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When peer-reviewed publications are not enough! Delivering science for natural resource management

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ABSTRACT

Over the last century, natural resource management on forest lands has shifted from a singular focus on resource extraction to many foci, such as recreation, tourism, conservation, view-scapes, cultural and spiritual values, sustainability, and other values. As a result, the information needs of land managers must now include social and cultural values. In addition, the public's interest in having greater participation in land management decisions and in generating scientific knowledge has never been greater. The generation of scientific knowledge which is expressed primarily through conventional means – such as peer-reviewed publications targeting academics and technology transfer (e.g., patents, licenses, agreements) primarily for government and industry – does not always satisfy the needs of resource managers and public. In recent decades, there has been rapid growth of methods to help bridge this gap by better connecting new knowledge and knowledge generation with public needs. The U.S. Forest Service is making *science delivery* as important goal as science creation, including structural institutional changes at the interface among researchers, resource managers, and the public, allocating an appropriate portion of project funding specifically for delivery. The Forest Service is considering increasing its use of *citizen science* and *participatory research* – which brings resource managers, decision makers, and the public into the research process to varying extents – as part of the agency's science delivery efforts. Here we explore citizen science and participatory research as possible vehicles to augment existing science delivery efforts from the perspective of a federal land management agency. We found that these mechanisms facilitate public involvement in fundamentally different ways. Depending on the type of research and desired use of research outcomes, either citizen science or participatory research could enhance the use of science in some natural resource management discussions, possibly leading to supportable solutions.

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1. Introduction

Aldo Leopold in "A Sand County Almanac" published after his death in 1949, describes the extensive reshaping of entire ecosystems he witnessed during his lifetime when natural resource extraction was a social priority with often ignored or unnoticed negative consequences. Increased demand for housing after World War II shifted the Forest Service's custodial role, since its inception in 1905, to one emphasizing timber production on public lands during the postwar development era in America (1946–1959). Leopold described then that scientists and public were just beginning to "understand the complexity of the land organism" and that land management needed to be more holistic to be sustainable. He was among the first American academics to describe the stirrings of what would be new discussions for how lands should be managed—a "land ethic."

Since that time, others have continued the discussion. In the multiple-use management era (1960–1969), more people began to recognize that population growth, environmental challenges, and increasing global demand for wood, fiber, fuel, clean water, and a host of ecosystem services pose significant challenges to the sustainable management of the world's renewable natural resources. In the United States, there began to be widespread public dissatisfaction over the practice of clear-cutting (Bliss, 2000). This issue would later come a head in the early 1970s, on the Monongahela National Forest in West Virginia when a lawsuit was filed against the agency, sparking what would be called the "timber wars" (Steelman, 2001; Bosworth and Brown, 2007).

In the late 1960s and 1970s, environmental advocacy came to the forefront of forest resource management discussions, ushering in an era of public participation (Steelman and Ascher, 1997; Steelman, 2001). It was during this era that a number of landmark legislative acts were passed by the U.S. Congress, such as the Clean Air Act 1970, Clean Water Act 1972, National Environmental Policy Act 1970, and National Forest Management Act (NFMA) 1976. These new laws

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brought about unprecedented environmental protections and levels of public participation in forest management. In fact, NFMA, also referred to as the 'experiment in democratic government,' was crafted by Congress to provide a remedy for public tensions over the Forest Service's then widespread practice of clear-cutting (Steelman and Ascher, 1997; Steelman, 2001). Farnham et al. (1995) documented continuation of the shift in emphasis from timber production to non-commodity resources through the mid-1990s, a trend which appears to continue to the present day.

Since 1993, ecosystem management has dominated discussions focused simultaneously on conservation of ecosystems and their sustainable use for public needs (Haeuber, 1998; Yaffee, 1999). This increasingly holistic view more explicitly values ecological, economic, and social systems. Ecosystem management has evolved into the concept of ecosystem services, a notion that places value on non-commodity processes that have value to the broader community (Costanza et al., 1997; Haeuber, 1998). The ecosystem service concept encourages the protection of ecosystem functions by defining and valuing services that ecosystem provide to society. The evolution of the focus of forest management toward ecosystem services coincided with increased understanding of and appreciation for the complexity and essential functions of ecosystems. Analysis of ecosystem services and consequent attempts to quantify their values has increased the attention being paid to the effective assessment of contemporary issues such as landscape conservation, mitigation of global climate change, and maintenance of water quality and quantity. Speth (2010) eloquently captured the need for accurate assessment of ecosystem service values — "Honest prices will ensure that people take into account the environmental and social impacts of their purchases, whether they are environmentally conscious or just minding their pocketbooks."

Discussion on America's land ethic continues to this day and will certainly continue to evolve. Often this discussion is expressed in the judicial system by groups wanting to suspend forest management activities that are perceived to not be aligned with their view of a land ethic (Steelman and Ascher, 1997). This highlights the fact that forest management necessarily takes place within a greater economic and social context — both are key dimensions of sustainability which have often been ignored (Pretty and Ward, 2001). The U.S. Forest Service has gained a greater appreciation of this ongoing discussion as a variety of forest management plans now depend on integration and synthesis among natural scientists, social scientists, managers, policymakers, and the public that they serve (Valfer et al., 1977; DeLeon and Steelman, 2001).

The mission of the U.S. Forest Service, carried out through five program mission areas (National Forest System, State & Private Forestry, Research & Development, Business Operations, and International Programs), is to sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations. Through the National Forest System, the agency manages 78 million ha of national forests and grasslands while sharing responsibility with state and local agencies for stewardship on approximately 224 million ha of nonfederal rural and urban forest land via State and Private Forestry (USDA, 2009a). The International Programs mission area works with partners across the globe in support of sustainable forest management.

Research provides the technical foundation for sound and sustainable forest management. The Forest Service Research and Development (R&D) mission area focuses on development and communication of the scientific information and technology required to manage, protect, use, and sustain natural resources in forests and on rangelands. Research conducted on 83 experimental forests and rangelands provides a scientific foundation that informs forest management for all Forest Service mission areas. Forest Service research is also utilized by other groups (e.g., the forest industry and state agencies). Research findings are translated into operational practices and policies through the process generically referred to as technology transfer.[1] The process normally *begins when research concludes* (often with a publication or, in the case of wood product development, a patent or license); results are used as a basis for development of management tools (e.g., stocking guides to ensure maximum tree growth, sedimentation guidelines to insure water quality, etc.). Technology transfer, which may not involve the scientists who conducted the original research, concludes with training of users to apply those tools.

Target audiences for technology transfer have typically consisted of professional foresters and managers with an expert knowledge base in related sciences. The internet has effectively expanded the audience to include a diverse and diffuse (in terms of geographic location as well as technical background and interest) array of individuals, many of whom may not have technical expertise or want or need only a cursory understanding of the material. Currently, there is no means in place to assess the degree of forestry and ecology knowledge of these users. Consequently, the emphasis has shifted from technology transfer to science delivery, where information is presented for use by the general public and is easily accessed through the Internet or libraries (e.g., USDA, 2009b, c). The key feature that distinguishes science delivery from technology transfer (the boundary can sometimes appear indistinct) is that science delivery entails professional attention to packaging the information for use by the nonprofessional public while technology transfer usually involves training professionals by scientists in a continuing education setting.

The Forest Service is exploring the potential for including the public at some or most stages of the research process to enhance science delivery (GAO, 2010; USDA, 2009b). One of the expected advantages of including the public in the research process is more accurate identification and characterization of complex environmental problems, a prerequisite for effective management (Petrokofsky et al., 2010; Fortmann and Ballard, 2011). Also, public inclusion could increase ecological literacy and scientific transparency (Ananda and Herath, 2003; Bonney et al., 2009; Dickinson et al., 2010; Groffman et al., 2010). Some practitioners of participatory approaches believe that there will be greater public support for subsequent management interventions and conservation goals based on outcomes of the research (White, 2001; Thompson et al., 2005; Cooper et al., 2007; Dickinson et al., 2010; Ottinger, 2010; Sekloca, 2010; Cheng et al., 2011; Talwar et al., 2011). John Dewey, an early American philosopher (1859–1952), argued that a complete democracy requires an educated and fully informed public, which is accomplished only through communication among citizens, technical experts, and decision-makers (Dewey, 2009). We describe two new popular processes that facilitate public involvement in research: citizen science and participatory research. Both are characterized by public engagement, but differ greatly in form, function, goals, and philosophical underpinnings.

The objective of this paper is to explore the potential for increasing public involvement in research as a means to broaden and deepen the impact of science delivery. This article is intended be viewed from the perspective of a federal agency which has both research and natural resource management functions. This paper is not intended to be a comprehensive review or research article, but rather a synthesis of our observations as scientists and senior science administrators. All of the authors received their advanced degrees and have conducted research in biophysical sciences, thus this paper is written from this perspective. Our observations are informed, in part, by extensive formal (interviews) and informal conversations (e.g., at national scientific meetings) with about thirty practitioners of citizen science and participatory research in both private and public sectors. Following a brief history of management focus within the agency, we present an overview of

[1] According to the Federal Laboratory Consortium Technology Transfer Desk Reference, 2011, "technology transfer is the process by which existing knowledge, facilities, or capabilities developed under federal research and development funding are utilized to fulfill public and private needs." Available online: http://www.federallabs.org/pdf/T2_Desk_Reference.pdf

several science-based decision models based on conventional science, citizen science, and participatory research processes. We then discuss the viability of citizen science and participatory research for the agency based on the need for such approaches, barriers to their use, and ability to remain true to differing needs of these approaches.

