutrient-poor sites (Mooney & Gulmon, 1982).

Observed increases in foliar metabolism (e.g. photosynthesis and respiration) and turnover along forest soil N gradients have led to the hypothesis that fine roots might respond to N concentrations in a similar manner to aboveground production, respiration rates and turnover rates increasing with N availability across sites (Hendricks *et al.*, 1993). Increases in fine-root turnover (or decreases in mean root life span) across N availability gradients, if large enough, could allow for increases in fine-root production even though fine-root biomass typically decreases along such gradients (Nadelhoffer *et al.*, 1985; Vogt *et al.*, 1986). The hypothesis that fine-root production increases with N availability contrasts with a number of studies (Grier *et al.*, 1981; Vogt *et al.*, 1986; Gower *et al.*, 1992) suggesting that fine-root production decreases as aboveground production and N availability increase.

Consistent observations of greater fine-root biomass at N-poor than at N-rich sites, together with reports of negative correlations between fine-root biomass and aboveground forest production, suggest that fine-root production might vary systematically with the more easily measured processes of aboveground growth and net N mineralization in forest soils. Most researchers, concerned with the nature of the relationship between fine-root production and N availability to forest trees, have largely discounted the possibility that there is not a general relationship between root production and N availability in forest soils. However, given the paucity of reliable estimates of fine-root production, we cannot as yet unequivocally reject the null hypothesis.

POSSIBLE RELATIONSHIPS BETWEEN FINE-ROOT PRODUCTION AND N AVAILABILITY

Unless fine-root production is unrelated to either N availability or aboveground production in forests, four possible relationships between fine-root turnover (the inverse of mean root life span) and N availability exist (Fig. 1). It is well established that fine-root (including mycorrhizal) biomass declines with increasing N availability. If fine-root turnover either does not vary (Fig. 1a) or decreases along N-availability gradients (Fig. 1b), then annual fine-root production rates (the product of mean fine-root biomass and turnover) must decrease. It follows that such decreases would be absolute (as less fine-root biomass is produced in N-rich than in N-poor sites). Therefore, progressively smaller proportions of total above- plus belowground production would be allocated to fine roots along N availability gradients. Alternatively, more rapid fine-root turnover could serve to increase fine-root production along N availability gradients. If turnover increased sufficiently along such gradients, the proportion of total net primary production allocated to fine roots could be relatively constant (Fig. 1c). Also, lower fine-root biomass together with increasing turnover rates could increase fine-root production in absolute terms even if fine-root production were to decrease relative to total above- plus belowground production (Fig. 1d).

Which of these four possible relationships (Fig. 1) is best supported by data? Unfortunately, the level of understanding of the way in which soil N availability influences fine-root dynamics is insufficiently developed to allow for a definitive answer. This is mainly because methods have not yet been developed for directly measuring root production in ecosystems. Reported 'measurements' of fine-root production (Gower *et al.*, 1996; Vogt *et al.*, 1998) are, in fact, estimates. Most of these estimates of fine-root production are derived from intensively sampling fine-root biomass across one or more growing seasons. Estimates have also been derived from the assumption that N used in fine-root production is the difference between annual net N mineralization and annual N uptake into aboveground biomass (Aber *et al.*, 1985; Nadelhoffer *et al.*, 1985). The 'root ingrowth' method in which root growth into *in situ* incubations of root-free material is assumed to equal root production in the surrounding soil (Raich *et al.*, 1994; Majdi, 1996) is also occasionally used to estimate fine-root production.

Where relationships between fine-root production and aboveground production or nutrient availability have been identified, however, conclusions as to the nature of the relationship are strongly method-dependent. For example, Nadelhoffer & Raich (1992) analyzed fine-root-production estimates based on one of three basic methods; fine-root biomass

