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Linking stakeholder research needs and the Federal Data Quality Act: A case study of an endangered forest shrub in the southeastern United States

Brian Roy Lockhart [a,*], Emile S. Gardiner [a], Theodor D. Leininger [a], Kristina F. Connor [b], Margaret S. Devall [a], Paul B. Hamel [a], Tracy Hawkins [a], Nathan M. Schiff [a], A. Dan Wilson [a]

[a] *U.S. Department of Agriculture, Forest Service, Southern Research Station, Center for Bottomland Hardwoods Research, P.O. Box 227, Stoneville, MS 38776, USA*

[b] *U.S. Department of Agriculture, Forest Service, Southern Research Station, Vegetation Management Research and Longleaf Pine Research for Southern Forest Ecosystems, 520 Devall Drive, Auburn, AL 36849, USA*

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ABSTRACT

The need for knowledge, ranging from development of new products or processes to the effects of specific actions on the environment, is greater now than at any point in the past. The greater need for research has generated stakeholder involvement in the research process. As a result, all facets of research, from planning through publication of results, are often scrutinized by stakeholders. While the basic nature of scientific inquiry has not changed, now more than ever the credibility of scientific results is based on thorough planning, peer reviews of experimental designs and analytical approaches, and assurance that data are of the highest quality. Public interest in the quality and accuracy of federal research rose to a level that resulted in the Data Quality Act of 2001. The Act required the establishment of guidelines for Federal research organizations and cooperators. We present a case study of the U. S. Forest Service's policies for research quality assurance and quality control, including developing quality assurance statements and plans, as applied to comprehensive research on the federally-listed, endangered forest shrub pondberry (*Lindera melissifolia* (Walt.) Blume).

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1. Introduction

> "We [U.S. Forest Service scientists] can expect to be increasingly queried about the quality of our research, and the steps we take to ensure, assess, and document that stated quality." (U.S. Forest Service, 2002)

The above statement, taken from the "Quality Assurance Implementation Plan" for the U.S. Forest Service's Northeastern Research Station (now part of the Northern Research Station) keenly reflects the current state of affairs, not just in forestry research, but scientific research in general. In today's litigious society, scientific knowledge in and of itself is simply not good enough; how this knowledge was acquired and assurance that it is truthful, in addition to useful, is as important as the knowledge itself. Stakeholders are increasingly demanding information behind the process of knowledge acquisition, in addition to the final products, to make better-informed decisions regarding forest resource management and forest sustainability.

Forest sustainability is defined as the capacity of forests, ranging from stands to ecoregions, to maintain their health, productivity, diversity, and overall integrity in the long run, in the context of human activity and use (Helms, 1998). The foundation of forest sustainability is based on knowledge acquired through research, observation, and experience. The acquisition and application of this knowledge is grounded in the U.S. Forest Service's mission—to sustain the health, diversity and productivity of the Nation's forests and grasslands to meet the needs of the present and future generations (U.S. Forest Service, 2000a). One goal under this mission is to develop and use the best scientific information available to deliver technical and community assistance, and to support ecological, economic, and social sustainability (U.S. Forest Service, 2000a). This goal mandates Research and Development, one of the branches of the U.S. Forest Service, to ensure its science is of highest quality based on standards, both internally through quality assurance programs and externally through various scientific disciplines, peer review, and stakeholder input. Simply put, quality of information is more important than quantity. Therefore, the objectives of this paper are to describe stakeholders, provide background of the U.S. Forest Service Research and Development (R&D) program and its role in assuring quality research to stakeholders, and describe the Data Quality Act of 2001 and how R&D has responded to the Act. We conclude with a case study of an ongoing R&D research project initiated in response to specific stakeholders needs, and describe how this project integrates concepts of research quality assurance with research planning and implementation.

* Corresponding author. Tel.: +1 662 686 3171; fax: +1 662 686 3195.
E-mail address: blockhart@fs.fed.us (B.R. Lockhart).

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2. Stakeholders

Random House (1980) defines a stakeholder as "the holder of the stakes of a wager." In today's vernacular, stakeholders are defined as individuals or groups who are affected by, or can affect, a given operation (The World Bank Group, 2004). They can be individuals, special interest groups, corporate organizations, government entities, or any and all combinations of these. Stakeholders have traditionally been viewed as the receivers or end-users of knowledge. Knowledge is developed through research by scientists and research organizations. This knowledge is oftentimes readily available to stakeholders, but in a form not easily useable by them. A third party is often necessary to link knowledge development to knowledge use. State extension programs and the Forest Service's State and Private Forestry branch have long filled this third-party role by presenting research knowledge in a form more useable to stakeholders.

Today's stakeholders are better educated than in the past and have greater access to knowledge and events throughout the World through improved communication technology such as the internet. These stakeholders encompass a broader view of knowledge, including development and verification of knowledge in addition to use of knowledge. This broader view can be found in the role stakeholders now play in forest certification programs. For example, the Forest Stewardship Council (one of several forest certification organizations) requires input from stakeholders regarding an organization's forest management practices during the certification process (Handford and Nussbaum, 2000). Stakeholders are consulted to provide information on the actual or potential impacts of management practices on local communities, cultural and historical sites, natural resources, ecosystems, and rare and threatened species. Stakeholder input is then used in the certification decision. Stakeholders routinely provide input during public comment periods in the development of U.S. Forest Service National Forest management plans. In fact, a set period of time for stakeholder comments is required during the planning process by the National Forest Management Act of 1976. A more recent evolution of stakeholder involvement in knowledge development and dissemination is in the planning, generation, and reporting of knowledge, that is, the research process itself. Greater scrutiny by stakeholders into the planning and implementation of research, including methods and measurements, has led to increased emphasis by research organizations on research quality assurance and research quality control policies and procedures.