2. Despite the explosive growth of science, knowledge gaps widen between science and natural resource management

Changing societal values and increased demands on forest resources, exacerbated by increasing population pressure and global climate change impacts, have made forest management more challenging. Consequently, the research required to inform effective forest management has increased in complexity, requiring greater scientific knowledge and more sophisticated technological tools. Some of these changes are reflected in the advanced qualifications of scientists. Before the 1970s, Forest Service scientists (and academic scientists as well) with M.S. degrees were not uncommon. Scientists typically spent a great deal of time directly interacting in the field with managers, technical staff, and individuals external to the Forest Service. The users of Forest Service research were easy to identify — the managers and landowners with whom scientists and researchers directly interacted; technology transfer occurred seamlessly through direct and ongoing contact. Interestingly, the management model of those early years strongly resembled what we currently call the participatory research-based decision model (Fig. 1), but without non-industrial public users. During the 1960s, the number of Ph.D.s awarded annually in life sciences increased dramatically (Alberts, 1999). As the complexity of research increased in forest related sciences, mid- and late-career scientists returned to universities to pursue Ph.D. degrees during the 1970s, and the Ph.D. was required for new scientists. Currently, most Forest Service Research Grade scientists have doctoral degrees, paralleling the trend in academia.

One important result of the advancement in scientific capacity was increased emphasis on peer-reviewed publications in the scientific enterprise. Forest Service scientists, along with their academic counterparts, increased their professional interactions external to their local field interests, presenting papers within their professional societies and participating in more basic (fundamental) research. Although this raised the level of science and apparent productivity under what we call the conventional science-based decision model (Fig. 2), this came at the expense of having less time and fewer incentives to interact with field personnel, managers, and the general public. In a recent survey of 268 scientists from 29 countries involved in some type forest related research, only 15% of respondents perceived peer-reviewed publication as an effective means to promote conservation or development (Shanley and Lopez, 2009). However, the survey also indicated that few scientists were engaged in activities that they perceived as necessary for the success in conservation and development. Widening this divide, it was believed that research should be done without public engagement to prevent bias (starting around the 1960s), especially with potentially controversial or sensitive information (Steelman, 2001; Robertson and Hull, 2003; Nie, 2004). It is unclear if the rise of PhDs during this period was, in part, a reaction to this changing social context.

Over the last 30 years, there has been a considerable shift in knowledge demands by public users (Innes, 2005). The Forest Service's Research & Development Program, which had served as a primary source of funding for the academic research community as well as its own researchers, began to compete for external research funding with the academic community as budgets supporting internally funded research began to shrink around 1980. The reward model for Forest Service researchers became more closely aligned with that of their academic counterparts (OPM, 2006). In this model, the scientist identifies researchable problems (often without direct public input), develops testable hypotheses, oversees data collection, analyzes results, and produces scientific reports and refereed publications. The time demands for execution of these activities necessarily limit the amount of time available for interacting with managers and field personnel in assessing needs and delivering knowledge. Today,

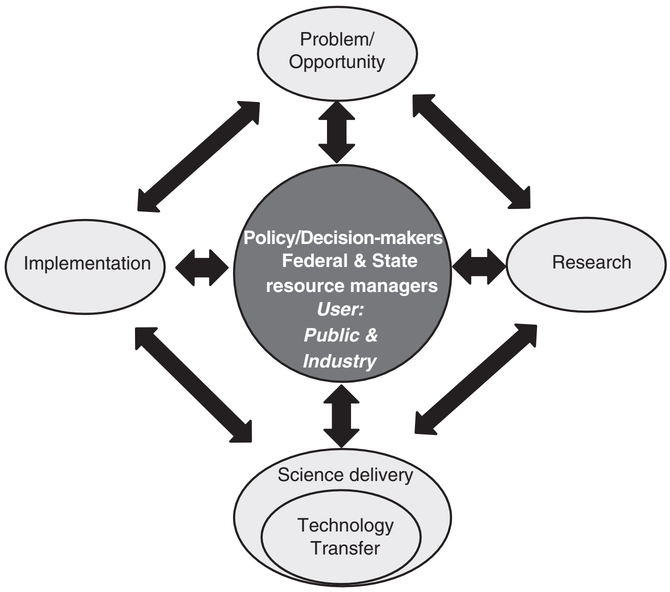

Fig. 1. The participatory research-based decision model used to translate research results into practices. In contrast with the conventional and citizen science-based decision models (Figs. 2 and 3), identification of the problem/opportunity and research process is shared among scientists and various public users. Science delivery strengthens connections among the various users, knowledge generation, and options for possible implementation based on research outcomes. Participatory research ensures that users are at the center of the decision process. It is believed that management actions based on participatory research outcomes will have greater public support.

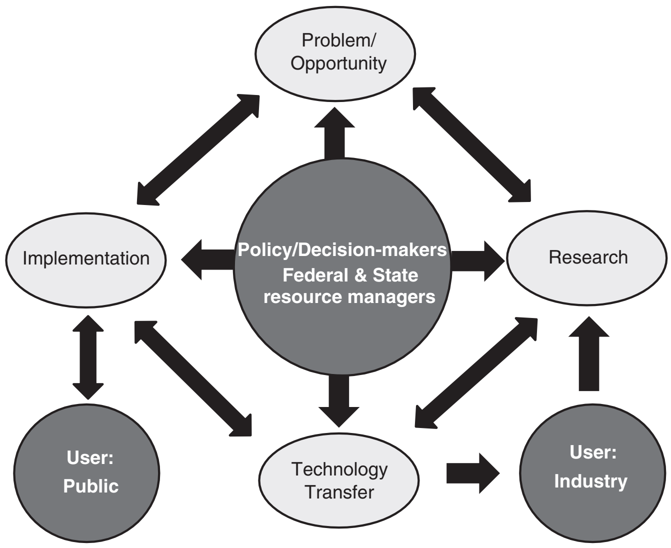

Fig. 2. The conventional research-based decision model used to translate research results into practices. Identification of the problem/opportunity, research, and science delivery is primarily the domain of the scientist. Non-industrial public users are largely absent from research cycle or present only at the beginning and/or end. Although industrial users are well served by conventional forms of technology transfer, non-industrial public users are not. In addition, the scientist may identify a problem or opportunity and solutions that does not align with users' needs nor useful for management. In a natural resource management context, the public user's lack of awareness of the problem or opportunity and limited access to the knowledge produced from the research may limit the application as well as trust in new knowledge. Direct public input and knowledge exchange with the public typically occur after options for implementation have already been formed.

conventional research is primarily driven by federal funding agencies (e.g., U.S. National Science Foundation, U.S. National Institutes of Health) responding to questions centered broadly on public interests posed by U.S. Congress, industry, and the scientific community. As the U.S. forest-based industries consolidated and supply from international sources began to fill wood shortages, the need for technology transfer associated with forest products (e.g., production forestry) in the United States has diminished. Shanley and Lopez (2009) reported that less than 3% of the 268 scientists they surveyed ranked industry as an important audience for their work; instead, 34% of the respondents ranked scientists as the most important audience.

The composition of potential public users of Forest Service research has also changed. Ownership of industrial forest lands has changed dramatically during the past decade. For example, Fernholz et al. (2007) show that timber investment management organizations (TIMOs) and real estate investment trusts (REITs) control nearly 5% of the total forestland in the United States and about 7% of the timberland as a result of industrial divestiture of lands. Forest industry had been an important consumer of Forest Service research; the degree of interest in research from TIMOs and REITs appears to be minimal.

The increased complexity of science, combined with an incomplete understanding of who uses research, poses added challenges for conventional forms of technology transfer (Thompson et al., 2005; Groffman et al., 2010). When scientists routinely interacted directly with land managers and landowners, the users of Forest Service research were obvious. Current users, by contrast, appear to be widely dispersed and largely undefined. Sixty-nine percent of U.S. timberland is privately owned (20 percent corporate, 49 percent noncorporate) (Smith et al., 2009), representing a potential user base for Forest Service research. Many users may not own any forest land, but may still seek information on management and conservation for personal interests, or to be able to better provide input to policy issues they are concerned with. Currently, the only readily available measure of their degree of interest in and use of Forest Service research products is the number of times that Forest Service websites are accessed (i.e., number of hits). In an attempt to reach this client base (ranging from the untrained public to professional resource managers), technology transfer is evolving into a process more fittingly referred to as science delivery.

The need for a strong Forest Service focus on science delivery is supported by results from an agency survey designed to assess the delivery of science (USDA, 2009d). Results indicated a relatively high level of user satisfaction with the quality of the science and competence of the researchers. However, the relevance of the research and communication, which had a large impact of customer satisfaction, was not as highly rated. The knowledge gap between science and natural resource management, however, is a well characterized problem of the institution of modern science (McNie, 2007; Shanley and Lopez, 2009; Sunderland et al., 2009; Arlettaz et al., 2010; Cabin et al., 2010; Esler et al., 2010; Groffman et al., 2010; Sessa and Ricci, 2010). Senior Forest Service leaders and some agency scientists are exploring ways to address these issues, focusing on improving the effectiveness of delivering knowledge (GAO, 2010).

