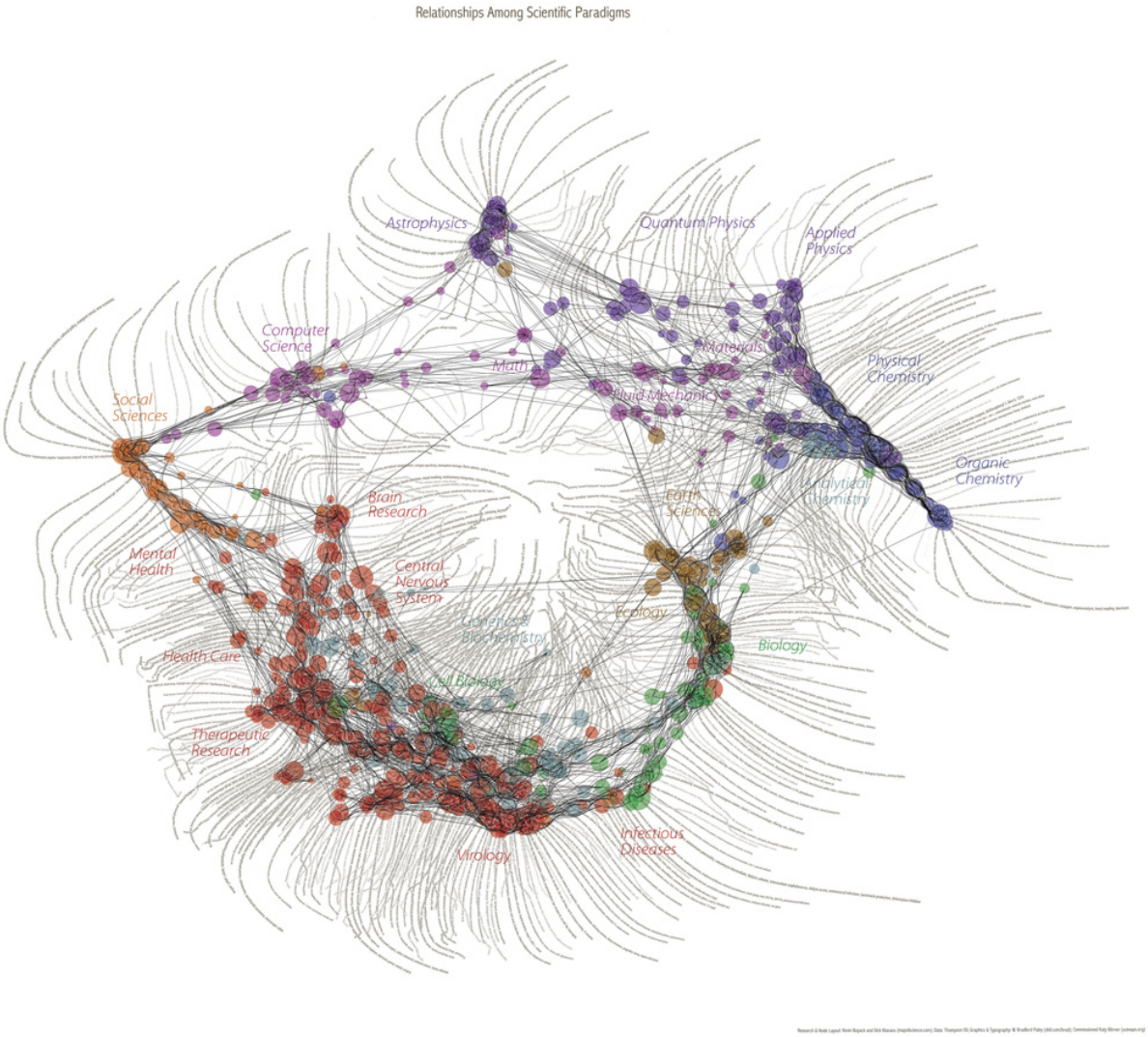
Addressing Complexity: Fostering Collaboration and Interdisciplinary Science Research at the Smithsonian

Volume II: Detailed Findings



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Acknowledgements

This report synthesizes some important insights about collaboration and interdisciplinary scientific research. The Office of Policy and Analysis hopes that these ideas will strengthen science at the Smithsonian Institution, address the challenges of pursuing research that draws together diverse disciplines and crosses organizational boundaries, and link the Institution's research to the successful resolution of some of society's challenging issues.