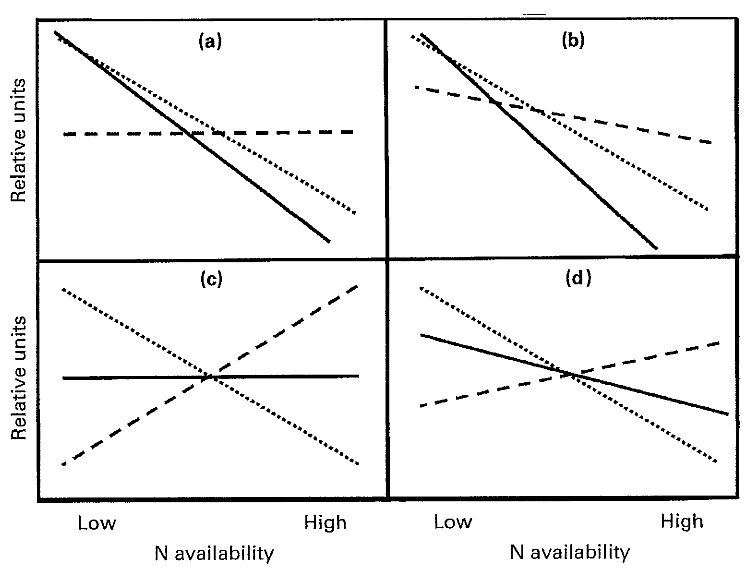

Fig. 1. Four possible patterns of fine-root turnover and proportional production along N-availabity gradients in forests. Fine root biomass declines in relation to N availability in all scenarios. Biomass, dotted line; turnover, broken line; percentage of net primary production (NPP), solid line. If fine-root turnover (the inverse of mean fine-root life span) is assumed constant (a), then the proportion of total NPP allocated to fine roots declines dramatically as soil N availability increases. If fine root turnover decreases with fine-root biomass (b), then the proportion of total NPP allocated to fine roots decreases even more than when fine-root turnover is constant. If fine-root turnover rates increase sufficiently as fine-root biomass declines (c), then the proportion of NPP allocated to fine roots could remain constant. However, slower increases in fine-root turnover and production along N availability gradients (d) would result in a declining proportion of NPP being allocated to roots as N availability increases.

sampling, ingrowth and N budget techniques. Fine-root production and aboveground production were not correlated in the data set that included all three techniques ($r^2 = 0.05$, $n = 54$). Yet fine-root and aboveground production were strongly correlated ($r^2 = 0.63$, $P < 0.0002$, $n = 16$) using the subset of data from forests where N budgets were used to estimate fine-root production. For the 32 sites at which sequential sampling of fine-root biomass was used to estimate fine-root production neither 'sequential coring' nor 'maximum–minimum' techniques (Aber *et al.*, 1985) yielded significant correlations with aboveground production. Fine-root production estimates derived from 'ingrowth core' studies showed a trend of increasing root production with aboveground production, but the number of studies employing this technique ($n = 6$) were too few for a robust statistical analysis (Nadelhoffer & Raich, 1992).

PROBLEMS AND PROGRESS IN ESTIMATING FINE-ROOT PRODUCTION

Summaries of results based on different techniques lead to strikingly different conclusions about whether, and how, fine-root production varies with N availability. Therefore, it is necessary to evaluate whether inherent weaknesses in the various methods used to estimate fine-root production seriously compromise conclusions derived from their use.

Sequential sampling of fine-root biomass is the most common means of estimating fine-root production. This technique has been strongly criticized on statistical grounds (Singh *et al.*, 1984; Lauenroth *et al.*, 1986; Sala *et al.*, 1988). The primary criticism is that repeated sampling of fine-root biomass confounds spatial and temporal variation in root biomass and often leads to overestimating fine-root-production rates. In addition, these critics point out that repeated sampling can also lead to underestimates, particularly if fine-root growth and mortality rates are synchronous. As such, statistical and sampling artefacts inherent in sequential sampling can lead to either underestimates or overestimates of fine-root production. Furthermore, the simultaneous growth and death of fine roots between sampling events can lead to underestimating production. Various means of improving biomass-based estimates have been developed, including the use of 'compartment flow' techniques (Santantonio & Grace, 1987). However, compartment flow analyses require information about fine-root decomposition which is difficult to acquire (Publicover & Vogt, 1993; Fahey *et al.*, 1999). Moreover, compartment flow-based estimates are highly sensitive to variations in values of the decay constants used to characterize fine-root decomposition. The statistical flaws and uncertain assumptions underlying biomass-based estimates are sufficiently serious that the value of cross-site comparisons based on these estimates is questionable.