3. Science delivery — increasing conduits for exchanging knowledge

The science delivery concept evolved from a process referred to as technology transfer. Before widespread distribution of personal computers and ease of Internet access, technology transfer was straightforward. The main vehicles of technology transfer were use of patents, licenses, release of public varieties, and cooperative research and development agreements (CRADA). Identity of the users as well as their needs and modes of accessing Forest Service research was well known. Mailing lists of users, maintained and frequently updated by the Forest Service, were used to contact and inform users of new research products. Workshops and field courses in which researchers interacted directly with users in the field, typically industry, were common.

That technology transfer model was successfully adopted by industrial forest cooperatives (co-ops). Housed within forestry departments at research universities, industry-supported academic researchers worked together, applying science to address industrial forest management issues related to tree production and environmental quality. Individual co-ops organized around a central theme (e.g., forest fertilization, genetic improvement, and hardwood silviculture) were guided by advisory committees composed of co-op members. Scientists provided publications geared toward forest managers and routinely led field workshops. Advances made in commodity production and continuing support for co-ops across the United States attest to their success. The research emphasis of many co-ops has shifted towards assessing management impacts on ecosystem function, reflecting the general trend across the United States.

Technology transfer underwent a large change in response to the decline of industrial users and expansion of personal computing and ease of Internet access, which provided a less costly and seemingly more efficient means for disseminating Forest Service research. Maintenance and updating of mailing lists were no longer necessary; effort was shifted to updating and maintaining the websites that serve as the primary access point for Forest Service publications. The responsibility for making users aware of new results effectively shifted to the users themselves. Forest Service research publications are freely available to anyone with a computer and connection to the Internet. However, many individuals lack effective Internet access because of a lack of physical access or technical knowledge; thus, they are not well served by reliance on technology.

Reliance on the web as a primary means for disseminating new knowledge has reduced the visibility of the interactions with the public and other users. As a result, the Forest Service has limited capacity to identify research users. The only information easily obtained is number of downloads or hits on a web site. It is challenging enough to provide effective service to clients when their identity and location are known; without that information the task is daunting. Instituting a web registration processes could provide more information about the users.

The fact that 69% of U.S. nonindustrial timberland is privately owned (Smith et al., 2009) suggests a potential need for relevant research for non-industrial public interests. Past research that has focused on commodity production has been successful within the parameters of the explicit goals of that research. There is a wealth of knowledge available to inform sustainable timber production for a variety of species across the United States. However, small nonindustrial private landowners are more interested in non-commodity values than in timber production (Farnham et al., 1995). Research focused on ecosystem services and sustainability likely will serve their interests more than research focused on commodity production. Science delivery is poised to play an important role.

Science delivery as considered here refers to the process of transferring and disseminating new knowledge produced from research to various user groups — expanding the audience beyond those traditionally reached by technology transfer (Figs. 1 and 3). Science delivery has the potential to connect a much wider variety of users with new knowledge — leading to new uses. For example, the National Forest Management Act requires opportunities for public review and comment with any management activity and planning on public lands. However, the public may lack access to relevant knowledge, technical expertise, and context of the science which underpins management activities. Some potential science delivery tools, by promoting public participation into research processes, could lead to supportable solutions and better management through increased science literacy and access (Bonney et al., 2009; Ottinger, 2010). Next, we explore two potential tools to first bring users into the research process and possibly later into science-based decision processes.

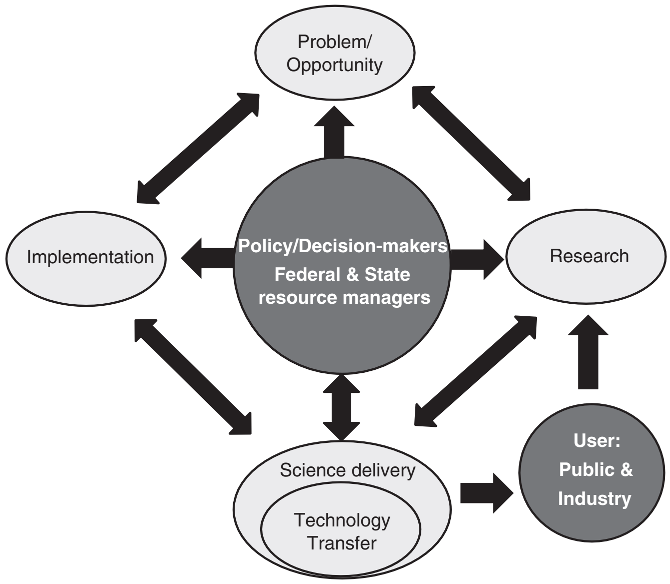

Fig. 3. The citizen science-based decision model used to translate research results into practices. Here science delivery includes the use of citizen science, proving a direct link to non-industrial public users. This creates more avenues of knowledge exchange and increased opportunities for education and science literacy for the public. Scientific and decision processes remain largely unchanged compared with the conventional research-based decision model (Fig. 2).

4. Connecting users with science: citizen science and participatory research

We found that the terms citizen science and participatory research are often conflated although they are different models which differ fundamentally in participation, process, and goals (Table 1). Others have also characterized the distinction between citizen science and participatory research (Robertson and Hull, 2003). Citizen science closely resembles the process and goals of conventional research and might be broadly characterized as an extension in researchers' capacity, "researchers" being scientists and public (Fig. 3). By contrast, participatory research might be characterized as democratization of the research process, whereby the public that uses the information is directly involved in the how and why the research is undertaken, with the intent of direct implementation based on research outcomes (Fig. 1). Next, we provide the historical context of citizen science and participatory research and their contemporary use. We then discuss their potential use by the agency, barriers to their use, and provide some examples of their successful use and potential application.

4.1. Citizen science

Citizens have played a role in producing scientific knowledge for hundreds of years (Couvet et al., 2008). Many early major scientific discoveries were made by amateur researchers, such as Michael Faraday, Gregor Mendel, Thomas Edison, and Albert Einstein. Today, expert scientists conduct most research. Scientists are responsible for formulating testable hypotheses, experimental design, data collection, analysis, and interpretation. Data collection, however, is usually done by technicians, students, interns, and postdoctoral scientists, but quality control and assurance, although shared, are ultimately the responsibility of the scientist. Data collection and processing are where citizens can have a substantive role in research (Dickinson et al., 2010). Some disciplines have not lost touch with the amateur researcher (e.g., ornithology, astronomy, atmospheric sciences) and others are trying to increase them (e.g., ecology) (Greenwood, 2007; Cohn, 2008; Sullivan et al., 2009; Dickinson et al., 2010).

Citizen science is based on the conventional research model, but differs with who collects the data and how the knowledge is exchanged (Table 1) (Couvet et al., 2008; Bonney et al., 2009; Silvertown, 2009; Dickinson et al., 2010; Wiederhold, 2011). The scientist maintains all responsibilities and processes as researchers using the conventional model. However, many citizen science projects, particularly those done by non-governmental organizations (NGOs), do not explicitly test scientific theory, but rather focus on biological or "surveillance" monitoring (Dickinson et al., 2010; Wiersma, 2010). Monitoring serves an important purpose of providing baseline information and sometimes detection of rare species or uncommon conditions (Yoccoz et al., 2001; Nichols and Williams, 2006; Dickinson et al., 2010; Ingwell and Preisser, 2011; Snall et al., 2011). Also, many NGOs use citizen science as a mechanism to engage the public and place less emphasis on publication in scientific journals. Methodologies are often just as rigorous as conventional research which allows researchers to produce peer-reviewed publications and gives additional credibility to the research outcomes (Galloway et al., 2006; Cohn, 2008; Dickinson et al., 2010; Crall et al., 2011). Many NGOs use citizen science as a method to educate volunteers on the topic, which is typically oriented towards conservation (Nichols and Williams, 2006). Citizen science broadens the reach of science by deliberately creating mechanisms to engage and educate the public (Bonney et al., 2009). Social scientists are assessing the effectiveness of citizen science for facilitating positive environmental change and use of the information generated by citizen science by decision-makers (Brossard et al., 2005; Conrad and Hilchey, 2011; Jordan et al., 2011).

There are many benefits using citizen science for the scientist (Wiederhold, 2011). Some scientists seek out volunteers to expand the spatial and temporal scope of data collection (Devictor et al., 2010; Conrad and Hilchey, 2011; Snall et al., 2011). Volunteers can greatly increase the rate of data collection and keep costs low. In addition, researchers can benefit by gaining valuable local or traditional knowledge which may aid in interpretation (Ballard et al., 2008; Dickinson et al., 2010; Fortmann and Ballard, 2011). In ornithology, a number of bird monitoring organizations have relied on citizen science for decades to enhance the scope of their data collection and scientific productivity (Cohn, 2008; Sullivan et al., 2009; Dickinson et al., 2010). For example, the North American breeding bird survey has generated approximately 500 scientific publications since 1966 with nearly 3000 participants (Dickinson et al., 2010). The National Audubon Society's annual Christmas bird count, with as many as 80,000 volunteers, is one of the largest citizen science programs in the world (Cohn, 2008). Also, Earthwatch, an internationally based NGO, recently worked with volunteers to collect data on nearly 150,000 trees with about 2200 participants, which would take a single researcher nearly 60 years to collect (Shetty, 2011).