3. U.S. Forest Service Research and Development

The Research and Development program is one of three branches within the U.S. Forest Service, the others being the National Forest System, and State and Private Forestry. R&D is an independent organization within the agency and is considered the world's largest forestry research program (Mills et al., 2002). R&D's mission is to "develop and deliver knowledge and innovative technology to improve the health and use of forests and rangelands" (Mary McCormick, USDA Forest Service, Executive Assistant to the Deputy Chief for Research & Development, Washington, DC, USA, pers. com. 18 July 2005). This mission is exemplified in R&D's goal to search "for better ways to sustain and protect [our Nation's natural] resources and to meet the needs of present and future generations" (Bartuska, 2004). This goal is accomplished through seven Research Stations assembled across the United States and Puerto Rico and further subdivided into 115 individual Research Work Units or Programs and 77 Experimental Forests and Ranges. Specific mission statements by Research Stations and Research Work Units provide a framework to meet the needs of stakeholders at local, regional, national, and international levels.

Forest Service R&D dates back to 1898 when Gifford Pinchot established the Section of Special Investigations in the Division of Forestry (later renamed the Forest Service) (Steen, 1983). The original mission of Forest Service research was to collect dendrological and other data as needed to manage the National Forests (West, 1990). In 1908, the first field research station, the Coconino Experiment Station (now the Fort Valley Experiment Forest Station) on the Coconino National Forest, was established in Fort Valley, Arizona by Raphael Zon, who stated "Here we shall plant the tree of research" (Steen, 1983; Olberding, 2000). The importance of research to the Forest Service was formalized in 1915 with the creation of a Branch of Research (precursor to R&D) in the Forester's Office (Washington D.C.). It was deemed necessary to base Research out of a central office to ensure research project planning on a national scale (West, 1990). By the end of the 1920s, a network of 12 regional stations representing all major forest regions was in place (Steen, 1983). These research stations had a decentralized organization structure so they could best serve the needs of the local National Forest (West, 1990). This decentralized structure is still much evident today, though current trends are towards greater centralization.

One impetus for forestry research in the U.S. was the limited applicability of European models (silviculture) to the management of U.S. forests, especially in dealing with the threat that fire posed and the wide array of forest cover types and species mixtures (West, 1990). The early years in R&D "saw investigators with little specialized training beyond a general education in forestry, and their publications emphasized the practical" (Steen, 1983). Little to no emphasis was placed on research quality assurance as researchers' training, names, and reputations were considered adequate. Forest Service research expanded little until the post-World War II economic boom and subsequent Cold War generated funding increases (West, 1990). Expansion during this time led to a peak in the number of Research Work Units and Experimental Forests and changes in mission statements. By the late 1950s, the structure of Forest Service Research changed to projects. Under this system, which is still in place today, a senior scientist leads a project (Research Work Unit) and supervises its staff (West, 1990).

Historically, R&D focused on quantitative studies of biophysical and socioeconomic phenomena (U.S. Forest Service, 1999). This research involved providing numerical estimates, with associated confidence limits, of the amounts, distributions, and variability in response variables of the phenomena under study. For example, scientists studied tree diameter response following different intensities of thinning to determine optimal thinning regimes to meet specific management objectives. Such research yields important results that enable scientists and managers to explain, predict, and generalize (U.S. Forest Service, 1999). Since the mid 1990s qualitative studies typically associated with the social sciences, where there is often interest in meanings, values, and beliefs have increased in research emphasis across R&D (U.S. Forest Service, 1999). In addition to providing greater breadth to the traditional quantitative studies, qualitative research is becoming increasingly important in multidisciplinary studies at regional and national scales to meet the needs of a wider variety of stakeholders. For example, the Southern Research Station recently initiated the Southern Forest Futures Project that will use technical forecasts and expert analysis to provide forest managers, policy makers, and science leaders with the clearest possible understanding of the potential long term implications of changes in southern U.S. forests (http://www.srs.fs.usda.gov/futures/). This project is based on input from a wide variety of stakeholder input.

Originally, R&D responded to a limited number of stakeholders, specifically the National Forests. Over time, the mission expanded to more and different stakeholders, including industrial and nonindustrial private forest landowners, leading to the evolution of Research Work Units. This expanded mission is best epitomized in a statement by a former Chief of the Forest Service as a goal for R&D "to develop scientific knowledge that enhances our fundamental understanding of renewable natural resources and undergirds their sustainable management on all lands, private as well as public" (Bosworth, 2002).

Research development to identify stakeholder needs takes many forms. The most simple is one-on-one contact between a scientist and an individual who has a specific problem with little knowledge currently available to quickly resolve it. The decentralized nature of individual Research Work Units facilitates much on-the-ground collaboration with local stakeholders. Forest Service scientists also have developed excellent relationships with scientists in universities and other agencies, as well as with foresters in forest industry and State organizations dedicated to solving problems common to all organizations (Barnett, 2004). These relationships lead to collaborative research efforts that provide for efficient use of limited research resources. R&D also responds to stakeholders' needs by formulating research initiatives in response to emerging issues (U.S. Forest Service, 1999). An example of a research initiative is the Southern Research Station's “A Strategic Framework for Forest Research and Development in the South” that requires scientists to integrate the biological, physical, and social sciences and collaborates with stakeholders on fundamental research and development of useful products. Achieving sustainability and incorporating human values requires an approach that addresses multiple-level questions in a stakeholder-driven framework (U.S. Forest Service, 2006). The objective to keep in touch with stakeholders while leveraging science and resources in an integrated fashion led to the development of five Science Areas within the Southern Research Station (Table 1).

