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Contributions of Acid Rain Research to the Forest Science-Policy Interface: Learning From the National Acid Precipitation Assessment Program

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The National Acid Precipitation Assessment Program (NAPAP) created a lasting legacy for forestry research in the USA, in particular how research organizations harness their science for better informed decision making. The blueprint for present day quality assurance in Forest Service research originated under NAPAP's Forest Response Program, as did much of the current thinking about big science, interdisciplinary efforts, timeliness of final products and valuing sustained communication. The degree to which knowledge and experience subsequently helped to shape and build a more credible science foundation has become increasingly evident over the intervening decade, yet has gone unrecognized by many of today's forest scientists and managers. *Key words: NAPAP peer review, quality assurance. science credibility, science relevancy, synthesis and integration.*

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INTRODUCTION

During the 1970s, there was growing concern by scientists, policy officials and the general public in the USA over the possible effects of acid rain on human health and the environment (crops, forests, water, etc.). The lack of science based information needed for policy and regulatory decisions led Congress to create an interagency task force in 1980 called the National Acid Precipitation Assessment Program (NAPAP 1991). By 1985, forest decline in Europe (Mayer & Ulrich 1978) had been widely reported, and concerns over similar symptoms of this decline were mounting in the north eastern United States (Johnson & Siccama 1983, McLaughlin 1985). The Forest Response Program (FRP) was formed in 1985 under NAPAP to provide information that was scientifically credible, of high quality and communicated in a timely manner. One central precept was to conduct research that was very focused on informing policy decisions (i.e. policy relevant research), along with a firm expectation of achieving answers to those policy questions in 10 yrs.

The variety of experimental approaches used under the FRP clearly posed some challenges for a synthesis of research results (Peterson et al. 1989, Mattson et al. 1990, Shriner et al. 1990), as well as the policy relevance of the results. The 1990s were not without retrospectives that focused on the shortcomings (e.g. Roberts 1991, de Steiguer 1992) of NAPAP in terms of product timeliness and programme accountability. However, the many ways in which knowledge and experience gained by participants in the FRP subsequently helped to shape a more credible science foundation, especially in Forest Service research, have unfortunately been overlooked or unrecognized by many scientists and managers.

THE LEGACY OF THE FOREST RESPONSE PROGRAM

The FRP set out to address three broad policy questions (Schroeder & Kiester 1989): (1) What is the significance of forest damage in North America caused by acidic deposition? (2) What causal relationship might exist between pollutants and forest damage? (3) What are the dose response relationships between acid deposition and forest damage?

The findings and discussions from the FRY are not the focus of this paper, but rather the factors along the way that contributed to the accountability and credibility of the scientific process. The FRP research process is still providing value in the way in which problems of today, such as regional scale forest

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planning and global climate change research, are being approached. The following approaches were central to the resulting successes and represent an ongoing legacy in Forest Service research programmes of today.

USHERING IN A NEW ERA OF INTERAGENCY CO-OPERATION

Although the US Environmental Protection Agency (EPA) had and has the authority to regulate pollutant sources under the Clean Air Act, and many of the other agencies had the resources with which to conduct research, the diversity of issues across scientific disciplines coupled with the geographical scope of the problem, were clearly beyond anyone agency's capability within the federal government. The NAPAP was conceived as a co-ordinated effort among 13 federal agencies as a means to deal with this issue, and differences among the agencies (see Winstanley et al. 1998), especially in organizational mission, can make collaboration challenging, if not prohibitive. Interagency planning, especially for a problem of that scope and magnitude and budget, was largely unprecedented at that time, but in the case of the FRP, interagency collaboration evolved over a period of years into an effective and efficient way to plan, execute, assure quality and peer review the complex research programme that developed.

The really significant outcome seen in interagency co-operation was an evolution of co-operative spirit to a point where agencies were willing and able jointly to plan research and set priorities, jointly agree to fund that research, issue interagency requests for proposals, and jointly manage the resulting programme. It took some time to reach that point, but by 1990, the interagency management within the FRP was working quite well. Over time, the regular meetings and participation of agencies managing various parts of the programme managed to change attitudes, create shared perceptions and foster an unprecedented level of trust across agency boundaries, perhaps unequalled since.