The less commonly used N-budget technique also suffers from uncertainties. Here, N used annually in fine-root production is assumed to be the difference between annual net N mineralization and net N uptake into aboveground production. Other fluxes are typically ignored. The inclusion of smaller N fluxes, such as N leaching below the rooting zone or N inputs via atmospheric deposition in the budgets is useful, but is not necessary if N inputs (deposition) and outputs (leaching, denitrification) largely offset one another or if these fluxes are small relative to annual net N mineralization and tree N uptake. This is normally the case for N saturated forests (*sensu* Ågren & Bosatta, 1988; Aber *et al.*, 1989). Most importantly, this method assumes that net N mineralization (the release of ammonium and nitrate from decomposing organic matter to plant roots) estimates derived using *in situ* soil incubations (using methods similar to Robertson *et al.*, 1999) provide reliable estimates of annual N uptake by forest vegetation (above- and belowground). Opinion varies as to the accuracy of *in situ* net N mineralization estimates in forests. Strong correlations between *in situ* measurements of annual net N mineralization and measurements of annual N uptake into aboveground production in forests (Aber *et al.*, 1985; Pastor *et al.*, 1993) and agricultural crops (Westermann & Crothers, 1980) provide indirect evidence that measurements of net N mineralization provide ecological insights.

Analysis of soil C budgets also suggests that fine-root production increases along N availability gradients in forests. This method assumes that annual changes in forest soil C content are small relative to C inputs (owing to litterfall and root death) and to C exports (owing to litter and root decomposition and to respiration of live roots). Analysis of soil respiration and litterfall data from forests along a global gradient of aboveground production suggested that total C allocation to roots (i.e. C used in root production + root respiration) increases linearly with N availability to forest trees (Nadelhoffer & Raich, 1992). Thus, independent analyses of forest ecosystem N and C budgets both suggest that fine-root production increases with aboveground production and N availability, even though fine-root biomass decreases.

FINE-ROOT DYNAMICS AND N AVAILABILITY IN FORESTS: LIKELY SCENARIOS

Which of the possible relationships linking fine-root turnover and production to forest N availability (Fig. 1) is the most likely? This question is best answered in the context of multiple-site comparisons in which methods used for estimating fine-root production are specified and evaluated.

As already stated, decreasing fine-root production with increasing N availability requires that root turnover either remains nearly constant (Fig. 1a) or decreases along N availability gradients (Fig 1b). If either of these patterns reflects reality, then the proportion of total primary production attributable to fine roots varies dramatically with N availability to forest vegetation. The possible extent of such variation is described by Vogt *et al.* (1986), who concluded from sequential sampling data that root inputs could be about four times greater than leaf litter inputs to temperate forest floors at nutrient-poor sites, whereas root inputs could be three times less than leaf inputs at nutrient-rich sites. Comparative studies of small numbers of sites (2–5) using repeated sampling of fine-root biomass to estimate production have suggested that fine-root production decreases with fine-root biomass as N availability and aboveground production increase (Grier *et al.*, 1981; Gower *et al.*, 1992). At face value, therefore, these studies support hypotheses depicted in Fig. 1a,b. However, it is likely that serious statistical problems (Singh *et al.*, 1984; Lauenroth *et al.*, 1986; Sala *et al.*, 1988) and violations of assumptions (e.g. that fine-root growth and death are largely asynchronous) implicit in biomass-based estimates of fine-root production underlie these conclusions.

Furthermore, many reports of fine-root production based solely on repeated root sampling either approach or exceed constraints on total belowground C allocation (Nadelhoffer & Raich, 1992). This casts additional doubt on the reliability of such measures given that total belowground C allocation (*sensu* Raich & Nadelhoffer, 1989) includes C allocated to live-root respiration as well as to root-biomass production. Clearly root respiration is a major portion of total belowground C allocation by forest trees. The evidence in support of either constant (Fig. 1a) or decreasing (Fig. 1b) fine-root turnover along N availability gradients is derived from studies using statistically flawed methods and small numbers of sites, and I consider both of these patterns to be unlikely.

Carbon budgets provide compelling evidence that the absolute amount of C allocated to roots increases with forest-site fertility. For example, annual soil respiration rates were 2–3 times greater than annual aboveground litter inputs to soils in the 30 forests analyzed by Raich & Nadelhoffer (1989). Clearly, most C respired from forest floors at all these sites was root-derived, released from the root decomposition and live-root respiration. Results of N-budget studies (summarized by Nadelhoffer & Raich, 1992) conducted at sites other than those used in C-budget studies, provide corroborating evidence that fine-root turnover along with aboveground production increases with N availability in forests. As with C budgets, estimates of the amount of N available for supporting fine-root production increased linearly with both net N mineralization and aboveground primary production.