Funding for citizen science projects is available from NGOs and some U.S. Federal agencies. For example, the U.S. National Science Foundation's Division of Research and Learning in Formal and Informal Settings (DRL) explicitly funds citizen science projects. Some Forest Service scientists have used citizen science extensively in their research programs. In addition, the agency recently published a report on how to conduct biological monitoring with volunteers, a form of citizen science (Pilz et al., 2006). Some researchers have suggested that using citizen science makes it easier to satisfy the "broader impacts" requirements of some federal funding agencies and may improve internal agency researcher evaluations.

The only barriers to citizen science that we have identified are that many projects are not conducive to using volunteers owing to the need for extensive training or that primary data collection is not needed (Dickinson et al., 2010; Kleinman et al., 2011; Parsons et al., 2011). In addition, some researchers are just uncomfortable with working with volunteers or think that it will take too much time given the context of their professional reward structure (Shanley and Lopez, 2009).

Table 1
Comparison of some major attributes of conventional research, citizen science and participatory research. Conventional research emphasizes knowledge generation in which the public user is often absent or very limited. Research outcomes from conventional research are generally not intended to inform non-technically oriented users, decision-makers, or resource managers and often not intended to directly inform choices for carrying out research outcomes. Citizen science uses public in conventional research, typically by including volunteers in data collection. Scientists can benefit from having more robust data sets where large amounts of data are needed over space or time. The most visible public benefit is greater science literacy. By contrast, participatory research emphasizes the needs of local public users by engaging them throughout the science-based decision process (Fig. 1). Knowledge generation is a shared domain of the public, professional resource managements, policy and decision-makers. Participatory research focuses on generating socially supportable management and action with research outcomes.
(Portions adapted from Cornwall and Jewkes, 1995).

	Potential knowledge generation pathways for science delivery		
Attributes	Conventional research	Citizen science	Participatory research
What is the research for?	Understanding with potential applicability for management	Understanding/public engagement and literacy, with potential applicability for management	Understanding/public engagement and literacy, explicit applicability for social or management action
Whom is the research for?	Explicit or implicit public interest, institutional, personal and professional interests	Explicit or implicit public interest, institutional, personal, professional and public interests	Explicit public interest
Whose knowledge counts?	Scientist's	Scientist's/Public's	Public's
Topic			
Origin	Congress, federal funding agencies, private institutions	Congress, federal funding agencies, private institutions	Local people but can be shared
Influences	Congress via funding priorities, institutional agendas, professional interests	Congress via funding priorities, institutional agendas, professional interests	Public or private funders, special needs
Methodology primarily chosen for…	Scientific rigor	Scientific rigor, sometimes public engagement and learning	Empowerment, mutual learning
Research cycle	Iterative in the domain of science	Iterative in the domain of science	Iterative in the domain of management
Primary research purpose	a priori hypothesis testing	Monitoring and fundamental biological understanding	Problem solving
Motivation			
Scientist	Self	Self (enhanced data collection)/ passion for science education and communication of conservation perspective	Self and desire to promote positive social action
Institution	Funding and reputation	Funding, reputation, education and potential espousal of conservation perspective and recruitment	Funding, reputation and enhanced capacity to promote positive social action
User	Access to best available science	Increase knowledge, satisfy curiosity, sense of service, personal pursuit	Tailored solutions
Stages of the research process			
Problem identification	Researcher/resource manager	Researcher, environmental NGO	Shared with local public and scientist
Data collection	Researcher, enumerator	Researcher, enumerator, public	Local public
Interpretation	Researcher — disciplinary concepts and frameworks	Researcher — Disciplinary concepts and frameworks	Shared: Researcher and local public — social and environmental context
Analysis	Researcher	Researcher, sometimes public	Shared: Researcher and local public
Presentation of findings	Researcher — various professional media	Researcher — various professional and public media, strong educational/ outreach emphasis	Shared: various media — process requires bidirectional communication and feedback
Research outcomes			
Action on findings	Not a priority	Typically not a priority	Integral to the process
Who takes action?	Policy/decision-makers, external agencies	Policy/decision-makers, external agencies	Local public with/without external support
Who owns the results?	Researcher	Researcher	Local people but can be shared
What is emphasized?	New knowledge, application of knowledge	New knowledge, application of knowledge	New knowledge and application of knowledge leading to action

4.2. Participatory research

Participatory research, sometimes called participatory action research, occurs when scientists with public participants apply their knowledge, skills, and expertise to real-world problem solving. Participatory research in natural resource management is based on the idea that community members, land managers, and natural resource users have a fundamental right to play a role in decisions about access to resources and environmental quality. Participatory research draws its strength from the recognition that community members' supportive involvement and site-specific knowledge are crucial in crafting and implementing sustainable solutions to local problems related to natural resource management.

Some of the earliest applications of participatory research were developed in the 1960s to help oppressed or marginalized communities to become aware of the political and social mechanisms that were contributing to their subjugation (Mayo and Craig, 1995). This "consciousness raising," particularly in developing countries, was framed as research; if it had been called "education," community members might have seen themselves as the objects of scrutiny instead of participants.

Throughout the 1970s and 1980s, the practice spread to the United States, particularly among researchers working with poor farming communities and issues of environmental justice (Shepard et al., 2002; Lengwiler, 2008). Participatory research continued to take root in many developing countries as a means of improving local decision-making. Researchers focused on capturing local and traditional knowledge about natural resources and management that might not have been empirically deducible. Research success was measured via an "empowerment" standard – boosting community capacity to conduct research – or a "functional" standard – transmitting technology or knowledge between the expert researcher and the community (Sutherland, 1998). Some United States federal agencies began using or supporting participatory research to better respond to public issues and gain access to information or collect data that would not otherwise be available, such as data that can only be collected by participants (e.g., patterns of illicit drug use). For example, the U.S. Agency for International Development has been using participatory research in developing nations since the early 1980s (USAID, 2007). World health organizations, including the U.S. National Institutes of Health, also recognize and currently fund participatory research methodologies to address public health issues.

Due to an increasing diversity of participatory research approaches by different disciplines over the past 30 years, there is a lack of clarity within the academic and scientific communities about the term's meaning and its place in advancing scientific knowledge, particularly for natural resource management. Participatory research has been adopted by researchers investigating everything from farming, to health issues, to sustainable agro-forestry, with the degree of "participation" ranging from minimal stakeholder participation to fully integrated community participation in knowledge creation.

The definition of participatory research varies widely among researchers and practitioners (Chambers, 1994). Much of the inconsistency centers on the level of public participation in the research process and the ultimate role of these public participants in decision-making. The following definition reflects our synthesis of current opinion but retains the historical elements of its original implementation (Cornwall and Jewkes, 1995). We were unable to identify any consistent and universally accepted definition of participatory research, therefore for the purposes of this report we have attempted to define it based on consensus of current literature, funding agencies, and scientists self-described as engaging in participatory research.

Participatory research refers to a set of methodological tools designed to include the public in research processes to varying degrees and then later in management decisions (Rocheleau, 1991; Greenwood et al., 1993; Everett, 2001; Pain and Francis, 2003; Krishnaswamy, 2004; Sheppard, 2005; Ballard and Belsky, 2010; Sessa and Ricci, 2010; Biegelbauer and Hansen, 2011). Research in any discipline using the appropriate or "best available" scientific methodology could potentially be defined as participatory research, provided that it satisfies four central elements: 1) the research builds capacities of groups or communities, including those who may have reduced access to information; 2) all participants (i.e. public, stakeholders, researchers and decision-makers) engage in the generation and exchange of knowledge; 3) the research answers relevant questions in the service of the local community and explicitly informs decision-making; and 4) methodologies facilitate public participation at all stages of the decision process, from identification of the issues or opportunities to ultimate implementation of research outcomes; in effect, this process is co-driven by the public (see Table 1). We believe that participatory research describes a fundamentally different research-based decision model (compare Figs. 1–3), rather than a radical departure from the scientific process.

Participatory research methodologies are typically highly iterative approaches (sometimes changing after reflecting on preliminary information or mid-study) in which stakeholders are fully integrated into all aspects of the research cycle, including identifying the problem/opportunity; assisting in experimental design; collecting and interpreting data; reflecting on how new information could be implemented or used to take action; and, ultimately, taking an action (Rocheleau, 1991). Some researchers also view non-iterative approaches with minimal stakeholder input similar to conventional research designs as a form of participatory research, such as biological monitoring. We suggest, depending on consideration of other attributes (see Table 1), that citizen science is a more appropriate term for such a process. Researchers, however, do not agree upon one methodology; in fact, according to Sutherland (1998), one of the "strengths" of participatory research is the "range of options" the framework presents to best meet community needs. Effective methodologies are still being developed and refined.