CREATING AN ERA OF INTERDISCIPLINARY "BIG SCIENCE" IN FOREST ECOLOGY

The nature of the problem created an era of "big science" in ecology, big in geographical scope, issues, complex interdisciplinary research and budgets. Before broad attempts were made to address the impacts of long range transported air pollution, research grants in the ecological sciences and forestry were typically small grants to individual investigators. As multidisciplinary research teams were convened to address issues of regional, national and international scale, it became evident that more resources were needed to fund the research, and much larger grants, previously extremely rare, became much more common thanks to the funding available through the NAPAP. For example, the budgets of typical FRP ecological research projects evolved from \$50 000 and \$100 000 per year to projects ranging from \$500 000 to \$1 000 000 in quite a number of eases. The significance here is not that the FRP was an easy source of dollars, but rather the recognition that the nature of the problem was so complex that business as usual was inadequate to answer the questions.

Increasing relevance of temporal and spatial scale

From its very inception, its unique temporal and spatial scale defined the problem of acid rain. The term acid rain was coined in an initial report by the Swedish Government to the United Nations (Engstrom et al. 1971), in which air pollutants transported from other nations were alleged to be associated with long term trends in the chemistry of precipitation, soils and surface waters in Sweden and, subsequently, Norway. These trends were only detectable as the result of a 20 yr monitoring effort in Sweden, over which time a significant increasing trend in precipitation acidity and subsequent surface water acidity had become evident. Recognition of this time and space element to the problem ultimately led to national and international programmes to evaluate long range transported air pollutants in Sweden, Norway, Canada, the UK, Germany and the USA. The relevance of policy was not only national but international in scope, demanding a high degree of accountability and scientific credibility from the information that was to provide the basis for policy.

In the USA, the time and space issues provided some of the most unique challenges to the ecological portions of the programme, and also some of the most enduring successes. For example, because as a nation the USA was unable to establish within statistically acceptable levels of certainty the spatial pattern of surface waters affected and their extent, a national surface water survey was designed and implemented. That survey not only provided a valuable snapshot in time in the 1980s, but has subsequently provided a defensible baseline against which to measure the success of the 1990 Clean Air Act in reversing earlier trends in lake and stream acidification, where a recent report concludes that the Clean Air Act Amendment (CAAA) regulations have resulted in a large and widespread decrease in the deposition of wet sulfur (Stoddard et al. 2002, Western Ecology Division 2003).

In forestry research, approaches developed to relate forest response to large scale regional patterns of pollutant deposition not only provided a significant input to the acid rain debate, but also became the progenitors of large scale ecological research that continues to build on the baseline established in the 1980s. For example, the Michigan Gradient Study (Witter et al. 1989) has maintained studies across a gradient in sulfur deposition for nearly two decades. Similar research across an elevational gradient in the Great Smoky Mountains (McLaughlin et al. 1997) continued for almost a decade.

A major challenge in the FRP's first policy question mentioned above was: (a) are there unexplained changes in regional growth trends and patterns, and (b) could they be related to acidic deposition? As a centrepiece for the FRP synthesis and integration effort in answering part (a), there were numerous debates over temporal and spatial scaling issues, such as whether or not the research on radial increment cores really could establish regional synchronicity in forest growth changes (e.g. declines), or whether studies of seedling and tree growth under controlled exposures to pollutants conducted across a large geographical area could demonstrate regional effects when taken together. Much of the debate about the interpretations of radial increments involved concern from forest mensurationists (e.g. Hyink & Zedaker 1987, Reams & Huso 1990, Reams & Peterson 1992) over statements from scientists who failed to take into account the natural changes in tree growth as trees and stands age, as well as the effect of stand dynamics (e.g. stand density affecting growth rates of individual trees within the stand) that are fundamental to the interpretations of tree and stand growth (e.g. Schumacher & Meyer 1937, Assman 1970). The use and interpretation of Forest Inventory and Analysis (FIA) data in estimating regional changes in forest growth were also contested (discussed in the next section).