The talent and skills of many contributed to this effort. The debt I owe to my extraordinary staff is substantial. Their thoroughness, knowledge, and professionalism are exemplary. Kathleen M. Ernst, a senior analyst, managed the project and, as always, did a wonderful job. Whitney Watriss provided a great deal of assistance during gathering, reduction, and analysis of data and contributed enormously to writing the report. Lance Costello, a steadfast, systematic researcher who participated in all of the project's stages, and James Smith, a brilliant senior editor, went the extra mile to finish the report. As always, we benefited greatly from the comments and suggestions of one another.

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Finally, I have been at the Smithsonian for nearly a decade and am grateful to have had the opportunity to look at organizational and managerial issues related to science. Before that, over a 15-year period, I had the opportunity to work with several Federal research organizations and learned much about their structures, management practices and processes, flow of knowledge, and idea and product creation. It has been a pleasure to return to the province of science and listen to voices who can improve the quality of our lives through research.

Carole M.P. Neves
Director
Smithsonian Office of Policy and Analysis

List of Acronyms

ARS	Agricultural Research Service (U.S. Department of Agriculture)
ASU	Arizona State University
BEES	Behavior, Ecology, Evolution, and Systematics Program (University of Maryland)
CBoL	Consortium for the Barcode of Life
CCRE	Caribbean Coral Reef Ecosystems
CDI	Cyber-Enabled Discovery and Innovation Program (National Science Foundation)
CEPS	Center for Earth and Planetary Studies (National Air and Space Museum)
CRC	Conservation and Research Center (National Zoological Park)
CTFS	Center for Tropical Forest Science (Smithsonian Tropical Research Institute)
DOE	Department of Energy
EOL	Encyclopedia of Life
EPA	U.S. Environmental Protection Agency
FY	Fiscal year
HHMI	Howard Hughes Medical Institute
IDR	Interdisciplinary research
IGERT	Integrative Graduate Education and Research Traineeship Program (National Science Foundation)
IGSP	Duke Institute for Genome Sciences & Policy
IT	Information technology
ITIS	Integrated Taxonomic Information System
MIT	Massachusetts Institute of Technology
MCI	Museum Conservation Institute
MMURC	Multipurpose, multidiscipline university research centers
MSN	Marine Science Network
NAI	National Astrobiology Institute
NAPA	National Academy of Public Administration
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCEAS	National Center for Ecological Analysis and Synthesis
NEON	National Ecological Observatory Network (NEON)
NFC	National Finance Center (U.S. Department of Agriculture)
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NMNH	National Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration (U.S. Department of Commerce)
NRC	National Research Council (National Academies)
NSF	National Science Foundation

NZP	National Zoological Park
OCIO	Office of the Chief Information Officer
OF	Office of Fellowships
OHR	Office of Human Resources
OP&A	Office of Policy and Analysis
OPASI	Office of Portfolio Analysis and Strategic Initiatives (National Institutes of Health)
OSP	Office of Sponsored Projects
OUSS	Office of the Under Secretary for Science
PAEC	Professional Accomplishment Evaluation Committee
PI	Principal Investigator
SAO	Smithsonian Astrophysical Observatory
SFI	Santa Fe Institute
SCEMS	Smithsonian Center for Education and Museum Studies
SCS	School of Computational Science and Information Technology (Florida State University)
SERC	Smithsonian Environmental Research Center
SFI	Santa Fe Institute
SIGEO	Smithsonian Institution Global Earth Observatory
SOLAA	Smithsonian On-Line Academic Appointments
STC	Science and Technology Center (National Science Foundation)
STRI	Smithsonian Tropical Research Institute
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey (U.S. Department of the Interior)

Introduction

Purpose of the Study

Over the past decade or more, there has been a marked shift toward scientific research that spans disciplines and organizational boundaries and is carried out by teams rather than individuals. One reason is the complexity and scope of the big challenges facing the world today. Global problems such as human diseases, climate change, and the rapid loss of natural resources resulting from human activities and population pressures cannot be addressed by individual scientists working alone within single disciplines. Moreover, it is evident that the innovative and transformative science that leads to breakthroughs often happens at the intersections of disciplines. In response to these realities, government policy and research funding have increasingly emphasized multi-organization, interdisciplinary research (IDR) aimed at solving or mitigating global problems and at transformative advances in science. Spurred by these trends, universities and other research organizations have taken measures to promote interdisciplinary research, including setting up new IDR centers, institutes, and programs.