Table 1
Science areas within the Southern Research Station to engage scientists in multiple-level, multidisciplinary research to meet the needs and anticipated needs of various stakeholders.

Science Area	Description
Inventory and Monitoring	Quantifying and monitoring the condition of natural resources in the South is critical for determining ecosystem responses to forest health threats and improvements in natural resource condition resulting from management activities. Natural Resources Inventory and Monitoring will provide the knowledge and tools required to quantify, monitor, and predict the condition of natural resources.
Forest Threats	Forest ecosystems in the South are facing increased threats from factors such as nonnative and native insects and disease, invasive plants and animals, wildlife, and climate change and variability. Threats to Forest Health will provide the knowledge and tools required to predict, prevent, eradicate, and mitigate the impacts of forest health threats.
Watershed Science	Forested watersheds (upland forests, working forest and agricultural lands, functioning wetlands, bottomland forests, and their components) will be increasingly relied upon to provide clean and dependable water to support aquatic ecosystems and satisfy the demands of a rapidly growing human population in the South. Forest Watershed Science will provide the knowledge and tools required to manage the full range of forest watershed resources in a dynamic and complex landscape.
Restoration and Management	Population growth and demographic shifts in the South are accelerating changes in southern forest ecosystems. New and improved tools and technologies are needed to successfully restore and manage ecosystems in this changing environment. Enhanced knowledge of forest genetics, physiology, silviculture, wildlife biology, and ecology is needed to create, develop and support the needed tools and technologies. Forest Ecosystem Restoration and Management will provide landowners with the awareness and ability to produce a wider array of economic, ecological, and societal benefits.
Forest Values	Natural resources and humans are inextricably linked in the South. These linkages will only strengthen as increased urbanization, globalization, and shifting values influence and alter how people interact with forests. Forest Values, uses, and policies will provide the knowledge and tools required to manage impacts and optimize benefits of human–forest interactions.

These areas can be accessed at http://www.srs.fs.usda.gov/research/strategic/framework_all.htm.

4. Quality research in Forest Service R&D

Research is defined as a systematic inquiry into a subject in order to discover or revise facts and theories (Random House, 1980). Researchers consider the importance of rigor and high quality standards so obvious as to be implied in all research activities from planning through implementation and publication. In today's politically-charged climate, the importance of research, and the research process as a whole, needs to be explicitly stated to various stakeholders. R&D research is now under intense scrutiny by various stakeholders, including special interest groups, politicians, the courts, and the scientific community, resulting in growing challenges to methods, results, and to the credibility of the R&D research organization, ranging from the Washington office through the Research Stations and Research Work Units (U.S. Forest Service, 1999). Research produced by R&D is being relied on in unprecedented ways to formulate management and policy decisions at local, regional, national, and international levels (U.S. Forest Service, 1999). Therefore, it is imperative that the quality of the data and methods by which these data are collected and analyzed be known. As stated in the Quality Assurance Plan for the Pacific Northwest Research Station, stakeholders “deserve assurances that we pay close and careful attention to the issue of quality” (U.S. Forest Service, 1999).

Quality research through employment of proper methods and data analysis, i.e., good scientific practices, were assumed inherent in early efforts of government research programs. This changed in the 1960s and 1970s as the general public, scientists, managers and others became more interested in what is now called the research- or science-policy interface (Guldin, 2003; Parrotta and Arce, 2003, Guldin et al., 2004; Janse, 2008). An interagency task force, the National Acid Precipitation Assessment Program (NAPAP), was created in 1980 to develop science-based information for policy makers regarding possible effects of acid rain on human health and the environment (NAPAP, 1991, Peterson and Shriner 2004). The Forest Response Program (FRP) was formed under NAPAP to “provide information that was scientifically credible, of high quality and communicated in a timely manner” (Peterson and Shriner 2004). Specific quality assurance procedures in the FRP served as a precursor to the current research quality assurance/quality control programs now in place in R&D. For example, research quality assurance objectives were developed for the Forest Health Monitoring (FHM) program in New England in 1990. Objectives included (1) assist in the development of clear, concise methods for collecting project data, (2) develop measurement quality objectives that identify data-quality limits for all variables and collected data, (3) assist in the development and evaluation of the training session for field crews, (4) audit field crew data collection to ensure compliance with project methods, and (5) coordinate and evaluate data from a remeasurement of a proportion of the field plots to quantify data quality (Brooks et al. 1992). Other large-scale projects that have included explicit quality assurance include assessing tree crown condition and soils as part of the Forest Inventory and Analysis Program's expansion of the FHM program (O'Neill et al. 2005, Schomaker et al. 2007), procedures in the North American Sugar Maple Decline Project (Millers et al. 1991), and monitoring of the Northwest Forest Plan (Mulder et al. 1999).