To address part (b) of the first policy question, the ability to regionalize or extrapolate findings also depended on how adequately one could characterize regional exposure patterns. The non meteorologists did not always appreciate the need to consider regional variability of air chemistry in addition to variability among trees and soils, and such doubt was sometimes manifested in the most fundamental ways. For example, most of the ozone monitoring sites in the western USA are located in urban areas for good reason (human health concerns), but almost no deposition monitoring was done at sites where forest condition was sampled and presumed to be affected by deposition (Böhm et al. 1991). Furthermore, whereas long term growth records for trees and forests can be obtained from long term (several decades) permanent growth plots or from retrospective samples (e.g. increment cores), many if not most deposition monitoring records were just a few years old. Therefore, relating unexplained changes in regional growth trends and patterns to acidic deposition, alone or in combination with other pollutants, is a fairly daunting task.

CHANGES TO NATIONAL FOREST INVENTORY AND ANALYSIS

When Sheffield & Cost (1987) discussed possible explanations or contributors (e.g. acid rain) to a documented reduction in pine growth in the southern USA, they were rewarded with a great deal of criticism. Nonetheless, they sparked discussion among the scientific community as to the measurements, methods to analyse changes in regional forest growth (and thus decline) and what data sets (individual studies. forest inventory and analysis, large forest surveys) were appropriate for analysis. Bechtold et al. (1991), along with the Resources Planning Act assessment at that time, unleashed a lot of pent up frustrations from the forest industry with FIA, especially questioning whether FIA's interpretation of inventory data supported FIA's estimates of changes in growth for southern pines. For example, Hyink & Zedaker (1987) stressed the importance of basic forest mensuration principles, such as accounting for stand age, site index and stand density to obtain a realistic expectation of stand growth in the absence of a decline agent (e.g. acid rain). Zeide (1992) concluded that the purported decline could he attributed to shifting sampling protocols rather than actual changes in growth. Two key Blue Ribbon Panel reports (American Forest & Paper Association 1998, 2001) and a number of published discussions (see Schreuder & Thomas 1991, Bechtold et al. 1991) that followed were a catalyst for sweeping changes in FIA that were expressed in the congressional legislation

(PL 105-185 the Agriculture Research, Extension, and Education Reform Act of 1998) to push for one sampling design for the country and annual reports on every state instead of reports every 10 yrs, as in previous years. In the end, nearly everyone who stayed close to the FIA data and growth reductions in Europe generally agreed that the largest contributor was prolonged regional drought (growth has since increased in both Europe and the eastern USA and the only thing that has really changed is precipitation, and of course stand structure).

The fact that FIA plots had been pressed into service to do forest health monitoring under NAPAP also led to a more formalized forest health monitoring (FHM) network post NAPAP (see Reams et al. 2004, Ritters & Tkacz, 2004) for change detection. In 2000, HEM detection monitoring became part of the FIA national programme. FIA adopted both the sampling design (annual panel system, continuous forest inventory) and plot design originally developed by FHM, and so FHM has had a profound effect on the current FIA programme.

Aside from the long intervals between collecting the data and reporting the data, the NAPAP experience also revealed a basic weakness in FIA analytical capabilities. Whereas FIA teams had been well trained in measurements, collections and reporting raw data, the background and experience of analysts in traditional hypothesis testing and the statistical methods (e.g. regression) necessary for those analyses were lacking, resulting in poor or incomplete interpretations of the changes in inventory. Consequently, a major effort by FIA units since the 1990s has been to build more analytical skills into the workforce. Another important benefit of this added capability has been to make other researchers more aware of the added information that is available and how FIA data can be used in an appropriate manner.