To help Smithsonian scientists confront the changing face of science, in early 2008 the Office of the Under Secretary for Science (OUSS) at the Smithsonian asked the Office of Policy and Analysis (OP&A) to look into ways to better facilitate collaboration and IDR at the Institution—within and across its science (and potentially non-science) units, and with outside organizations. When the current Secretary, Wayne Clough, came onboard in July 2008, he fully supported the study and a move toward more IDR. In his installation remarks in January 2009, Secretary Clough noted the Smithsonian's potential to tackle complicated issues and that doing so would require the type of interdisciplinary work that occurs at the boundaries between disciplines. The Smithsonian would also need to find new ways to utilize its assets to support deeper engagement in the important issues of our day (Smithsonian Institution, 2009).

The study team investigated both the policies, procedures, incentives, and mechanisms that foster collaboration and IDR, and the bureaucratic, administrative, cultural, and other barriers that impede it. More generally, the study team looked at how the nature of scientific research is changing and what factors and conditions increase the chances for innovation and scientific breakthroughs. In conjunction with the strategic planning process underway for the Institution, this study considers the relevance and comparative advantage of Smithsonian science, taking into account both its historical science mission and "real world" questions that confront society. Relatedly, OUSS raised the issue of how the Smithsonian can better marshal dispersed science

activity for greater impact, and how it can present a better case for the relevance of Smithsonian science to Congress, the Office of Management and Budget, donors, the public, and other stakeholders, with the goal of diversifying the funding base for science research.

The study team focused on seven Smithsonian units or bureaus that conduct science research and are located organizationally under the OUSS: Museum Conservation Institute (MCI), National Air and Space Museum's Center for Earth and Planetary Studies (CEPS), National Museum of Natural History (NMNH), National Zoological Park (NZP) and its Conservation Research Center (CRC), Smithsonian Astrophysical Observatory (SAO), Smithsonian Environmental Research Center (SERC), and Smithsonian Tropical Research Institute (STRI) (Table 1).[1]

Context of the Study

While this study focused on problems, for example, the cultural, administrative, and structural barriers that impede Smithsonian science from greater flexibility in mobilizing cross-unit interdisciplinary teams to address complex questions and problems of societal import, it must be viewed in the larger context of the many changes implemented and progress made in response to extensive scrutiny by three external review bodies in 2002-03—the Smithsonian Science Commission, National Research Council (NRC), and National Academy of Public Administration (NAPA)—and in carrying out the Smithsonian Science Strategic Plan that was finalized in 2005. The Science Commission, NRC, and NAPA found Smithsonian science to have unique national value, but they also found weaknesses, which are detailed in their reports.

This study comes at a time of new science leadership at the Smithsonian, with Secretary Wayne Clough and the as-yet-to-be named Under Secretary for Science, when it is appropriate to ask, "What's next?"

[1] Scientific and science-related research is conducted in other Smithsonian units; for example, the Freer and Sackler Galleries' Department of Conservation and Scientific Research uses scientific methods to study works of art; the National Museum of the American Indian's research areas include geography, cultural anthropology, and archaeology; environmental historians and others in the National Museum of American History's Division of Medicine and Science collaborate with NZP and NMNH scientists.