Analyses of forest C and N budgets suggest that fine-root turnover increases with N availability across forest sites (Fig. 1c,d). Early N-budget analysis (Nadelhoffer *et al.*, 1985) suggested that fine-root turnover increased sufficiently with N availability such that the proportion of total primary production attributable to fine roots remained constant along N availability gradients even though mean fine-root biomass decreased (Fig. 1c). Subsequent and more comprehensive C and N analyses (Nadelhoffer & Raich, 1992) suggested that although fine-root production is likely to increase in absolute terms because of increased turnover with N availability, fine-root production does not increase as much as aboveground production along N-availability gradients. Therefore, although root turnover and production are likely to increase with N availability and aboveground production in forests, the proportion of total production accounted for by fine roots probably declines (Fig 1d).

The overall pattern of fine-root turnover and production increasing with N availability, accompanied by a decline in fine-root production as a proportion of total above- plus belowground production (Fig 1d), appears to be the most likely of the scenarios proposed here. This conclusion, while not definitive, reflects the alternative which is best supported by comparative studies using data derived from methods which are the least problematic and which conform to realistic constraints imposed by ecosystem element fluxes. It is also consistent with increases in fine-root N concentrations in fine-root tissues collected from temperate forests along a nitrate-availability gradient (Fig. 2) as reported by Hendricks *et al.* (2000). The gradual increase in fine-root N concentrations with increasing N availability suggests that root metabolism and susceptibility to herbivory are likely to increase with N-cycling rates. As with foliage, this could lead to more rapid turnover of fine-root tissue.

The conclusion that root turnover and relative production are related to N availability as indicated in Fig. 1d, and its underlying assumptions, require more extensive testing at local and regional to global scales. The combined use of minirhizotron-based root observations and fine-root-biomass sampling (Hendrick & Pregitzer, 1992, 1993) are providing additional insights into root dynamics. Also, useful information on root dynamics is forthcoming from measurements of natural ^{14}C contents of fine roots, forest-floor components and respired CO_2 (Gaudinski *et al.*, 2000), from studies using ^{15}N tracers (Hendricks *et al.*, 1997) and root ingrowth cores (Raich *et al.*, 1994). Another promising approach is that of Jenkinson *et al.* (1999) who integrated information on soil $\delta^{14}C$, $\delta^{13}C$, total C and microbial C and on biomass removal in burning, grazing and harvesting to calculate the level of plant C needed to enter soils annually to maintain soil C in savanna sites. Their approach allows estimation of belowground production by difference and could provide more definitive estimates of root production than presently exist.

FINE ROOTS AND N DEPOSITION

Hendricks *et al.* (1993) compared the hypothesis that fine-root turnover increases with N availability with alternative hypotheses that turnover either does not change or decreases as N availability increases. They suggested that mechanisms contributing to increases in root-turnover rates with N cycling were similar to those contributing to increases in foliage turnover. Recent results (Fig. 2) further suggest that similar eco-physiological processes drive increases in root turnover as follows. Higher N availability and lower fine-root biomass on relatively N-rich soils lead to greater N uptake per unit fine-root mass. Higher fine-root N concentrations are required for enzyme synthesis that is necessary for active nutrient uptake. Higher metabolic rates on more N-rich sites increase the sink strength of fine roots, thereby increasing the absolute allocation of C below ground (Fig. 3). Because above- plus belowground production also increases with N availability, proportionally less C might be allocated to fine-root than to aboveground production. Fine-root turnover increases (or life span decreases) as more C is consumed in growth, maintenance and uptake respiration and as proportionally less C is allocated to structural and defensive compounds. This is consistent with Hendricks *et al.* (2000) who also reported higher concentrations of soluble C in fine-root tissues from forests which were richer in N. Higher N concentrations and lower C allocation to defensive compounds is likely to increase susceptibility to mortality and consumption by soil fauna and to more rapid decomposition. As with leaf litter on richer sites, more rapid decomposition of fine roots on sites with low C:N ratios feeds back to maintain high N-

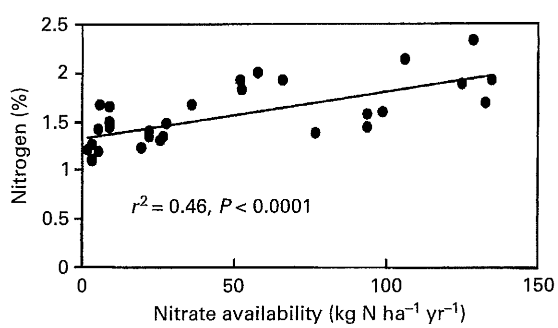

Fig. 2. Nitrogen content in fine roots sampled from forests along a nitrate-availability gradient in Wisconsin and New England forests. *From Hendricks* et al. (*2000*).