Implementing national quality, assurance and quality control

The Environmental Protection Agency's environmental research laboratory in Corvallis, Oregon, USA, was the quality assurance (QA) flagship for that agency, and the FRP efforts in QA, quality control (QC), synthesis and integration were directed from that location. As part of the FRP Quality Assurance Team, Cline & Burkman (1989) stressed that a primary role of QA was to ensure that issues such as sampling methods, measurements and site selection were comparable among the studies and legally defensible. They contended that while QA may be practised in most cases, the approach to QA and QC in the scientific community is relatively informal (i.e. usually undocumented) compared with research and development in the industrial sector. Building on a strong EPA foundation for QA (US EPA 1976-1983), several internal QA guides were developed under the FRP to address site classification and various field measurements. It was widely acknowledged that white research studies and results are increasingly challenged in court (i.e. are they legally defensible), QA is simply a part of good sound scientific practice.

Because of difficulties inherent in conducting controlled exposures with mature trees (e.g. size and complexity of the experimental material), seedling exposure studies were initiated in the FRP as the quickest way to detect acute effects and determine the relative sensitivity of tree species in response to simulated acid precipitation and gaseous pollutants. These studies covered a wide range of treatment combinations, facilities and exposure regimens; and yet, this suite of national studies represented both a concern and an opportunity for a couple of reasons. First, these experiments used controlled treatment levels and thus were excellent candidates for QA processes. Secondly, these studies, representing millions of dollars in investment, needed to be comparable if any synthesis of the science were to be attempted. Thus, a key major programme output of the FRP (Peterson et al. 1989) incorporating many aspects of QA/QC, was intended explicitly to reveal the barriers in experimental studies that would need to be addressed before any comparisons across national studies could be achieved, let alone possible meta-analyses.

For examples illustrative of the importance of documenting data quality and statistical issues such as power and the trends of increasing uncertainty as one moves from closely controlled experiments to the field (i.e. defining the scope of inference), see Peterson & Mickler (1994). The practice of QA/QC and the credibility that many researchers gained as a result of their participation provided the impetus for a national QA/QC effort launched in Forest Service research in the late 1990s. The International Union of Forest Research Organizations (IUFRO) guidelines for designing multipurpose resource inventories (Lund 1998) also incorporated a significant portion of the FRP experience in QA.

Today, nearly all USDA Forest Service Research Stations have approved QA plans on file that are being implemented through peer reviewed team or project problem analyses, major study plans, and improved data management and security. Forest Service research data are being increasingly scrutinized and challenged as they have become more and more relevant in the policy making arena, especially in the conservation of wildlife and fish species. For example, the USDA Forest Service is currently being petitioned under the Data Quality Act to correct information disseminated by the Forest Service on the northern goshawk.

CREDIBILITY FROM THE FORMAL PEER-REVIEW PROCESS

The very foundation of both individual and organizational science credibility rests heavily on the peer-review process. Any scientist who conducts research and publishes the results understands that fundamental notion, even if it is only at the level of hoping for at least two positive reviews out of a standard three reviewers. However, most research or consulting science is never challenged in court unless it supports or influences policy or a legal decision where some party perceives a significant loss from that decision. Strong peer reviewed science is necessary for any credible science based decision. Four major synthesis documents were produced under the FRP, the first of which established a benchmark for formal peer reviews of such documents.

For example, rather than use only three or perhaps four reviewers, the first major programme output (Peterson et al. 1989) was reviewed by three scientists within the EPA (including one statistician) plus 14 more from universities and the USDA Forest Service (including two more statisticians). The 14 reviewers external to the programme were selected from a list of scientists arrayed according to scientific discipline and whether they were a specialist or a generalist, generalists being those who could see whether the entire report accurately reflected the component parts or sections. Each of the comments from the 17 reviewers was explicitly referenced in the reconciliation memo as to how the author was addressing the comment; if the reconciliation resulted in a change to the manuscript, then the nature of that change and the location in the manuscript were noted. The reconciliation memo for this first FRP deliverable (a 104 page manuscript) was itself a 60 page, single spaced document. The report and the reconciliation document were then both reviewed by the laboratory director and kept on file. Although this was a very meticulous and timeconsuming process, it was also very robust since one negative review (out of the 17 reviews received) was less likely to undermine the credibility of the paper.