Table 1. Smithsonian Science Units

Smithsonian Science Units	Mission	Primary Research Location(s)
Museum Conservation Institute (MCI)	To become the center for specialized technical collections research and conservation for all Smithsonian museums and collections. http://www.si.edu/mci/english/about_mci/index.html	Suitland, MD
National Air and Space Museum/ Center for Earth and Planetary Studies (NASM/CEPS)	[CEPS] performs original research and outreach activities on topics covering planetary science, terrestrial geophysics, and the remote sensing of environmental change. http://www.nasm.si.edu/research/ceps/	Washington, DC
National Museum of Natural History (NMNH)	We inspire curiosity, discovery, and learning about nature and culture through outstanding research, collections, exhibitions, and education. http://www.mnh.si.edu/about/mission.htm	National Mall-Washington, DC Suitland, MD Fort Pierce, FL Carrie Bow Cay, Belize
National Zoological Park/Conservation and Research Center (NZP/CRC)	We advance research and scientific knowledge in conserving wildlife. We teach and inspire people to protect wildlife, natural resources, and habitats. http://nationalzoo.si.edu/AboutUs/Mission	Washington, DC Front Royal, VA
Smithsonian Astrophysical Observatory (SAO)	To pursue studies of those basic physical processes that determine the nature and evolution of the universe. http://www.cfa.harvard.edu/about	Cambridge, MA Amado, AZ Mauna Kea, HI
Smithsonian Environmental Research Center (SERC)	[SERC] leads the Nation in research on linkages of land and water ecosystems in the coastal zone and provides society with knowledge to meet critical environmental challenges in the 21st century. http://www.serc.si.edu/inside/mission.jsp	Edgewater, MD
Smithsonian Tropical Research Institute (STRI)	To increase understanding of the past, present and future of tropical biodiversity and its relevance to human welfare. http://www.stri.org/index.php	Barro Colorado Island, Panama

Methodology

The OP&A study team completed the data collection for this study in the fall of 2008, and conducted the analysis and writing in early 2009. The analyses and data in the report are based on the following sources and methods:

- A literature review of published and unpublished documents, Smithsonian materials, and websites pertaining to collaboration and interdisciplinary research and education. A bibliography appears in Appendix A.

- Interviews with 92 Smithsonian scientists, managers, and administrative staff and interviews and group discussions with 43 external scientists and staff in universities, museums, Federal science agencies, private research organizations, and foundations (Appendix B). Because OP&A assured interviewees of confidentiality, this report does not contain names or references that would identify specific individuals, unless their comments were clearly in the public domain or the interviewee granted permission. Any quote that appears without attribution is from an interviewee.

- Analysis of interviews using NVIVO 8 qualitative analysis software.

- Analysis of trend data on Smithsonian science budgets, grants and contracts, scholarly awards, staffing, and fellowships obtained from the OUSS, Human Resources (OHR), Planning, Management, and Budget (OPMB), Fellowships (OF), and Sponsored Projects (OSP).

- Analysis of Smithsonian scientist co-authorship data from the ISI Web of Science (Thompson ISI Corporation) and network mapping, using Microsoft Node XL social network analysis software.

- Concurrent with this study, OP&A analyzed over 1,000 Smithsonian employee responses to an online survey that was part of the 2008-09 Smithsonian-wide strategic planning process. Many of the responses echoed and amplified the comments of Smithsonian scientists and others in this study. Some of the responses have been incorporated into this report.

- Analysis of the responses of 68 Smithsonian biologists to a survey questionnaire that was part of Science strategic planning effort in 2002. Selected responses have been incorporated into this report.

Defining "Interdisciplinary"

Early in the interviewing phase, the OP&A study team realized that people were using different definitions of the word "interdisciplinary." The confusion was compounded when terms such as "multidisciplinary" and "transdisciplinary" were thrown into the mix. For this report, the study team uses definitions from three complementary sources.[2]

First, the 2004 National Academy of Sciences (NAS) report *Facilitating Interdisciplinary Research* distinguishes between

- The *additive* results of *multidisciplinary* research, in which two or more disciplines make *separate* contributions to a research problem, and

- The *integrative* results of *interdisciplinary* research, in which information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines are synthesized to advance understanding of or solve problems that lie beyond the scope of a single discipline or field of research practice (National Academy of Sciences, 2004).

Second, in "A Rough Guide to Interdisciplinarity: Graduate Student Perspective," Tress, et al., (2003, referenced in Graybill, et al., 2006) further tease out the characteristics of the different approaches:

- A *multidisciplinary* approach involves researchers from two or more disciplines working collaboratively on a common problem, but without modifying disciplinary approaches or developing synthetic conceptual frameworks.

- An *interdisciplinary* approach involves the use of an innovative conceptual framework to synthesize and modify two or more disciplinary approaches to a research problem.

- A *transdisciplinary* approach involves nonacademic practitioners working with academics to identify, research, and develop solutions to real-world problems.

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[2] NSF scientists' definitions of "multidisciplinary" and "interdisciplinary" varied somewhat from the definitions above. Multidisciplinary was used in the context of collaborators being from recognizably different disciplines, e.g., mathematicians working with biologists, where "no discipline is subordinate to the other," and with the measure being whether research findings could be published in the leading journals of both disciplines. Interdisciplinary may "tend to dwell in one domain," where people are within disciplines and subdisciplines in a particular field, e.g., inorganic chemists working very closely with physical chemists.