In light of increased research scrutiny during the 1990s, R&D developed a Quality Assurance Implementation Plan (hereafter referred to as the Plan), finalized on May 7, 1998. The need for the Plan was based on growing concerns by stakeholders for assurances of research quality. Specifically within R&D, methods, results, and credibility are constantly challenged in a variety of venues: in the courts, by people seeking to stop management practices which are based on R&D research; by other research organizations competing with R&D for limited research funds; and by an increasingly sophisticated public who want to know more details of R&D research

(U.S. Forest Service, 2002). The need for the Plan was further defined based on the desire to continually strengthen research programs and assure the credibility of scientific information (U.S. Forest Service, 1998). Gone are the days when it could be assumed that quality research was inherent in scientists' behavior and that pride in their work automatically ensured the principles of quality assurance (U.S. Forest Service, 1999). While the production of quality research stems from a person's internal values and pride in their work, the current social and political environments demand the influence of external checks and balances. The need for quality assurance of research must be communicated to all R&D employees, from the Washington Office through Research Station administration to scientists and research support staff, and made an explicit part of the way in which all employees approach their jobs. Quality assurance must also be applied to all research collaborators working with Forest Service scientists. Finally, adherence to a research quality assurance program or plan will contribute "to consistent achievement of planned goals by strengthening efforts to choose appropriate questions for study; to document and validate scientific processes and outcomes; and to support the dependable production of distinguished research" (U.S. Forest Service, 1998). In essence, adherence to quality research assurances and research controls will provide increased research credibility to various stakeholders while increasing the likelihood that the research process and public have results that will withstand the harshest scrutiny, even as part of the litigation of management or policy issues.

The Plan provides a framework for quality assurance in R&D, including a recommended outline for Research Station Quality Assurance Implementation Plans, a draft revised Study Plan Outline which addresses research quality assurance issues, and a recommended structure for Study Files. Each Station was encouraged to develop a Quality Assurance Implementation Plan. Plans have been developed for all eight Research Stations (Table 2). While many components of these plans are similar, each plan has unique sections to fit particular Research Station programs. Individual Station plans can be further incorporated or modified at the Research Work Unit level.

Quality Assurance Implementation Plans developed at the Research Station level led to the term "QA/QC" Plans, meaning quality assurance and quality control. Quality assurance (QA) is defined as a process to produce research data and results with known precision, completeness, representativeness, comparability, and accuracy (U.S. Forest Service, 1998). Quality control (QC) is defined as the routine application of prescribed field or laboratory methods to reduce random and systematic errors and ensure that data are generated, analyzed and interpreted, synthesized, communicated, and used within known and acceptable performance limits (U.S. Forest Service, 1998). In short, QA includes guidelines that ensure using sound scientific procedures, including testing and review, while QC is concerned with methods to ensure effective implementation of QA steps (U.S. Forest Service, 1999). The general goal of QA/QC plans is to ensure that all research data collected, synthesized, and utilized by, or for, the Forest Service are scientifically sound, of known quality, and thoroughly documented (U.S. Forest Service, 1998). This general goal has been revised by the various Research Stations to include development of important scientific questions and transfer of results to various stakeholders (U.S. Forest Service, 1998; 1999; 2000b). The general QA/QC goal reaffirms adherence to the basic principles of scientific inquiry—objectivity, peer review, and documentation, essentially validating the scientific process (U.S. Forest Service, 1999; 2000b). In summary, QA/QC is designed to certify that scientific findings and recommendations can withstand the most rigorous challenges when used as a basis for policies and decisions that affect forest ecosystems and the public welfare (U.S. Forest Service, 1998). QA/QC is now an essential element in strategic research planning and considered essential to remain competitive in scientific research. QA/QC further ensures effective investment of public-supported research and development.

Table 2
Quality assurance plans by U.S. forest service research Station.

Research station	Plan title and date published
Forest Products Laboratory	Research Quality Management Program (1996)
International Institute of Tropical Forestry	Quality Assurance Implementation Plan (2004)
Northeastern Research Station[a]	Quality Assurance Implementation Plan (2002)
North Central Research Station[a]	Research Quality Assurance Program (1998)
Pacific Northwest Research Station	Quality Assurance Plan (1999)
Pacific Southwest Research Station	Quality Assurance Implementation Plan (2001)
Rocky Mountain Research Station	Quality Assurance Plan (2005)
Southern Research Station	Quality Assurance Implementation Plan (2000)

[a] The Northeastern Research Station and the North Central Research Station recently combined to form the Northern Research Station.

The Northeastern Research Station's (now part of the Northern Research Station) Plan contains five operating principles as part of its vision of quality research. First, research quality comes from within. Everyone has responsibility for the conduct and assurance of quality research. Second, the Northeast Research Quality Management staff, consisting of biometricians and QA specialists are not the "Quality Police". Scientists and technical staff are trusted to adhere to the Station's QA/QC plan, and feedback mechanisms are in place to ensure Research Station policies are followed and to facilitate the process of conducting quality research. QA/QC staff will not serve as *ex-officio* research administrators or explicitly direct research. Third, the function of the staff is to assist researchers in establishing, documenting, controlling, measuring, and improving research quality. Fourth, everyone involved in research is accountable for its credibility by conducting themselves professionally in accordance with the Forest Service Code of Ethics (http://www.fs.fed.us/research/pdf/fs_code_of%20_scientific_ethics.pdf). Finally, quality research requires work. It is no longer sufficient to rely solely on a researcher's reputation to defend research quality. The courts reject this; other agencies with strong QA programs in place also reject this, and are positioned well to compete for funding because of their QA programs (U.S. Forest Service, 2002).

The organization structure of QA/QC for the Pacific Northwest Research Station shows a chain-of-command for QA/QC implementation. It begins with R&D in the Washington Office and proceeds through Research Station leadership, including an advisory group, program managers (equivalent to Project Leaders at other Research Stations), team leaders, scientists, and research support staff. Each level has specific responsibilities for QA/QC that are addressed in the QA plan. For example, scientists have responsibilities that address actual on-the-ground research (Table 3), including assuming ultimate responsibility for data quality, documentation, and interpretation. Similar organizational structures are located in the QA/QC plans for other Research Stations.