Whereas the number of reviews per document will vary, the major value in the formal reconciliation process is demonstrating to the reviewers and the public that each comment is assessed and taken seriously. In the 1990s, this valuable lesson of formal reconciliation of comments from many reviewers was followed in the Forest Service Pacific Northwest Research Station in the general study plan for researching "Alternatives to clear cutting in oldgrowth forests of southeast Alaska", and also the Station's general study plan for "Demonstration of ecosystem management objectives", which tests the effects of variable retention harvests on biological diversity in Douglas fir under the Northwest Forest Plan.

FRAMING THE ROLE AND NEED FOR SYNTHESIS AND INTEGRATION

Perhaps the most significant challenge for the FRP was to create a capacity for integrating results from a wide variety of research approaches, and then synthesizing the information in a policy relevant fashion (Schroeder & Kiester 1989). In particular, the challenge was to assimilate field survey information with results from experimental studies, focusing heavily on the linkages among biological levels of organization. The FRP was really the first attempt nationally at conducting interdisciplinary studies, or at least linking inferences among single discipline studies. One example is testing for changes in growth, often via physiological mechanisms that ultimately affect wood production in response to simulated atmospheric changes (acid rain, ozone, sulfur dioxide, nitrogen dioxide, etc.) in controlled studies. This effort was probably one of the earliest examples, at least in forestry research, of a strong role for modelling and the coupling of models as integral tools in the process of planning, guiding and synthesizing research.

Four major programme outputs were produced under FRP as synthesis documents (see Peterson et al. 1989, Reams et al. 1990, Mattson et al. 1990, Kiester et al. 1990). Following the end of the FRP, new interdisciplinary field studies integrating wood production with other values (e.g. water quality, aesthetics and wildlife habitat) were implemented operationally in numerous areas of North America in the 1990s (e.g. Peterson & Monserud 2002, Shifley & Kabrick 2002) as an integral piece of ecosystem management for US Forest Service research.

Over and above the biological integration, which was manifested at several scales, one could argue that the concept of integrated assessment evolved in a significant way over the course of the FRP and has appeared repeatedly in subsequent years. The idea of conducting a comprehensive, integrated assessment of multiple endpoints, multiple drivers or stressors, and alternative scenarios on a regional to national scale opened conceptual doors for a lot of people during that period, and had some influence on major Forest Service eforts, such as the assessment of the Columbia River basin and Southern Appalachian assessment. In addition, multiple institution partnerships were needed to tackle these kinds of issues, a natural extension of integrated interdisciplinary research.

THE RELEVANCE AND TIMELINESS OF SCIENCE FOR CONSIDERATION IN POLICY

As Bernabo (2003) points out, NAPAP was not the genesis of research on acid rain, but rather the "beginning of a nationwide consciousness to not just do research, but to harness that research in service to society, to try to help us make some decisions." The shortcoming of NAPAP not having economic assessments was one source of discontent. For example, de Sterguer (1992) cited a NAPAP review saying that science and technology drove issues instead of assessment need. However, this was clearly acknowledged by Jim Mahoney, Director of NAPAP (e.g. Roberts 1991). For any assessment, there is a need for policy relevance. but equally so, information must be produced on time if it is to be considered for the decision-making process (Pitelka 1994).

As Winstanley et al. (1998) point out, "the scientific credibility of the assessment process will be questioned at every conceivable opportunity, so managers need to be prepared to defend the assessment." They also point out that during NAPAP, the science policy interface required careful management and communication on both sides. This has since become increasingly important in US Forest Service research assessments over the past decade (e.g. Mills & Clark 2001). One could argue that a great deal of the NAPAP information was delivered to the Administration and Congress in a timely fashion. In fact, it is not unusual for policy decisions to be made on the strength of the information gathered before a final report is published and distributed. Although the Final NAPAP State of Science reports (e.g. Shriner 1990) produced for the 1990 summit at Hilton Head clearly followed the changes in policy (i.e. amendment of the Clean Air Act by President Bush earlier that year). the administration was receiving scientific and technical input throughout the late 1980s via numerous congressional testimonies by people involved in the research, including hundreds of briefings and technical exchanges There is a long documented history of communication over scientific issues between NAPAP and the Congress from 1984 to 1990, in addition to the complete set of NAPAP Annual Reports (Ringold 2003). That process of routine communication and briefings helped to develop interpersonal relationships and credibility that benefited NAPAP, Congress and the Administration. This issue of timely completion and reporting of research results has become paramount in the Forest Service for policy relevance of information.