The research outcomes derived from the participatory research processes in the past did not necessarily lead directly to publications, the standard metric today for evaluating researcher productivity and quality, rather participatory research focused on community capacity building which is difficult to evaluate (Greenwood et al., 1993). Recently, participatory research has utilized the best available and most rigorous scientific methods in mainstream health, social, and biophysical research, leading to peer-reviewed publications although production of publications is not necessarily the primary objective (Greenwood et al., 1993). Our discussion is centered on this increasingly popularized use of rigorous scientific methodologies in participatory research. Today, participatory research may well more appropriately describe a fundamentally different science-based decision model than the displacement of conventional research (Sessa and Ricci, 2010).

Participatory research has the potential to yield new empirical information while explicitly integrating societal values into research (Whyte, 1989; Sessa and Ricci, 2010). It might also increase the capacity to discover knowledge in novel domains that are relevant to users' needs and contribute to decision support (Sessa and Ricci, 2010). In theory, because participatory research is directly responsive to public needs, Forest Service programs focused on finding sustainable solutions could be enhanced. Levin (1997), responding to an essay by Baskerville (1997), suggested the greatest challenge in resource management was addressing conflict among stakeholders while achieving adequate representation of the underrepresented, especially future generations (Baskerville, 1997; Levin, 1997).

Some Forest Service researchers have used participatory research or similar approaches, primarily for social science and extension, but it has not been widely implemented, particularly in biophysical sciences. Although participatory research has many potential benefits for Forest Service research, it will pose some institutional challenges and may challenge entrenched philosophical beliefs.

The cultural or philosophical barrier is probably the most important —a scientist's willingness to accept the legitimacy of participatory research. Most contemporary research rarely involves participation of non-scientists beyond data collection owing, in part, to a belief that science should be the sole domain of scientists and scientists should not be advocates (Nelson and Vucetich, 2009). Researchers may be reluctant to concede some control over experimental design, data collection, and interpretation. In addition, some researchers may be disinclined to engage in participatory research as it can change the role of the scientist or technical expert in the science-based decision model — to one of equal footing with the public.

The so-called demarcation problem has to do with how and where to draw the lines around science; the boundaries between science and non-science continue to be hotly debated. Basic and applied science, though similar in methodology, have different philosophical foundations, sometimes leading researchers trained in basic science to view applied science as non-science. Similarly, both basic and applied science practitioners may view non-a priori hypothesis driven research unfavorably (e.g., biological monitoring). There is also unproductive debate surrounding the qualitative vs. quantitative divide, with critics regarding qualitative approaches to science as "soft" (Cornwall and Jewkes, 1995). Because participatory research process has very strong roots in applied and social sciences, scientists conducting basic research or "hard" sciences, such as biophysical scientists, are often reluctant to consider participatory approaches which try to explicitly integrate social values. In fact, a number of the biophysical scientists in basic sciences we interviewed view participatory research as antithetical to their formal training and role as a scientist.

Availability of funding drives most research. Thus, researchers struggle to reconcile the demands of funding agencies for conventional performance evaluation and constraints of the outcomes demanded by an academic-like culture – focused on publishing peer-reviewed research – with the use of a more participatory approach (Cornwall and Jewkes, 1995). Scientists are mainly in the "publish-or-perish" mindset; they are often reluctant to engage in often time-consuming participatory research, even if they receive lower ratings on other performance factors (e.g., community outreach, consultation) for fear of failing to meet requirements for peer-reviewed publications and winning grants to support their research programs (De Rond and Miller, 2005; Shanley and Lopez, 2009). As a result, many researchers interested in participatory research who want to meet performance requirements based on today's conventions are often forced to straddle both conventional and participatory research models. This can be accomplished by publishing portions of information gained from the participatory research cycle the scientist can control, while continuing to participate in knowledge exchange and public dialog.

Scientists are unlikely to risk including participatory research in their programs without incentives such as more funds or greater weight in performance evaluations. Unlike citizen science, few sources of external funding for participatory research are available to Forest Service scientists, particularly in biophysical sciences. Although funding agencies increasingly demand more technology transfer, they might inadvertently discourage participatory research by using the number and quality of peer-reviewed publications as a heavily-weighted metric in performance evaluations (Shanley and Lopez, 2009). In addition, some types of research are expensive or difficult to redirect or retool after methods have been established; the highly iterative approach associated with participatory research might not be a viable option for many lines of research without funding and incentives clearly designated to overcome these constraints.

The rise of participatory research in the United States parallels the discussion on public participation in natural resource policymaking and, more broadly, in democracy. Since the end of the post-war development era around 1960, the expert-driven model of decision-making has been increasingly replaced with participatory models (Steelman, 2001; Collins and Evans, 2002). This change is a result of a changing culture, which is increasingly skeptical of management and demands representation of broader public values (Steel and Weber, 2001; Steelman, 2001; Munnichs, 2004; Groffman et al., 2010; Cheng et al., 2011; Clement and Cheng, 2011). This view is reflected in the National Forest Management Act of 1976, which requires public input in any management action and planning on National Forests. Democratic theorists debate what the appropriate role of the public in policymaking is (Fischer, 1993; DeLeon, 1995; Steelman and Ascher, 1997; Steelman, 2001). Some theorists suggest that an expert-driven decision model, which prevails in federal land management agencies, protects against decisions based purely on values or emotions made by uniformed publics (Steel and Weber, 2001; Munnichs, 2004; Sekloca, 2010). By contrast, those espousing more participatory decision-making suggest that not including public participation in natural resource management ignores local knowledge and social values, thus lowering public support for resulting action (Fischer, 1993; Bliss, 2000; Steelman, 2001; Lujan and Todt, 2007). In this context, the origins and needs of participatory research come into focus. Participatory research is not antithetical to conventional research; rather we suggest it describes a more fully democratic science-based decision model (Robertson and Hull, 2003). Participatory research creates opportunities for the public to become informed by being active in all stages of the decision process alongside the technical experts, other publics, decision-makers, and ultimately, share in decision-making (Fig. 1). According to John Dewey, these are needed pieces for a complete democracy (Dewey, 2009).

The legacy of the Tall Timbers research station in north central Florida provides a classic example of participatory research. Concerned about the decline of the bobwhite quail in the 1920s, a group of wealthy landowners recruited and sponsored Herbert Stoddard to research the reason for the species decline through the U.S. Bureau of Biological Survey (transferred in into the U.S. Department of Interior and renamed the U.S. Fish and Wildlife Service) (Way, 2006). Although the core of his research was not fully participatory (Stoddard was responsible for experimental design, data collection, and interpretation), he did have constant communication with his sponsors – public stakeholders – at the beginning and throughout the project. Stoddard linked the decline of the bobwhite quail to habit losses caused by fire suppression (Way, 2006). He went on to challenge anti-fire dogma of the time espoused by federal land management agencies, and ultimately reestablish the ecological role of fire in much of the region to the benefit of many other ecosystems and declining species, including long-leaf pine (Way, 2006). This sweeping change in management occurred because of the deep public trust and support of Stoddard's research. Today, the state of Florida continues to have one of the most progressive fire management programs in the world, which depends largely on social license first cultured decades ago with Stoddard.

The philosophical underpinnings and local scope of participatory research pose some challenges for the agency's use of participatory research, especially on public lands. Shared decision-making is an explicit feature of participatory research, but the agency has the sole authority to make decisions affecting public lands. Because participatory research generally concentrates on meeting local needs, resulting action on research outcomes for local communities on public lands may be derailed by interests at broader scales. Public lands are owned by all citizens, each of whom by law has a voice in management. The values and needs of the local community are sometimes not shared by the national public or vice versa (Raymond, 2002; Singleton, 2002). There also is a concern that eliminating the boundary between the technical expert and public will result in the indefinite extension of technical decision-making rights (Collins and Evans, 2002; Evans and Plows, 2007). In addition, some might not view participation processes organized by government as democratically legitimate or could even be a form of control and co-optation (Hagendijk and Irwin, 2006; Thorpe and Gregory, 2010). The agency's changing role in deliberative decision-making and need to reconcile the local focus of participatory research with national interests determine how and if participatory research can be applied on public lands. However, the agency's State and Private Forestry program has a strong presence on private lands, where most of these issues do not apply. The continued growth and form of participatory research will depend on the ongoing discussion on what is the ideal balance of public and expert decision-making in democracy (Evans and Plows, 2007; Bohman, 2010; Williams, 2010).

5. Summary/conclusions

Today's natural resource issues are increasingly challenging and interdisciplinary; meeting these challenges requires continuing communication between well-informed land managers and the public (Groffman et al., 2010; Sekloca, 2010). In recent decades, the attitudes and perspectives held by the public, natural resource managers, and scientists have changed in a number significant ways. Chief among these changes in the United States is a shift from a focus on production forestry to a greater appreciation and awareness of ecosystem services and social values (Robertson and Hull, 2003). In the United States, diverse perspectives often manifest themselves through strong public resistance to forest management (Steelman, 2001). Moreover, globalization has drastically altered the production and distribution of forest products as well as the forest industry as a whole. The Forest Service and other research organizations recognize these changes and the need to continually adapt to rapidly changing conditions to be relevant throughout the 21st century (DeLeon and Steelman, 2001).