Third, Rhoten and Pfirman (2007) break down the concept of interdisciplinarity into four modes of practice:

- *Individual "cross-fertilization"* occurs when individual researchers make cognitive connections among disciplines and single-handedly knit together ideas, approaches, and information from different fields.

- *"Team collaboration"* occurs by virtue of several individuals working together in formal or informal teams or networks that span fields and/or disciplines.

- *"Field creation"* involves the bridging of existing research domains to form new disciplines, subdisciplines or "inter-disciplines" at their intersections.

- *"Problem orientation"* involves interdisciplinary research that is oriented toward problem solving, especially "real world" questions that confront society. Problem-oriented IDR draws on multiple fields but also serves multiple stakeholders and broader missions outside of academe.

In practice, of course, the use of such terms tends to be much looser. For example, several projects described by Smithsonian interviewees as "interdisciplinary" were in fact "multidisciplinary"—that is, they involved scientists working alongside each other, but not working together in an integrative sense.

Organization of the Study Reports

This report, *Addressing Complexity: Fostering Collaboration and Interdisciplinary Research at the Smithsonian*, Volume II, *Detailed Findings*, contains additional information and quotes from the data collection phase of the study, supplemented by five appendices: A, the bibliography; B, the organizations contacted for interviews; C, types of IDR entities; D, collaboration mechanisms; and E, unit human resources data for four units. Volume I, *Summary Study Report*, presents conclusions and recommendations, along with a summary of the findings.

A Shifting Paradigm for Science Research

> *Scientific progress is based ultimately on unification rather than fragmentation of knowledge (Kafatos and Eisner, 2004).*

> *The image of the scientist alone at the workbench, plucking ideas out of the ether was true up to about the end of the Second World War, but not any more (Brian Uzzi as quoted in Whitfield, 2008b.)*

Over the past decade or more, the conduct of scientific research has shifted away from single principal investigators (PIs) working in departments aligned with traditional scientific disciplines to collaborative, problem-based, interdisciplinary teams that span institutional boundaries. The change has occurred due to a general understanding that innovative, transformative science often happens at the intersection of disciplines:

> *Discovery increasingly requires the expertise of individuals with different perspectives—from different disciplines … working together to accommodate the extraordinary complexity of today's science and engineering challenges (National Science Foundation, 2006).*

Science policy reports such as the National Academies' *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* emphasize the importance of interdisciplinary research to scientific development and national competitiveness (Rhoten and Pfirman, 2007).

Historically, the synthesis of discipline-specific knowledge and methods spawned inter-disciplinary fields such as astrophysics, biochemistry, and econometrics. More recently, the trend has engendered new subject areas in academe such as global health, climate change, neuroscience, and systems biology (Whitfield, 2008b). Students are increasingly interested in complex problems of global scale that have practical consequences, such as disease prevention, economic development, social inequality, and global climate change—all of which are best addressed through interdisciplinary research (National Academy of Sciences, 2004). Other contemporary fields that use interdisciplinary approaches include nanotechnology, genomics, bioinformatics, conflict resolution, and terrorism (Klein, 2005). Natural and social scientists tackling complex ecological problems increasingly recognize the value of one another's research (Graybill, et al., 2006).

This shift has also come as a result of financial incentives to partner. For example, government science funding—the single most important source of money for academic research—has been directed toward "big science" initiatives in fields such as nanotechnology, advanced energy, hydrogen fuel, climate change, ocean science, and networking and information. Universities and other research institutes have responded by creating structures that foster collaboration, integrative problem solving, and development of new hybrid fields. Some have built state-of-the-art facilities dedicated to such research, such as Stanford University's Bio-X program in Palo Alto, California and Arizona State University's (ASU) Biodesign Institute in Tempe. Similarly, at Howard Hughes Medical Institute's (HHMI) new residential laboratory, Janelia Farm, physicists, computer scientists, chemists, and engineers work with biologists to create synergies.