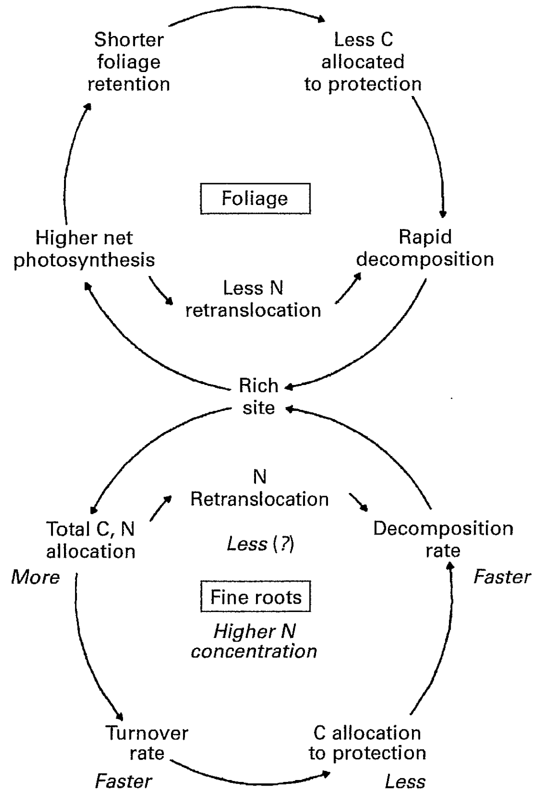

Fig. 3. Above- and below-ground feedbacks that could feedback to increase foliar and fine-root turnover when soil N availability is high. *Modified from Hendricks* et al. (*1993*).

cycling rates. It is unclear, however, whether fine roots retranslocate significant amounts of N before death and whether retranslocation from senescent fine roots varies with N availability.

If turnover, production and decomposition of root and foliar tissues are similarly influenced by N availability, fine-root responses to N deposition could be similar to those of leaves as hypothesized by Aber *et al.* (1989, 1998). Hypotheses regarding changes in root dynamics with N deposition are shown in graphical representations (Fig. 4) in a figure modified from Aber *et al.* (1989, 1998). If chronically elevated N deposition increases net N-mineralization rates in soil (either directly or indirectly via feedbacks such as greater N mineralization from N-enriched litter) or nitrate availability to plant roots, then more N becomes available for root uptake and enzyme synthesis in fine-root tissues. Greater N uptake leads to higher N concentrations and metabolism in fine roots. Increased photosynthesis (resulting from increased foliar N) provides more photosynthate to meet the metabolic demands of greater root growth and nutrient uptake. However, other factors such as less allocation to defensive compounds and faster metabolism feed back to shorten fine-root life spans (or to

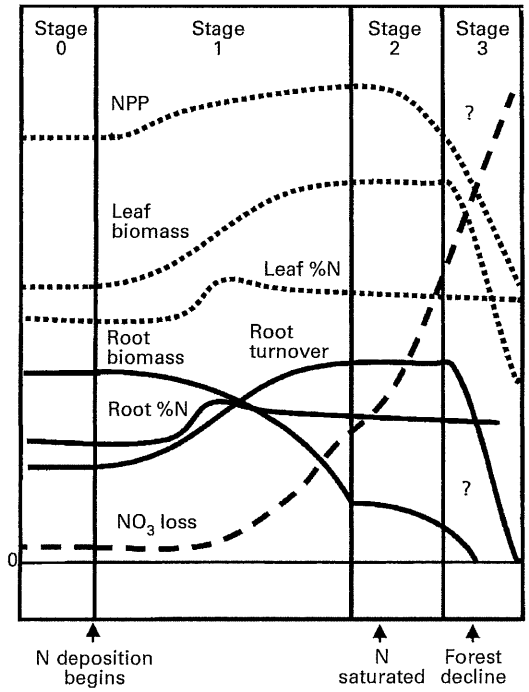

Fig. 4. Hypothesized fine-root responses (solid lines) to chronic N deposition. Stages, as described in Aber *et al.* (1989) represent ecosystem responses to N loading. Stage 0 represents pre-N deposition conditions. Stage 1 follows the onset of elevated N deposition. Where N limits growth, increases in foliar and fine root N could lead to increased N concentrations in resource acquiring organs (leaves and fine roots), greater turnover and increases in net primary production (NPP). These increases, however, might be difficult to detect, particularly at low rates of N input. Nitrate losses above background levels can occur, but they are not large. If forests advance to Stage 2, nitrate losses increase and biomass responses are more easily detected. If forest decline (Stage 3) occurs, tree mortality is high, NPP decreases, and nitrate losses are large.