While the need for research has never been greater, the changing need and composition of the research user community poses new challenges to research and science delivery. This changing management environment has led to ambiguity as to what new knowledge is needed, who needs it, and how it should be best delivered. Forest research organizations in the United States and elsewhere are recognizing that collaboration in management and research is essential for sustainable management. Ironically, the trend in many organizations to focus on increasing productivity of the individual scientist has an unintended consequence — some needs of the public and natural resources managers have not been met. We suggest that actively bringing the users into the research process (Figs. 1 and 3), as depicted in the citizen science and participatory-research decision models, is essential for sustainable forest management.

To better serve public interests and needs of managers in the coming years, Forest Service research programs will take on increasingly complex interdisciplinary questions and problems (GAO, 2010). Identification of scientifically and socially credible solutions or opportunities for management and policy development will be a challenge. The present-day science model, where user involvement is minimal or absent, often produces knowledge that cannot be readily used or easily accessed or does not adequately address the needs of land managers, decision-makers, and the public. As a result, the Forest Service and others are considering citizen science and participatory research to help move towards a balanced management model that better serves the broader and varied needs of current and potential users of knowledge. Public participation has a co-benefit of revealing the identity of research users and their needs so that technology development and traditional forms of technology transfer can be more adaptable, deliberate, refined, and effective.

Participatory research might be an appropriate mechanism to address some of most challenging and socially complex natural resource issues. Within the Forest Service, participatory research might be an important tool to improve some research programs, enhancing overall effectiveness by better engaging both the public and natural resource managers. Specifically, participatory research could strengthen the public interface with research, thereby increasing user feedback in identifying problems and opportunities and information for possible implementation of the research outcome. Participatory research can be especially useful where knowledge must be generated through a process that is transparent and credible.

There are present-day examples showing the potential value of the participatory research-science decision model. For example, in the United States, Urban Long-Term Research Areas (ULTRAs) are beginning to resemble a participatory research model by involving the public in research to various degrees, giving them the knowledge needed for potential management activities to improve environmental health and community well-being (Barbosa et al., 2004; Anderson et al., 2008; Pickett et al., 2011). The ULTRAs bring together diverse groups of scientists, both social and biophysical, to focus expertise on broad ranges of issues focused on urban areas (Wolf and Kruger, 2010).

Another example where citizen science and participatory research could be applied by the Forest Service is Landscape-Scale Conservation (LSC). This is a proposed approach to land management that frames issues and their solutions at broad geographic scales, encompassing multiple ownerships and jurisdictions. The science behind LSC depends on receiving baseline information across broad geographic areas and over long periods of time. Citizen science projects might be well suited in generating this information while also providing opportunities for public education on various relevant land management issues. In addition, participatory research could be used in areas within the landscape that have issues with both strong social and biophysical dimensions, such as the threat of wild land fires in the Wildlife–Urban Interface (Sisk et al., 2006). Greater use of either tool, however, will need support.

Targeted funding may attract scientists wishing to engage in participatory models where opportunities exist that cannot be funded otherwise. Large initiatives, like ULTRAs, are funded directly or indirectly through multiple federal and state agencies and sometimes private foundations, but relatively few of these arrangements currently exist. Such institutional arrangements allow the participants (including researchers) to leverage limited resources and encourage researchers with diverse areas of expertise to focus their efforts on science delivery. Targeted funding may be used to contribute to current or new initiatives or support individuals or small groups of scientists.

Changes in institutional arrangements and incentives, in addition to targeted funding, could allow citizen science and participatory research to contribute more to management. Federal research scientists are evaluated on four factors, which include: 1) the research assignment; 2) supervisory controls; 3) guidelines and originality; and 4) contributions, impact, and stature (OPM, 2006). The 4th factor is weighted double relative to each of the other three. A number of Forest Service scientists indicated that their involvement in citizen science and participatory research has increased their scores in the 4th factor, especially under "impact" and "stature." The evaluation for "impact" includes: "has an impact on scientific and/or societal issues" and "drives management and policy outcomes." The evaluation for "stature" includes: "requests for expert advice/consultation by other professionals and managers." However, "contributions," an evaluation of "research publications" and "innovations and technology transfer" are perceived by the Forest Service researchers we interviewed to be the key consideration for promotion — implicitly having greater weight. Federal researchers can be successful meeting conventional evaluations while using some level of participatory approaches as long as they maintain or increase production of peer-reviewed publications. In the case of citizen science, the federal research scientist might benefit greatly from citizen participation. To encourage greater involvement of scientists with the public and decision-makers, the Forest Service R&D program area is considering 9-factor scientist positions that are evaluated more on the basis of a "delivery and adoption" of knowledge for public consumption than on the basis of conventional metrics for 4-factor research scientists. They will potentially work alongside or compliment the work done by 4-factor research scientists. These 9-factor scientists will have greater freedom to employ participatory approaches and will be evaluated on their ability to synthesize bodies of knowledge and reach various publics with new knowledge.

In addition to the new scientist positions, several positions could be devoted to science delivery. These positions could be filled by individuals with a background in Science Interpretation, a field that has gained great interest in academia; substantial resources are being allocated for its development. The academic programs that focus on Science Interpretation are based on a combination of field-oriented biological sciences, communication, and effective mastery of technological tools for information delivery. The naturalist is the precursor to the development of the Scientific Interpretation academic program. Academic programs with majors or minors in natural history interpretation are beginning to appear (e.g., at State University of New York — College of Environmental Science and Forestry and at University of Northern Iowa).

The wide distribution of personal computers, coupled with the accessibility of the Internet, has provided a powerful tool for science delivery. Those tools are invaluable in the hands of individuals with technical abilities to make full use of them. In fact, many citizen science projects are Internet based. Social media, such as Twitter and Facebook, are being used to communicate science. However, even for those sufficiently familiar with computer technology, lack of fundamental knowledge of science and ecology effectively limits the utility and communication of science. Science delivery needs a concerted effort to organize and package research results in a form that can be easily accessed and used by individuals who may not have a background in biological science, ecology, and other disciplines.

The availability and ease of information access via the Internet have contributed to the illusion that knowledge and understanding can be obtained in a vacuum. While information such as technical reports and refereed publications can be accessed with relative ease, integration and application to problem solving require interaction and engagement within the community.

Recent assessment of the efficacy of online learning modules as a tool for supplementing learning experiences for the Arizona Master Watershed Steward (MWS) program provides important insights. Crimmins and Rupprecht (2010), in addition to collecting website use statistics for four interactive learning modules designed to support the MWS place-based program, conducted two evaluation workshops. One of the most important findings was that online modules were effective supplements but were not a substitute for personal instruction. Twenty-one participants, after taking pretests, completed online modules followed by post- and follow-up tests; 86% had improved post- compared with pretest scores, which suggested improved understanding. Participants strongly preferred online modules to MWS text. We found that the fundamental innovations in science delivery are based on identifying users and connecting these users with knowledge; computer based technologies merely serve as tools to deliver content that strengthens those connections.

Historically, one of the great strengths of the Forest Service is that research need not be bound by short-term funding cycles. Assurance of support for long-term projects allowed research to span decades, resulting in some robust research findings. For example, the Coweeta Hydrologic Laboratory has comprehensive data sets dating back to the 1930s, which provide rare insights into, and valuable historical context for, hydrological and forest processes. Forest Service researchers then were held to standards based on concerns with empowering communities and providing industry (the principle user at the time) with knowledge; knowledge transfer was built on relationships that were carefully cultivated over many years. In the new knowledge generation era, competitive grants rarely extend beyond three years and performance of researchers is measured primarily by peer-to-peer publications; opportunities to empower users and build long-term relationships have been greatly reduced.

It is increasingly clear that the best way to serve the public interest might be to engage in a dialog built on the cogeneration of knowledge. Some argue that scientists should play a significant role in creating and maintaining systems that are more democratic and orientated toward deliberative decision-making (Bohman, 1995; Williams, 2010). Greater use of citizen science and participatory research by federal scientists might be appropriate tools to address some of our most challenging natural resource management issues by better balancing empirical research and social values in decision-making (Sessa and Ricci, 2010). To be clear, these approaches would augment rather than replace conventional approaches to science. Federal scientists are, or often could be, uniquely positioned to serve as a central hub in the creation and dissemination of knowledge in a broader forest management community that includes academic scientists, decision-makers, industry, and the general public (Wondolleck and Ryan, 1999; Innes, 2005). Contributing in this role would fill a critical void that cannot be easily filled by academic researchers who must rely on funding that is commonly short-term in nature and might serve priorities that are not aligned or too broad for addressing the specific needs of certain publics and natural resource managers.

"Nothing so important as an ethic is ever 'written'… it evolves in the minds of a thinking community" (Leopold, 1949). Some 60 years later, America's land ethic is still evolving, as do our social and cultural values. Delivering new knowledge plays a key role in ensuring that all people have a stake, and a role, in the sustainable management of our natural resources. The rise of citizen science and participatory research is a contemporary manifestation of an ever evolving democracy and land ethic. Forest Service R&D is committed to producing knowledge to help provide for "the greatest good, for the greatest number, for the longest time" (Gifford Pinchot, founder and first Chief of the U.S. Forest Service, 1905).

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References

Alberts, B.M., 1999. Are our universities producing too many PhDs? Trends in Biochemical Sciences 24, M73–M75.