New alliances between industry and government include think tanks, projects, and teamwork. In business and industry, work is carried out through ad hoc projects, teams, working groups, and task forces. Academe has seen an increase in matrix structures, research institutes and centers, interdisciplinary studies, networks, and invisible colleges. The growing presence of such hybrid communities documents the widely perceived gap between the traditional structure of knowledge and the needs and interests of the modern world (Klein, 1998).

One Smithsonian scholar summed up the changing situation in these words:

> *Being small minded, we can't encompass the world, [so] we focus, we compartmentalize, we have disciplines that have grown—chemists, biologists, physicists. You have structures that grow up around journals, meetings, societies, a whole reward system, departments, experiments, labs that focus on your areas. [But] it's often between those areas where you have the real breakthroughs, [as in] astrophysics … where there is this combination of different approaches, methodologies, sets of instruments, questions. It's that merger between [disciplines] that often gives you this new breakthrough—a whole other way of looking at the world, of asking questions. You never know when that's going to happen, but that's often where you get a real spark.*

Interdisciplinary Centers: Universities and Private Research Institutes

The IDR centers that have sprung up in most major research universities and the interdisciplinary approach to high-risk science funding pursued by private organizations attest to the pendulum swing toward a new scientific paradigm. As one close observer of the trend noted,

> *Today, some analysts claim that academic science has already embraced the idea of consilience and that a transformation is well underway from the traditional manner of doing research—homogeneous, disciplinary, hierarchical—to a new approach that is heterogeneous, interdisciplinary, horizontal and fluid (Rhoten, 2004).*

According to Bozeman and Boardman (2003), about one third of academic scientists and engineers today are affiliated with multidisciplinary, and often multi-university, research centers, which number in the hundreds. Jones, et al. (2008) examined 4.2 million papers published over three decades and concluded that multi-university collaborations were the fastest growing type of authorship structure, produced the highest-impact papers when they involve a top-tier university, and were increasing stratified by in-group university rank. Teamwork in science that spans university boundaries generalizes across all fields of science, engineering, and social science.

The study team looked at a number of IDR centers—some well-established and others newly created—many of which had undertaken reforms to traditional discipline-based department structures on their campuses (descriptions of 35 IDR centers and organizations and a typology based on their primary location and functions are found in Appendix C). Interviewees offered insights into why and how their centers were established and what they saw as the advantages of an interdisciplinary approach. For example, one university administrator said:

> *Problem-oriented research is one of the top areas responsive to interdisciplinarity. Studying and describing in the [traditional] taxonomic sense are activities you can basically carry out on your own or through correspondence or visits with colleagues who share your "angels on the head of a pin" interest. The kinds of problems we have not been able to solve are much more complex—real-world problems that take insights from multiple disciplines, analytical techniques from different approaches, and integrated … frameworks to begin to reconcile.*

A director of a biomedical IDR center picked up on the same theme:

> *I think everyone realizes that in order to conduct meaningful experiments and derive meaningful answers, it's no longer adequate simply to be trained as a molecular biologist or to use those sorts of approaches. We need to have people who are true physiologists—systems-level people who bring quantitative approaches such as computer science, computation modeling, chemistry, physics, and engineering to bear on the problem, to really understand how a complex system works, [and] to make and design new [research] technologies.… The challenge of understanding the life sciences in general, and particularly the way the human body works, is to put the pieces together and understand at a systems level the functioning of complex systems, whether they are organs like the brain or … energy and the environment.*

At the Massachusetts Institute of Technology (MIT), one interviewee observed a fundamental change in traditional discipline-centric identification evidenced by the faculty hiring and tenure process. As many as half a dozen people would apply to more than one faculty search by completely different departments—even in different schools within the university—and all would be shortlisted. Eventually, such applicants were hired into a specific department, but in

some ways that was just their parking spot; they did research that cut across disciplinary boundaries and made connections with people in several different departments. The goal used to be to make a name for yourself on your own within a disciplinary niche; today there is increasing emphasis on interdisciplinary collaboration for junior faculty to get tenure.

Another university center director talked about how Harvard University has been organizing to address large-scale questions on energy and the environment. Traditionally, people in the Kennedy School of Government and the law school worked on the policy side of these issues, while people in the schools of engineering, arts and sciences, and medicine worked on the hard science side. The result was that "everybody has a smallish program on energy, but no one is looking at the big picture. And with so many actors on campus, it's a typical collective action problem." The center tried to break through that. The interviewee identified a key ingredient to success—a center director who is passionate about that particular issue and leads the center to become an administrative base for growing the new university-wide energy initiative.