SUMMARY

The FRP was a major investment and success in assessing the health or condition of the US forested ecosystems, and in providing some direction as to the importance of monitoring changes in natural resources. The scope and complexity of that interdisciplinary and interagency task forever changed how issues of forest health are conceptualized by agencies, especially the USDA Forest Service. For major research and development efforts, it is necessary to assemble a team that is funded off the top and involved early in the design stage, and whose sole objective is to synthesize and integrate results in a way that clearly links scientific hypotheses to policy issues, from initial study plans to final reports. A major foundation of synthesis and integration is QA, an attribute that must be addressed by every principal investigator and individual who has responsibility for producing a credible and defensible product.

However, the formation and implementation QA/QC and synthesis and integration were not without considerable friction. It took a couple of years of practice and constant communication before scientists and managers would view these practices as improving the quality and credibility of their science, rather than viewing them as a threat or added burden to their science efforts. Scientists increasingly recognized the potential for meta analyses or combining results across several studies, beyond reporting results from their own study. The same could be said for scientists accepting the EPA's peer review process with formalized reconciliation that clearly demonstrates to anyone who might challenge the results that the author read and addressed every comment from each reviewer, an increasingly important process for science that might be used for policy decision making in the US Forest Service today.

Most explicitly, the FRP legacies in Forest Service research include implementing national QA programmes, significantly changing the way in which forest inventory and analysis programmes are conducted, anti increasingly synthesizing what have been learned, highlighting the relevance to policy and societal issues. Moreover, the ever increasing challenges to science results (e.g. current lawsuits under the Data Quality Act) and the ways in which that scientific information is being used to make policy, reinforce the notion that the foremost source for accountability and scientific credibility is a foundation of QA with strong peer review of major programme elements and outputs throughout the process, being able to demonstrate the relevance of the science through a strong synthesis effort, and appreciating the value of communicating internally and externally throughout the process.

The authors believe that the innovations developed for the FRP in the process of research planning, implementation, administration, integration and synthesis created a lasting legacy for forestry research in the USA that has been manifested in diverse ways in forest planning and in major research programmes such as global climate change and fire research.

Convert of the issue

The FRP is an excellent example of how the temporal and spatial scale of issues can play a critical role. Increasingly, forest science is being called upon to provide the foundation to support management actions by land management agencies, and playa more significant role at the science-policy interface. More and more, the context for management decision making is regional to national in scale, and the thought processes that evolved during the FRP have aided such discussions.

Polirr decision process

Current policy development needs are taking a cue from the FRP experience by recognizing the critical role of a strong science foundation in establishing the credibility necessary to inform all interested parties in the policy debate. The FRP process brought an unprecedented level of credibility to an issue that was highly complex and highly contentious, and did so in such a way that, although the timeliness of the final reports was criticized, the foundational science, in the end, was rarely questioned.

Credibility and quality of the science

Innovation in synthesis and integration, QA and a formalized peer review process all enabled improved communication of the science to policy makers, forest managers and the public at large, and to varying degrees has continued to influence the conduct of policy relevant research in the Forest Service. Another valuable lesson that continues to be emphasized is the absolute necessity to place high priority on the timeliness of policy driven research. All of these lessons taken together contributed substantially to enhancing the credibility of the scientific process and the science information that continues to be produced.

Sustained communication

Finally, while QA, syntheses and good science practices will enhance communication, communication throughout the programme is invaluable in setting expectations, clearly formulating the policy and research questions, and securing the needed resource. Timely communication of results and their uncertainty, and the degree to which they answer the original questions, is imperative when considering the differing timeframes for writing and enacting policy versus producing a final, published, peer-reviewed product.

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