Five key components, in addition to other Station-dependent components, are found in all Station QA/QC plans: study plan, statistical review, peer review, training, and data archiving. Research study plans set the stage for acquiring high quality data and structured, relevant data analyses (U.S. Forest Service, 1999). A general Study Plan Outline has long been available for R&D scientists and includes the basic literature review, objectives, materials and methods, and literature cited sections. Additional sections include the application of research results, which identify who will benefit from the research and how best to communicate the results to these stakeholders. A safety and health section requires documentation of potential safety hazards, how to avoid them, and the appropriate response in the event an accident causes bodily harm. A unique aspect in the methods section of the Study Plan for the Northeastern Research Station's Quality Assurance Plan is the establishment of

Table 3
Scientist responsibilities according to the Pacific Northwest research station's quality assurance plan (U.S. Forest Service, 1999).

Assume ultimate responsibility for data quality, documentation, and interpretation
Arrange for appropriate statistical review and peer review in study planning, implementation, and reporting of research results.
Maintain up-to-date study files, data files, and metadata; and archive upon completion of the work
Communicate quality assurance expectations and standards, including limits of precision and accuracy with technical support staff and research partners.
Establish specific agreements with external research partners regarding quality assurance policies and procedures
Provide timely and thorough monitoring of data collection and documentation activities
Provide appropriate quality assurance/quality control training opportunities to technical support staff
Ensure that research equipment is properly maintained, calibrated, and serviced
Develop or assist in the development of Standard Operating Procedures and Measurement Quality Objectives.

Measurement Quality Objectives (MQOs). MQOs are field equivalents to the laboratory standards, called standard operating procedures, developed by various research institutions (e.g., U.S. Environmental Protection Agency, 2001). MQOs are objective, quantitative statements describing the tolerable level of error (deviation between the true and measured value) in a given measurement. The objective of MQOs is to develop standards, from the literature or experience, against which data quality is measured. MQOs define the level of measurement error that is tolerable to the research question, and the application of appropriate MQOs highlight measurement errors larger than expected, which may help identify problems in the measurement process. MQOs also define the maximum acceptable error size and the percent of the time that measurement error must be less than or equal to the maximum error. The lead scientist is responsible for establishing MQOs for all measurements and is responsible for justifying his or her choice of MQOs. MQOs are explicitly stated in each Study Plan and the scientist determines during the course of the study whether or not collected data meet the MQO. Examples of MQOs are provided in Table 4.

A statistical review is defined as the process in which a qualified statistician reviews sampling plans, analysis procedures, study design, and validity of inference and conclusions (U.S. Forest Service, 1999). Each study plan requires a thorough statistical review by a qualified statistician. The individual must be able to work independently and free of any conflict of interest. Furthermore, as part of manuscript peer review during the publication process, a statistical review may also be necessary.

The peer review process is considered the cornerstone of QA in scientific research (U.S. Forest Service, 1999). Key components of the peer-review process, for study plans and manuscripts, include a technical editor at the Station level in addition to technical reviewers that may be selected by the technical editor or the scientist. Each Station has specific rules for peer review. This review is oftentimes in addition to journal-specific peer-review procedures for submitted manuscripts.

Training is required of all participants to have the knowledge and skills necessary to meet their job responsibilities (U.S. Forest Service, 2000b). Training can be as simple as demonstrating the proper use of tree diameter tapes, including repeated practice by the field research crew, to off-site learning and operation of complicated laboratory analytical equipment. Two important points about training are to train personnel in proper techniques as required by the research, and document when and how the training was accomplished.

Table 4
Examples of Measurement Quality Objectives (MQOs) used in the Northeastern Research Station's Quality Assurance Implementation Plan (U.S. Forest Service, 2002).

Variable	Measurement unit	MQO
Diameter (d.b.h.)	1 cm	±1 cm of true value, 95% of the time
Height	0.3 m (1 ft)	±10%, 90% of the time
Species	Scientific name	No errors, 99% of the time
Tree grade	Tree grade	No errors, 95% of the time

Finally, all research information contained in study files must be archived (U.S. Forest Service, 1999). Copies of all information should be stored at different locations to guard against the loss of information. At present, no standard is available for the types of technology to use in storing archived data, particularly for older studies completed prior to the widespread use of computers. Metadata, that is the structured information that describes data, is expected in all archives to provide sufficient information for a technical expert to understand the way the data were collected, and when and how data use is appropriate (U.S. Forest Service, 1999).

5. QA/QC worldwide

Principles of QA/QC date back to the building of the Egyptian pyramids where specific stone sizes were needed for construction (Millard, 1996). These principles were refined through the centuries, primarily with the evolving engineering profession, as building designs and tools became more sophisticated. QA/QC has also been a guiding force in the medical profession due to the need for accuracy and precision in tests leading to decisions regarding human health. Only recently have QA/QC principles been applied to the natural sciences. While QA/QC has been assumed in the scientific process, one of the first examples of explicit QA/QC guidelines applied to large-scale research projects involved acid rain and other airborne pollutants (Cline and Burkman, 1989; Peterson and Shriner, 2004). Accurate and reliable data from experiments and monitoring programs, ranging from sources of pollution to the deposition of pollutants and their effects on plants, wildlife, and human health, were necessary since results were used in public policy programs and laws. Organizations where QA/QC guidelines were developed and implemented for climate change related research include the European Forest Institute (Bortoluzzi, 2000) and the National Acid Precipitation Assessment Program (NAPAP, 2005). Further, the Intergovernmental Panel on Climate Change (IPCC) serves as a world source of information for policy makers on climate change based on research by numerous scientists (IPCC, 2007).