According to its strategic plan, the Institute for Genome Sciences & Policy (IGSP) at Duke University was established

> *with the explicit conviction that scientific advancement in genetics and genomics requires more than just exceptional science carried out within the confines of traditional disciplines; it requires exploration and scholarship carried out at the intersection of traditional disciplines in the life and health sciences, social sciences and engineering, embedded in a thorough discussion of the relevant social, ethical, legal and public policy issues ... The creation of the IGSP represented Duke's recognition of the need to build bridges among researchers, clinicians, policy experts, and scholars based in all of Duke's schools and to ensure that the next generation of scholars is trained across the range of experimental, quantitative and social sciences and humanities disciplines needed to address the challenges and opportunities represented by the Genome Revolution (Duke University, Duke Institute for Genome Sciences & Policy, 2007).*

Some interdisciplinary research organizations fill the niche of funding high-risk but potentially high-return research that would not find support elsewhere. Every aspect of the environment of HHMI's new ultra high tech, "green," 689-acre research complex, Janelia Farm, has been designed to bring researchers from diverse disciplinary backgrounds together to "have a flash of insight" and to push the boundaries of current scientific knowledge as relates to neuroscience that focuses on brain circuitry and tools for brain imagery. Janelia Farm's success is predicated on the ability to do long-term research; the director cites academic culture with its traditional grant funding cycles, peer review process, and career and reward structure as stifling to long-term, high-risk, high-reward research. In funding such basic research, HHMI/Janelia is, in his words, "betting $10 million on each researcher" (Howard Hughes Medical Institute, 2006).

The Santa Fe Institute (SFI) draws renowned scientists in the physical, biological, computational, and social sciences from all sectors of science research to study problems that involve complex interactions among human, natural, and artificial systems and how complex adaptive systems relate to key environmental, technological, biological, economic, and political challenges. Much of the work of this "open institute" is done in a distributed fashion among scholars in different locations (www.santafe.edu).

There has been a similar shift in science research approaches and structure throughout Europe in the last ten years. Some examples are the University of Manchester, UK's, Interdisciplinary Biocentre (MiB), a $68 million facility opened in 2006 that can house 75 research groups and more than 600 staff; University College London's CoMPLEX program, launched in 1998; and the Max Planck Institutes' interdisciplinary efforts, which include an Institute for Dynamics of Complex Technical Systems in Magdeburg, Germany (Vastag, 2008). Schindel (2002) reports a growth in European counterparts to the National Science Foundation's (NSF) center programs devoted to long-term research in emerging fields, graduate student training, interdisciplinarity, and collaborations with private industry. Many European center programs include international cooperation and mobility in their core missions (Schindel, 2002).

Science Agencies

Science agencies conduct and fund a considerable amount of basic research.[3] The 2004 NAS report describes how the research imperative of science agencies has shifted to address complex contemporary problems with practical ramifications:

> *Research in agencies is organized primarily to serve the scientific and technological objectives of their overall missions. Within that mandate, however, flexibility has evolved in recent years, especially among agencies whose missions have taken new directions. The evolution of missions is a natural consequence of broader societal change, such as the end of the Cold War and a growing urgency of environmental and energy issues (National Academy of Sciences, 2004).*

NSF interviewees recalled that as early as the late 1980s, there was already a conversation about how science and engineering were moving in a more interdisciplinary direction. Over the past

[3] Federal funding for basic research is $29.3 billion in fiscal year (FY) 2009, up from $28.5 billion in FY 2008 and a 37 percent increase over the $21.3 billion in FY 2001. Funding for basic research represents 20 percent of the total FY 2009 Federal R&D budget of $147 billion. Some science agencies' budgets increased considerably in the last decade, notably NSF, Department of Energy Office of Science, and National Institute of Standards and Technology, with 55%, 48%, and 83% increases respectively since 2001 (due in part to the American Competitiveness Initiative). The NIH budget is 43% higher, and the National Aeronautics and Space Administration's is 17% higher than in FY 2001. (Office of Science and Technology Policy, 2009.)

two decades, NSF has developed a portfolio of funding programs designed to promote team approaches to integrative science. One of the earliest, the Science and Technology Center (STC) program, began in 1989, and in 1998 introduced an integrated partnership component. Other NSF programs that seek to nourish transformative science are the Integrative Graduate Education and Research Traineeship Program (IGERT) and, more recently, the Cyber-Enabled Discovery and Innovation Program (CDI). Per the guidance of the NAS and National Science Board, NSF centers operate under the principle that questions from the scientific community should drive research.