Ananda, J., Herath, G., 2003. Incorporating stakeholder values into regional forest planning: a value function approach. Ecological Economics 45, 75–90.

Anderson, C.B., Likens, G.E., Rozzi, R., Gutierrez, J.R., Armesto, J.J., Poole, A., 2008. Integrating science and society through long-term socio-ecological research. Environmental Ethics 30, 295–312.

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T.S., Sierro, A., Watson, J.E.M., Braunisch, V., 2010. From publications to public actions: when conservation biologists bridge the gap between research and implementation. Bioscience 60, 835–842.

Ballard, H.L., Belsky, J.M., 2010. Participatory action research and environmental learning: implications for resilient forests and communities. Environmental Education Research 16, 611–627.

Ballard, H.L., Fernandez-Gimenez, M.E., Sturtevant, V.E., 2008. Integration of local ecological knowledge andconventional science: a study of seven community-based forestry organizations in the USA. Ecology and Society 13. Article #37, Available online: http://www.ecologyandsociety.org/vol13/iss2/art37/.

Barbosa, F.A.R., Scarano, F.R., Sabara, M.G., Esteves, F.A., 2004. Brazilian LTER: ecosystem and biodiversity information in support of decision-making. Environmental Monitoring and Assessment 90, 121–133.

Baskerville, G., 1997. Advocacy, science, policy, and life in the real world. Conservation Ecology 1 Article #9.

Biegelbauer, P., Hansen, J., 2011. Democratic theory and citizen participation: democracy models in the evaluation of public participation in science and technology. Science and Public Policy 38, 589–597.

Bliss, J.C., 2000. Public perceptions of clearcutting. Journal of Forestry 98, 4–9.

Bohman, J., 1995. Public reason and cultural-pluralism: political liberalism and the problem of moral conflict. Political Theory 23, 253–279.

Bohman, J., 2010. Participation through publics: did Dewey answer Lippmann? Contemporary Pragmatism 7, 49–68.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V., Shirk, J., 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy. Bioscience 59, 977–984.

Bosworth, D., Brown, H., 2007. After the timber wars: community-based stewardship. Journal of Forestry 105, 271–273.

Brossard, D., Lewenstein, B., Bonney, R., 2005. Scientific knowledge and attitude change: the impact of a citizen science project. International Journal of Science Education 27, 1099–1121.

Cabin, R.J., Clewell, A., Ingram, M., McDonald, T., Temperton, V., 2010. Bridging restoration science and practice: results and analysis of a survey from the 2009 Society for Ecological Restoration International Meeting. Restoration Ecology 18, 783–788.

Chambers, R., 1994. The origins and practice of participatory rural appraisal. World Development 22, 953–969.

Cheng, A.S., Danks, C., Allred, S.R., 2011. The role of social and policy learning in changing forest governance: an examination of community-based forestry initiatives in the US. Forest Policy and Economics 13, 89–96.

Clement, J.M., Cheng, A.S., 2011. Using analyses of public value orientations, attitudes and preferences to inform national forest planning in Colorado and Wyoming. Applied Geography 31, 393–400.

Cohn, J.P., 2008. Citizen science: can volunteers do real research? Bioscience 58, 192–197.

Collins, H.M., Evans, R., 2002. The third wave of science studies: studies of expertise and experience. Social Studies of Science 32, 235–296.

Conrad, C.C., Hilchey, K.G., 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental Monitoring and Assessment 176, 273–291.

Cooper, C.B., Dickinson, J., Phillips, T., Bonney, R., 2007. Citizen science as a tool for conservation in residential ecosystems. Ecology and Society 12, 11.

Cornwall, A., Jewkes, R., 1995. What is participatory research? Social Science & Medicine 41, 1667–1676.

Costanza, R., dArge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., vandenBelt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Couvet, D., Jiguet, F., Julliard, R., Levrel, H., Teyssedre, A., 2008. Enhancing citizen contributions to biodiversity science and public policy. Interdisciplinary Science Reviews 33, 95–103.

Crall, A.W., Newman, G.J., Stohlgren, T.J., Holfelder, K.A., Graham, J., Waller, D.M., 2011. Assessing citizen science data quality: an invasive species case study. Conservation Letters 4, 433–442.

Crimmins, T.M., Rupprecht, C.L., 2010. Online learning modules for an extension program. Journal of Natural Resources and Life Sciences Education 39, 102–108.

De Rond, M., Miller, A.N., 2005. Publish or perish — bane or boon of academic life? Journal of Management Inquiry 14, 321–329.

DeLeon, P., 1995. Democratic values and the policy sciences. American Journal of Political Science 39, 886–905.

DeLeon, P., Steelman, T.A., 2001. Making public policy programs effective and relevant: the role of the policy sciences. Journal of Policy Analysis and Management 20, 163–171.

Devictor, V., Whittaker, R.J., Beltrame, C., 2010. Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. Diversity and Distributions 16, 354–362.

Dewey, J., 2009. Democracy and Education: An Introduction to the Philosophy of Education. WLC Books, New York, p. 290 (originally published in 1916).

Dickinson, J.L., Zuckerberg, B., Bonter, D.N., 2010. Citizen science as an ecological research tool: challenges and benefits. Annual Review of Ecology, Evolution, and Systematics 41, 149–172.

Esler, K.J., Prozesky, H., Sharma, G.P., McGeoch, M., 2010. How wide is the "knowing-doing" gap in invasion biology? Biological Invasions 12, 4065–4075.

Evans, R., Plows, A., 2007. Listening without prejudice? Re-discovering the value of the disinterested citizen. Social Studies of Science 37, 827–853.

Everett, Y., 2001. Participatory research for adaptive ecosystem management: a case of nontimber forest products. Journal of Sustainable Forestry 13, 335–357.

Farnham, T.J., Taylor, C.P., Callaway, W., 1995. A shift in values: non-commodity resource-management and the Forest Service. Policy Studies Journal 23, 281–295.