QA/QC principles are now a common component of research programs worldwide. The International Union of Forest Research Organizations (IUFRO) has several units that explicitly involve QA/QC, including Division 4—Forest Assessment, Modeling and Management, Division 6—Social, Economic, Information, and Policy Sciences, and the Forest Science-Policy Task Force. Quality control testing has shown the need for additional training to ensure measurement consistency in a variety of research including monitoring symptoms of ozone injury (Bussotti et al., 2003), lichen biomonitoring (Brunialti et al., 2002), molecular genetic testing (Dequeker et al., 2001), and forest inventory and analysis programs (Lund, 1998; Burkman, 2008). Quality control testing has led to refinements in QA/QC procedures, leading to the development of standard protocols for a variety of research and monitoring, including forest health (Brooks et al., 1992; Smith and Potash, 2004) and fisheries (Botkin et al., 2000) among others.

Unfortunately, few refereed publications report explicit QA/QC procedures and how results compare to data quality objectives (Oliva and Raitio 2003). These “burdensome” or “boring” results are oftentimes left on final project reports or computer printouts in filing cabinets and not published in the refereed literature. Leininger (1998) reported precision and completeness data quality objectives and achievements for 12 response variables related to oak (*Quercus* spp.) seedling allometric relationships and physiological processes. Greater reporting of QA/QC objectives and accomplishments is needed to ensure soundness in the science and trust with stakeholders. In the future, publication of QA/QC results in the refereed literature may become standard procedure with the implementation of the Data Quality Act of 2001 and other policies and legislation throughout the World. At a minimum, experiment-specific QA/QC procedures and results can be published on the World Wide Web and referenced in individual published articles.

6. Data Quality Act of 2001

The Data Quality Act of 2001 (hereafter referred to as the Act) was an attempt by Congress to ensure that federal agencies use and disseminate accurate information (Bisong, 2003). The Act was enacted primarily in response to the increased use of the internet, which gives federal agencies the ability to communicate information easily and quickly to various stakeholders and the public in general (Federal Register, 2001). The intent of the Act was to prevent harm that can occur when government websites disseminate inaccurate information (Bisong, 2003). Therefore, the Act applies to all federal agencies that are subject to the Paperwork Reduction Act of 1995.

The genesis of the Act resides in two paragraphs inserted within the Treasury and General Government Appropriations Act of 2001, Section 515 (Public Law 106-554, Appendix C 114 Stat. 2763A: 153–154). The Act was designed to ensure that researchers produce high-quality information for stakeholder use. It requires Federal agencies to develop Information Quality Guidelines to accomplish three goals (Guldin, 2004): (1) to establish a basic standard of quality—that is, utility, objectivity and integrity—of information (including statistical information) that agencies disseminate to the public, (2) to establish administrative mechanisms that allow "affected persons" to file a petition requesting the correction of information they feel does not comply with those standards, and (3) to report periodically to the Office of Management and Budget (OMB) on the number, nature, and treatment of complaints received by the agencies regarding the accuracy of information disseminated by each agency. Objectivity is defined as information presented in an accurate, clear, complete, reliable, and unbiased manner. Utility is defined as the usefulness of the information to intended users—any limitations or reservations must be clearly articulated. Finally, integrity involves the security of the information and protection from unauthorized access or revision that leads to corruption or falsification.

Following passage of the Act in 2001, OMB issued regulations in 2001 (Federal Register, 2001) and 2002 (Federal Register, 2002) providing guidance on the implementation of the Act. The U.S. Department of Agriculture then issued Information Quality Activities in response to OMB and the Act (http://www.ocio.usda.gov/qi_guide/index.html). OMB published an additional regulation in 2004 to clarify the peer review process (Federal Register, 2005). The history behind the development of the Act is considered by some to be somewhat suspicious as it was "buried" in the Appropriations Act without legislative hearings, committee review, or debate (Herrick, 2004; CPR, 2005). CPR (2005) stated that "while ensuring high-quality information is a worthy goal, procedural requirements have an important side effect—they slow down the government's capacity to act and, if they are sufficiently burdensome, they can bring government to a standstill." Furthermore, CPR (2005) indicated that quality assurance benefits derived from additional procedures have to be balanced against the consequences to the public of delaying agency action—that striking an appropriate balance between protecting the public and the environment and improving the quality of information is a complex matter. Due to the potential or actual misuse of the Act, it has also been referred to as a "can of worms" (The Water Resources Research Institute, 2004), a "nemesis of regulation" (Weiss, 2004), and "... a tool to clobber every effort to regulate. In my view, it amounts to censorship and harassment." (Weiss, 2004).

The impact of the Act on the Forest Service, and particularly R&D, has been mixed. R&D, with prior knowledge of discussions on research quality assurance preceding the Act, implemented the Quality Assurance Implementation Plan in 1998 using the FRP as a guide (see description above). Research Station Plans, including QA/QC plans, were either implemented or near completion prior to passage of the Data Quality Act. These plans provided adherence to satisfy the first goal of the Quality of Information Guidelines. Therefore, the recent focus within R&D has been on the processes for requesting correction, requesting reconsideration, and reporting the number of complaints regarding the accuracy of disseminated information.