increase turnover) (Fig. 3). Increased turnover offsets increased growth and fine-root biomass gradually declines as both above- and belowground production increase. The combination of increased nitrification (Gundersen *et al.*, 1998) and lower fine-root biomass would be likely to exacerbate nitrate-leaching losses. If, after prolonged and highly elevated N deposition, forests advance to later stages of N saturation and forest-stand decline, nutrient imbalances and other stresses could eventually serve to disrupt fine-root functions. For example, calcium (Ca) concentrations increased with recovery of mycorrhizal associations and fine-root 'vitality' when large N inputs were removed by collecting and filtering forest throughfall on roof-covered Scots pine (*Pinus sylvestris*) plots subject to high rates of N deposition (Boxman *et al.*, 1995). A multiple-site study of fine-root responses across experimental and geographical N-deposition gradients in Europe (the NITREX and EXMAN studies; Wright & Rasmussen, 1998) showed that mycorrhizal associations were diminished and fine-root biomass declined under high rates of N deposition (Boxman *et al.*, 1998). Lower incidences of mycorrhizal associations, lowered Ca:N ratios, or dramatically diminished fine-root biomass as observed at the NITREX sites, could serve to diminish uptake efficiencies of fine roots for N and possibly other nutrients. Such impacts on fine roots would feed back to exacerbate forest decline.

It is important to realize that advanced stages of N saturation represent end points that are difficult to predict. Many, if not the vast majority of forests receiving excess N deposition might approach states of N saturation or stand decline (Fig. 4, stages 2, 3) very slowly if at all. Forests receiving comparatively low rates of N deposition could remain at early stages for prolonged periods. Still, it might be expected that N deposition would result in increased root growth and turnover and decreases in fine-root biomass to the extent that soil N and nitrate availability increase.

CONCLUSIONS

Predicting forest fine-root responses to chronically elevated N deposition is compromised by limited knowledge of the way in which fine-root production might vary in relation to soil N availability to tree roots. Insufficient multiple-site comparisons of fine-root dynamics along N-availability and N-deposition gradients exist to allow for strong conclusions. Moreover, conclusions are highly dependent on methods used to estimate fine-root production. Critical review of methods for estimating root production suggests that many studies using biomass sampling to estimate root production, though providing more data than other methods combined, are highly suspect. As such, generalizations about relationships between fine-root production and either aboveground production or soil N availability based on multi-site comparisons of biomass-based fine-root production estimates are probably misleading. Independent analyses of forest C and N budgets to estimate root turnover and production provide better-constrained and possibly more robust estimates of root processes. Element budgets, together with chemical compositions of fine roots sampled along N-availability gradients suggest several working hypotheses.

- Fine root and foliar dynamics are similarly influenced by and feed back to maintain soil N availability.
- Although fine-root biomass typically decreases as N availability increases, fine-root turnover and production increase, with increases in aboveground production and litterfall, across N-availability gradients.
- If N deposition increases N availability to plants, net N mineralization or nitrification in forests,

then fine-root biomass will be likely to decrease. However, fine-root turnover and production will probably increase.

- Although the absolute rates of root production probably increase along N-availability gradients, the proportion of total above- plus belowground production accounted for by fine roots probably decreases with N availability.
- Decreased root biomass in forests at late stages of N saturation will contribute to dissolved-nitrate losses.

These hypotheses require further testing by more extensive and rigorous applications of ecosystem element budgets and by new methods that hold potential for providing insights into patterns and controls of root dynamics.

ACKNOWLEDGEMENTS

I thank Rich Norby and collaborators who organized, funded and invited my participation in the *New Phytologist* Symposium–GCTE Workshop and offered the opportunity to write this paper. I also thank collaborators, particularly James Raich, John Aber and Joseph Hendricks, but also many others for stimulating my thinking about roots. Two anonymous reviewers and Rich Norby supplied thoughtful comments and criticisms on an early draft of the paper. Grants from the US National Science Foundation (NSF-DEB 9411975 and NSF-DEB 9815990) and the A. W. Mellon foundation provided salary and other resources to support this effort.