Fernholz, K., Bowyer, J., Howe, J., 2007. Timos & Reits: What, Why, and How they might Impact Sustainable Forestry. Dovetail Partners, Inc., Minneapolis MN. Avialable online: http://www.forestinfo.orgwww.forestinfo.org/files/DovetailTIMOREIT0507wo.pdf.
Fischer, F., 1993. Citizen participation and the democratization of policy expertise: from theoretical inquiry to practical cases. Policy Sciences 26, 165–187.
Fortmann, L., Ballard, H., 2011. Sciences, knowledges, and the practice of forestry. European Journal of Forest Research 130, 467–477.
Galloway, A.W.E., Tudor, M.T., Vander Haegen, W.M., 2006. The reliability of citizen science: a case study of Oregon white oak stand surveys. Wildlife Society Bulletin 34, 1425–1429.
GAO, 2010. Forest Service Research and Development: Improvements in Delivery of Research Results can Help Ensure that Benefits of Research are Realized. Government Accountability Office, GAO-11–12, Washington DC, p. 64.
Greenwood, J.J.D., 2007. Citizens, science and bird conservation. Journal of Ornithology 148, S77–S124.
Greenwood, D.J., Whyte, W.F., Harkavy, I., 1993. Participatory action research as a proces and as a goal. Human Relations 46, 175–192.
Groffman, P.M., Stylinski, C., Nisbet, M.C., Duarte, C.M., Jordan, R., Burgin, A., Previtali, M.A., Coloso, J., 2010. Restarting the conversation: challenges at the interface between ecology and society. Frontiers in Ecology and the Environment 8, 284–291.
Haeuber, R., 1998. Ecosystem management and environmental policy in the United States: open window or closed door? Landscape and Urban Planning 40, 221–233.
Hagendijk, R., Irwin, A., 2006. Public deliberation and governance: engaging with science and technology in contemporary Europe. Minerva 44, 167–184.
Ingwell, L.L., Preisser, E.L., 2011. Using citizen science programs to identify host resistance in pest-invaded forests. Conservation Biology 25, 182–188.
Innes, J.L., 2005. Multidisciplinarity, interdisciplinarity and training in forestry and forest research. The Forestry Chronicle 81, 324–329.
Jordan, R.C., Gray, S.A., Howe, D.V., Brooks, W.R., Ehrenfeld, J.G., 2011. Knowledge gain and behavioral change in citizen-science programs. Conservation Biology 25, 1148–1154.
Kleinman, D.L., Delborne, J.A., Anderson, A.A., 2011. Engaging citizens: the high cost of citizen participation in high technology. Public Understanding of Science 20, 221–240.
Krishnaswamy, A., 2004. Participatory research: strategies and tools. Pactitioner: Newletters of the National Network of Forest Practioners 22, 17–22.
Lengwiler, M., 2008. Participatory approaches in science and technology — historical origins and current practices in critical perspective. Science Technology & Human Values 33, 186–200.
Levin, S.A., 1997. Management and the problem of scale. Conservation Ecology 1 article #13.
Leopold, A., 1949. A Sand Country Almanac. Ballantine Books, New York, 296 p.
Lujan, J.L., Todt, O., 2007. Precaution in public: the social perception of the role of science and values in policy making. Public Understanding of Science 16, 97–109.
Mayo, M., Craig, G., 1995. Community participation and empowerment: the human face of structural adjustment or tools for democractic transformation? In: Craig, G., Mayo, M. (Eds.), Community Empowerment: A Reader in Participation and Development. Zed Books, London, pp. 1–11.
McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environmental Science & Policy 10, 17–38.
Munnichs, G., 2004. Whom to trust? Public concerns, late modern risks, and expert trustworthiness. Journal of Agricultural & Environmental Ethics 17, 113–130.
Nelson, M.P., Vucetich, J.A., 2009. On advocacy by environmental scientists: what, whether, why, and how. Conservation Biology 23, 1090–1101.
Nichols, J.D., Williams, B.K., 2006. Monitoring for conservation. Trends in Ecology & Evolution 21, 668–673.
Nie, M., 2004. State wildlife policy and management: the scope and bias of political conflict. Public Administration Review 64, 221–233.
OPM, 2006. Research Grade Evaluation Guide. Washington, DC, p. 25.
Ottinger, G., 2010. Buckets of resistance: standards and the effectiveness of citizen science. Science Technology & Human Values 35, 244–270.
Pain, R., Francis, P., 2003. Reflections on participatory research. Area 35, 46–54.
Parsons, J., Lukyanenko, R., Wiersma, Y., 2011. Easier citizen science is better. Nature 471, 37.
Petrokofsky, G., Brown, N.D., Hemery, G.E., Woodward, S., Wilson, E., Weatherall, A., Stokes, V., Smithers, R.J., Sangster, M., Russell, K., Pullin, A.S., Price, C., Morecroft, M., Malins, M., Lawrence, A., Kirby, K.J., Godbold, D., Charman, E., Boshier, D., Bosbeer, S., Arnold, J.E.M., 2010. A participatory process for identifying and prioritizing policy-relevant research questions in natural resource management: a case study from the UK forestry sector. Forestry 83, 357–367.
Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Boone, C.G., Groffman, P.M., Irwin, E., Kaushal, S.S., Marshall, V., McGrath, B.P., Nilon, C.H., Pouyat, R.V., Szlavecz, K., Troy, A., Warren, P., 2011. Urban ecological systems: scientific foundations and a decade of progress. Journal of Environmental Management 92, 331–362.
Pilz, D., Ballard, H.L., Jones, E.T., 2006. Broadening participation in biological monitoring: handbook for scientists and managers. PNW-GTR-680. USDA Forest Service, Pacific Northwest Research Station, p. 131.
Pretty, J., Ward, H., 2001. Social capital and the environment. World Development 29, 209–227.
Raymond, L., 2002. Localism in environmental policy: new insights from an old case. Policy Sciences 35, 179–201.
Robertson, D.P., Hull, R.B., 2003. Public ecology: an environmental science and policy for global society. Environmental Science & Policy 6, 399–410.
Rocheleau, D.E., 1991. Participatory research in agroforestry: learning from experience and expanding our repertoire. Agroforestry Systems 15, 111–137.
Sekloca, P., 2010. Four forms of relationships between the public, citizens and science: from the representative scientifc publicness toward the engagement of citizens in the production of knowledge. Annales-Anali Za Istrske in Mediteranske Studije-Series Historia Et Sociologia 20, 91–102.
Sessa, C., Ricci, A., 2010. Working with and for the citizens. Innovation-the European Journal of Social Science Research 23, 49–60.
Shanley, P., Lopez, C., 2009. Out of the loop: why research rarely reaches policy makers and the public and what can be done. Biotropica 41, 535–544.
Shepard, P.M., Northridge, M.E., Prakash, S., Stover, G., 2002. Preface: advancing environmental justice through community-based participatory research. Environmental Health Perspectives 110, 139–140.
Sheppard, S.R.J., 2005. Participatory decision support for sustainable forest management: a framework for planning with local communities at the landscape level in Canada. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 35, 1515–1526.
Shetty, P., 2011. Citizen scientists' climate-impact survey wraps up: forest monitoring project has measured 150,000 trees and provided researchers with reams of data. Nature News, http://dx.doi.org/10.1038/nature.2011.9697.
Silvertown, J., 2009. A new dawn for citizen science. Trends in Ecology & Evolution 24, 467–471.
Singleton, S., 2002. Collaborative environmental planning in the American West: the good, the bad and the ugly. Environmental Politics 11, 54–75.
Sisk, T.D., Prather, J.W., Hampton, H.M., Aumack, E.N., Xu, Y.G., Dickson, B.G., 2006. Participatory landscape analysis to guide restoration of ponderosa pine ecosystems in the American Southwest. Landscape and Urban Planning 78, 300–310.
Smith, W.B., Miles, P.D., Perry, C.H., Pugh, S.A., 2009. Forest Resources of the United States. GTR WO-78. USDA Forest Service, Washington, DC, p. 336.
Snall, T., Kindvall, O., Nilsson, J., Part, T., 2011. Evaluating citizen-based presence data for bird monitoring. Biological Conservation 144, 804–810.
Speth, G., 2010. Towards a new economy and a new politics. Solutions 5. Available online: http://thesolutionsjournal.com/node/619.
Steel, B.S., Weber, E., 2001. Ecosystem management, decentralization, and public opinion. Global Environmental Change-Human and Policy Dimensions 11, 119–131.
Steelman, T.A., 2001. Elite and participatory policymaking: finding balance in a case of National Forest planning. Policy Studies Journal 29, 71–89.
Steelman, T.A., Ascher, W., 1997. Public involvement methods in natural resource policy making: advantages, disadvantages and trade-offs. Policy Sciences 30, 71–90.
Sullivan, B.L., Wood, C.L., Iliff, M.J., Bonney, R.E., Fink, D., Kelling, S., 2009. eBird: a citizen-based bird observation network in the biological sciences. Biological Conservation 142, 2282–2292.
Sunderland, T., Sunderland-Groves, J., Shanley, P., Campbell, B., 2009. Bridging the gap: how can information access and exchange between conservation biologists and field practitioners be improved for better conservation outcomes? Biotropica 41, 549–554.
Sutherland, A., 1998. Socio-economic Methodologies Best Practice Guidelines: Participatory Research in Natural Sciences. Natural Resources Institute, the University of Greenwick, London.
Talwar, S., Wiek, A., Robinson, J., 2011. User engagement in sustainability research. Science and Public Policy 38, 379–390.
Thompson, J.R., Elmendorf, W.F., McDonough, M.H., Burban, L.L., 2005. Participation and conflict: lessons learned from community forestry. Journal of Forestry 103, 174–178.
Thorpe, C., Gregory, J., 2010. Producing the post-Fordist public: the political economy of public engagement with science. Science as Culture 19, 273–301.
USAID, 2007. Adapting to Climate Variability and Change: A Guidance Manual for Development Planning. United States Agency for International Development, Washington, DC. Available online: http://pdf.usaid.gov/pdf_docs/PNADJ990.pdf.
USDA, 2009a. The United States Forest Service — an overview. FS 923, Washington, DC. Available online: http://www.fs.fed.us/documents/USFS_An_Overview_0106MJS.pdf.
USDA, 2009b. Final Report Assessment of Technology Transfer within the Forest Service. USDA Forest Service, State and Private Forestry, p. 25.
USDA, 2009c. Focused science delivery program. Available online: http://www.fs.fed.us/pnw/about/programs/fsd/index.shtml.
USDA, 2009d. Customer Satisfaction Survey: Final Report, p. 122. Avialable online: http://www.fs.fed.us/research/pdf/2009-fs-rd-customer-satisfaction-survey-report.pdf.
Valfer, E., Laner, S., Dravnieks, D., 1977. Public Involvement Processes and Methodologies: An Analysis. Management Sciences Staff, USDA Forest Service, CA, p. 145.
Way, G.A., 2006. Burned to be wild: Herbert Stoddard and the roots of ecological conservation in the southern longleaf pine forest. Environmental History 11, 500–526.
White, S.S., 2001. Public participation and organizational change in Wisconsin land use management. Land Use Policy 18, 341–350.
Whyte, W.F., 1989. Advancing scientific knowledge through participatory action research. Sociological Forum 4, 367–385.
Wiederhold, B.K., 2011. Citizen scientists generate benefits for researchers, educators, society, and themselves. Cyberpsychology, Behavior and Social Networking 14, 703–704.
Wiersma, Y.F., 2010. Birding 2.0: citizen science and effective monitoring in the web 2.0 world. Avian Conservation and Ecology 5, 9.
Williams, S.N., 2010. A twenty-first century Citizens' POLIS: introducing a democratic experiment in electronic citizen participation in science and technology decision-making. Public Understanding of Science 19, 528–544.
Wolf, K.L., Kruger, L.E., 2010. Urban forestry research needs: a participatory assessment process. Journal of Forestry 108, 39–44.
Wondolleck, J.M., Ryan, C.M., 1999. What hat do I wear now?: an examination of agency roles in collaborative processes. Negotiation Journal-On the Process of Dispute Settlement 15, 117–133.
Yaffee, S.L., 1999. Three faces of ecosystem management. Conservation Biology 13, 713–725.
Yoccoz, N.G., Nichols, J.D., Boulinier, T., 2001. Monitoring of biological diversity in space and time. Trends in Ecology & Evolution 16, 446–453.