Guldin (2004) summarized the effect of the Act on R&D research scientists as follows:

(1) If the research is not documented, then it does not count. Without documentation, a research scientist cannot prove that the research was actually conducted.
(2) Skipping steps at the beginning of the research process makes a research scientist responsible forever for the research quality.
(3) Study files must be complete, contain appropriate metadata, and be retained in a secure manner. Sloppy record-keeping will destroy a scientist's integrity and credibility.
(4) Peer review is of paramount importance. Having colleagues review study plans and manuscripts and not documenting how you responded is unacceptable behavior.
(5) Relying on journal peer review alone is insufficient. Internal reviews, especially from long-distance colleagues, add a valuable layer of protection.
(6) Researchers should make clear for whom they are speaking by using a disclaimer ... "The views expressed in the paper are mine, and do not necessarily reflect the view of the agency."
(7) Petitions are costly and time-consuming. Forewarned is forearmed, i.e., documenting all aspects of the research process, from planning to publication, will aid research scientists in the event their work is disputed, even to the point of going to court.

In summary, the Data Quality Act was passed as part of the Treasury and General Government Appropriations Act of 2001. The Act was designed to make federal agencies and cooperators more research conscious by making them legally responsible to stakeholders for the knowledge and methods behind knowledge development produced by their research. It also gives U.S. citizens the right to petition government agencies to correct information that is being disseminated that they believe to be factually inaccurate, not objective, inappropriate or not useful, or which they suspect has been tampered with, corrupted, or falsified (Guldin, 2004). Unfortunately, the potential for abuse of the Act, especially by professional conflict groups, is real (Herrick, 2004). As with all relatively new legislation, it will take time, and fine-tuning, before the Act becomes an effective tool for credible science.

7. Case study—pondberry

Pondberry (*Lindera melissifolia* (Walter) Blume) is a rhizomatous shrub that exists as colonies of stems that grow up to two meters tall in seasonally flooded forested ecosystems and the wet edges of sinks, ponds, and depressions in the southeastern United States (Radford et al., 1968; U.S. Fish and Wildlife Service, 1993; Devall et al., 2001). Pondberry has been described as one of the rarest shrubs in the United States (Steyermark, 1949), and was listed as a federally endangered species by the U.S. Fish and Wildlife Service in 1986 as directed by the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service, 1986). A subsequent Recovery Plan, published in 1993 (U.S. Fish and Wildlife Service, 1993), documented the need to acquire additional knowledge on the biology and ecology of this species. The lack of such knowledge has hampered development of strategies to recover pondberry and subsequently remove it from the endangered species list.

Pondberry occurs as isolated populations in seven states across the southeastern United States (U.S. Fish and Wildlife Service, 1993; Schotz, 2005). Though the current and historical extents of pondberry distributions are unknown, the U.S. Fish and Wildlife Service speculates that the present rarity of the species is due to habitat alterations from drainage modification with subsequent changes in hydroperiod and conversion of the habitat to other uses (U.S. Fish and Wildlife Service, 1993).

Although pondberry was described nearly 100 years ago, research on pondberry biology and ecology has been sparse. Most research has been piecemeal based on interests of individual scientists (Wright, 1989, 1990a, 1990b; Devall et al., 2001; Smith, 2003). Until recently, no major concerted effort had been put forth to conduct comprehensive research on the biology, ecology, and effects of forest management practices on pondberry (Aleric and Kirkman, 2005; Lockhart et al., 2006).

Recent pondberry research interest was sparked by the Reformulation Report for the Yazoo Backwater Area in Mississippi (U.S. Army Corp of Engineers, 2000a). The Reformulation Report includes plans to build a 396 m^3s^{-1} (14,000 ft^3s^{-1}) pumping station (Yazoo Pump Project) with a year-round pump operation elevation of 26.5 m (87 ft) NGVD (National Geodetic Vertical Datum) adjacent to the Steele Bayou flood control gate (32.72° N latitude, 91.01° W longitude). A component of the Report included a Biological Assessment to evaluate potential impacts of the Reformulation Project on endangered species, including pondberry. The Biological Assessment concluded that implementation of the Yazoo Pump Project was not likely to adversely impact pondberry, especially on the Delta National Forest (DNF), which is about 50 km northeast of the Yazoo Pump Project, and contains a significant number of pondberry colonies. This assessment was based on research into impacts of backwater flooding and localized hydraulic regimes on the current distribution of pondberry (U.S. Army Corp of Engineers, 2000b, 2000c). The U.S. Fish and Wildlife Service disagreed with the findings of the Biological Assessment regarding pondberry, concluding that the magnitude of reduction in flooding by the Yazoo Pump Project would likely adversely affect pondberry. Part of the disagreement involved the statistical procedures used in inferring the absence of any ecological relationship or effect of flood frequency upon the distribution, abundance, and performance of pondberry (U.S. Fish and Wildlife Service, 2000). One effect of this disagreement was a re-evaluation of the Biological Assessment regarding the Yazoo Pump Project on pondberry.