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Gail Hanley

From:	larryballantine@yahoo.com
Sent:	Thursday, February 13, 2014 10:02 AM
To:	Gail Hanley
Cc:	Jerry Potamis
Subject:	Fw: CAA and Nitrogen improvements

Gail, can you include this with yesterday's CCWPC minutes.

Thanks,

Larry

----- Forwarded Message -----
From: Jerry Potamis <jpotamis@falmouthmass.us>
To: larryballantine@yahoo.com
Sent: Friday, February 7, 2014 11:20 AM
Subject: FW: CAA and Nitrogen improvements

This is a unique example of reduction of N that has to be primarily from atmospheric deposition

Clean Air Act has led to improved water quality in the Chesapeake Bay watershed

Submitted by Amy Pelsinsky on Wed, 11/06/2013 - 10:27am
in

- Appalachian Laboratory

Subtitle:
Declines in atmospheric nitrogen pollution improved water quality over a 23-year period
FROSTBURG, MD (November 6, 2013) – A new study shows that the reduction of pollution emissions from power plants in the mid-Atlantic is making an impact on the quality of the water that ends up in the Chesapeake Bay. The study by scientists at the University of Maryland Center for Environmental Science confirms that as the amount of emissions of nitrogen oxide from coal-fired power plants declined in response to the Clean Air Act, the amount of nitrogen pollution found in the waterways of forested areas in Pennsylvania, Maryland and Virginia fell as well.
"When we set out to reduce nitrogen pollution to the Chesapeake Bay, deposition of nitrogen resulting from air pollution on the watershed was considered uncontrollable," said Donald Boesch, president of the University of Maryland Center for Environmental Science. "This study shows that improvements in air quality provided benefits to water quality that we were not counting on."
Researchers evaluated long-term water quality trends for nine forested mountain watersheds located along the spine of the Appalachian Mountains from Pennsylvania to southern Virginia over a 23-year period (1986 to 2009). The sampling began slightly before the Clean Air Act of 1990 imposed controls on power plant emissions to reduce nitrogen oxide pollution through its Acid Rain Program. According to the EPA, total human-caused nitrogen oxide emissions declined 32% from 1997 to 2005 in 20 eastern U.S. states that participated in the program.
Intended to reduce the emissions (sulfur dioxide and nitrogen oxide) that caused acid rain, the program had the unintended consequence of reducing the amount of nitrogen oxide particles landing on forests in the sample area and ultimately improving water quality in the watershed.
"It worked for something nobody anticipated," said lead author Keith Eshleman, a professor at the University of Maryland Center for Environmental Science's Appalachian Laboratory. "The original idea was to reduce nitrogen oxide concentrations in the atmosphere because that would reduce acidity of precipitation and decrease ozone in the atmosphere. The other result was that water quality has improved, a side benefit that was unanticipated."
Air pollution that falls on the land (known atmospheric deposition) is one of the biggest sources of pollution to the forested area that impacts the Chesapeake Bay--sixty percent of the watershed. Nitrogen accumulation has significant consequences for air quality, human health, and the health of aquatic ecosystems. When excess nitrogen enters the streams and waterways, it can cause algae blooms that significantly impact water quality and marine life.
"In our most pristine and most heavily forested basins, nitrogen deposition is a primary driver of pollution," said Eshleman. "Where we are located in the Mid Atlantic, we've historically had some of the highest rates of deposition, and received some of the greatest reductions owing to the Clean Air Act."
The study, "Surface water quality is improving due to declining atmosphere N deposition" is published in the November 5 issue of Environment Science and Technology by Keith Eshleman, Robert Sabo and Kathleen Kline of the University of Maryland Center for Environmental Science.
The Appalachian Laboratory is located in the mountains of western Maryland, the headwaters of the Chesapeake Bay watershed. Since 1962, the Frostburg-based institution has actively studied the effects of land-use change on the freshwater and terrestrial ecosystems of the region, how they function in the Chesapeake Bay watershed, and how human activity may influence their health and sustainability on local, regional and global scales. The scientific results help to unravel the consequences of environmental change, manage natural resources, restore ecosystems, and foster ecological literacy.

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