With an impasse over the role of hydroperiod on the distribution, growth, and development of pondberry, the need for further knowledge on pondberry biology and ecology became obvious. The U.S. Army Corps of Engineers approached the U.S. Forest Service Southern Research Station's local Research Work Unit, the Center for Bottomland Hardwoods Research, located in Stoneville, MS, about conducting research on the biology, ecology, and ecophysiology of pondberry. An Interagency Agreement was signed September 2001 between the U.S. Army Corps of Engineers and the U.S. Forest Service specifying responsibilities between the two agencies regarding funding and conduct of pondberry research. A supplemental Interagency Agreement was signed in May 2002 that included the U.S. Forest Service National Forest system and U.S. Fish and Wildlife Service in addition to the U.S. Army Corps of Engineers and U.S. Forest Service R&D. Therefore, three agency stakeholders became involved in pondberry research. The U.S. Forest Service National Forest system's interests lie in the fact that a large number of pondberry colonies are in the DNF. Forest managers on the DNF need information to aid in their decisions regarding the possible effects of hydroperiod, natural disturbance, and silvicultural treatments on pondberry. Further, all National Forests are required to perpetuate endangered species whenever possible. The U.S. Fish and Wildlife Service is responsible, under the Endangered Species Act of 1973, for providing guidance to ensure no harm comes to threatened or endangered species and to develop plans that lead to the eventual recovery of such species. The ongoing pondberry research studies should provide useful knowledge to aid the U.S. Fish and Wildlife Service with their recovery efforts. Finally, the U.S. Army Corps of Engineers wants to know more about the possible differences in environmental factors, i.e., hydroperiod and light availability, on the distribution, growth, and development of pondberry in the area affected by proposed flood control projects to ensure that future U.S. Army Corps of Engineer activities do not jeopardize this endangered species and assist in the recovery process.

A unique aspect of the pondberry research was the coming together of three Federal agencies to agree on a framework governing the respective responsibilities of each agency regarding the funding and conduct of research on the species. All three agencies will benefit from the scientific knowledge discovered about pondberry, as will state agencies and non-governmental organizations. Under the Interagency Agreement, the U.S. Fish and Wildlife Service was responsible for providing a flooding impoundment facility for research purposes, all necessary maintenance and security of the impoundment facility, technical consultation services, and assisting in obtaining all necessary permits required to conduct research with an endangered species. The U.S. Army Corps of Engineers' responsibilities included funding about one-half of the research costs and providing all engineering and technical support services as necessary on the impoundment facility. Finally, the U.S. Forest Service R&D was responsible for the other half of the research costs, obtaining necessary permits from the U.S. Fish and Wildlife Service to collect cuttings for propagation and to ship plants across state lines, collecting cuttings for plant propagation, mass-producing a planting stock of pondberry in support of the research, and conducting the research in accordance with the approved study plans.

The pondberry research program within the Center for Bottomland Hardwoods Research is divided into two primary thrusts: ecology and ecophysiology. The goal of the ecology research is to understand the ecosystem dynamics and the sustainability of native pondberry colonies in Mississippi. The goal of the ecophysiology research is to determine the interactive effects of hydroperiod and light availability on the growth and development of pondberry seedlings. The ecophysiology research resides at a field location, the Flooding Research Facility (FRF), an impoundment facility that contains 12, 0.4-ha cells that can be artificially and independently flooded to desired levels for specific periods of time. Pondberry plants growing in each impoundment cell were exposed to three different levels of light availability created by artificially manipulating natural sunlight using shadecloth. Further information on the FRF and associated treatments was detailed in Lockhart et al. (2006).

All pondberry research is subject to the Southern Research Station's QA/QC policies. Achieving, or even exceeding, standards set forth in the QA/QC plan was critical to our pondberry research because pondberry is an endangered species and environmental-activist-organization stakeholders have made clear their intent to sue the U.S. Army Corps of Engineers to stop the Yazoo Pump Project. For example, MQOs were developed for the various field measurements, including seedling heights and caliper diameters taken in the ecophysiology studies (Table 5). Environmental monitoring equipment and laboratory balances were calibrated by respective manufacturers, and log books kept to ensure maintenance of these standards. Field crews were specifically trained in proper plant maintenance techniques and the importance of quality measurements that are repeatable. Consistency in achieving the prescribed standards was the responsibility of senior principal investigators to assure the goal of providing the highest quality biological information about pondberry that could be used by stakeholders to determine best management practices.

Table 5
Examples of Measurement Quality Objectives (MQOs) used in the pondberry ecophysiology research program.

Variable	Measurement unit	MQO
Stem diameter	0.1 mm	±0.5 mm of true value, 95% of the time
Stem length	1 cm	±10%, 90% of the time

8. Conclusions

Challenges to research quality are becoming a daily fact of life. Examples of scientific misconduct, e.g., the incident over Canadian lynx (*Lynx canadensis*) research, have made headline news stories and further reduce the credibility, not just of the individuals involved, but, of the scientific profession as a whole (Stokstad, 2002). Scientists are no longer trusted on the basis of their training and position, and scientific research is no longer accepted *ipso facto* by the public. "Just as land managers of public forests have seen their decisions challenged repeatedly in court, scientists are now confronted with the same tactics from professional conflict groups who may not like the science that supports the management, so they attack the science on the basis of process issues" (John Stanturf, USDA Forest Service, Project Leader and Research Ecologist, Athens, GA, USA, pers. com. 20 June 2005). The Data Quality Act of 2001 will eventually help science because it is a mechanism to encourage the production of high quality science. Fine-tuning provisions of the Act is needed to prevent possible widespread abuse to circumvent the regulatory process. The Act will also provide accountability for how public money is used in research. Scientists "can no longer afford to do science for the sake of science or for the edification of scientists; the public wants to see value for their dollar" (Stanturf, pers.com. 20 June 2005). In essence, the Data Quality Act may have an impact similar to the Freedom of Information Act of 1966 (as amended in 2002). Adherence to the Act will be a time-consuming, but necessary, process for the integrity of the various scientific disciplines. Without research quality assurance and quality controls, the integrity of science may be compromised among various stakeholders agendas.

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