The study team spoke to a number of science administrators who explained how their agencies have restructured to mobilize interdisciplinary research teams to work on strategic science initiatives, and what they have done to move the scientific culture toward a more problem-solving, impact-driven approach. A prominent example is the National Institutes of Health (NIH) Roadmap for Medical Research, developed by former NIH Director Elias Zerhouni. According to an interviewee, Zerhouni recruited "physicists and all kinds of people to work at NIH because his own biomedical researchers hit their boundaries in disciplinary terms and could not resolve issues beyond that." The Roadmap's Initiative for Interdisciplinary Research addresses such emerging areas as neuropsychiatric phenomics; geroscience; obesity; organ design/engineering; genome engineering; drug discovery; stress, self-control, and addiction; and oncofertility.

At the Department of Energy (DOE), the Office of Science continues to rely on merit review and the peer review process, but now has an expectation written into almost all of the research funded across its portfolio at the national labs that scientists will work in teams, not as individual investigators.

The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) was restructured under a matrix management system, with regional locations crossed by national programs. The areas of focus for ARS's research are developed through a process of stakeholder workshops and action plans written in collaboration with scientists in the field. One ARS scientist described how, over the last 10 to 15 years,

> *It has become ingrained [in our culture] that we are problem-solvers [who are] impact-driven. We do, however, recognize the importance and value of conducting very fundamental, very basic research. A lot of our stuff is at the molecular level. But it is conducted with an alignment of its potential for impacting a particular issue or solving a particular problem. Some of it is very basic in its nature, but it has that potential application—even if it's five, ten, or fifteen years off, it has that as an eventual goal.*

An ARS manager described some of the trade-offs of pursuing results-driven science in a political environment:

You get everybody focused on a national program, and you lose the accidents and the creativity. So there's a balance you have to strike. We struggle with that constantly. We have scientists who say that they're so scripted that they no longer have the freedom to follow their own lines of inquiry. … You want to write objectives targeted on a national program, yet leave it loose enough that [the scientists] can get there however they want. … It would be nice if you could take a million dollars and sit in your lab for the next eight years and discover something, but you've chosen to work for a public research organization. You have a guaranteed source of funding—unlike at a university, where you're more grant-driven—and there's some accountability that comes along with that.

At the U.S. Geological Survey (USGS) (U.S. Department of the Interior), one science manager related that earlier attempts at integration did not get very far because of cultural resistance, but as scientists came to understand that interdisciplinary science is necessary to answer the big questions, "that turned the light bulb on and got them excited." USGS has adopted an ecosystem-based approach that requires integration across sciences, and the disciplinary barriers—biology, geography, geology, and water—are breaking down. For example, "the minerals program doesn't just look at extraction of minerals—it looks at environmental ecological effects, and it can take its geophysics and apply it to water systems." This interviewee elaborated:

You do geology, you do paleoecology, you do volcanology, but you have a huge understanding of biological processes. You can't study carbonate rocks without understanding biogenic and biological functions. Likewise, you can't understand biology unless you understand water [and the] the physical constraints of the environment.

The science manager attributed the growing willingness of USGS scientists to accept the breakdown of disciplinary silos in part to the formulation of six strategic goals that require disciplinary integration in areas such as climate change adaptation, water resources, and energy. USGS also formed science councils to bring scientists' ideas forward and to "build a common vernacular between sciences."

The Environmental Protection Agency (EPA) integrates its science at several levels. Its own staff of ecologists, biologists, hydrologists, and other scientists typically do the initial part of the agency's ecosystem services work. The agency then engages other disciplines—sociologists, economists, lawyers, and so on, usually through grant funding—to evaluate how EPA's data can be used within their disciplines. For example, economists use the data to work on the valuation of ecosystem services. The agency is now grappling with the next, transdisciplinary stage—getting the ecologists, sociologists, economists, and other specialists together to think about how their work ties together and can be used to support policy decision making.

The National Academies' Keck Futures Initiative uses conferences, grants, and communication awards to encourage interdisciplinary inquiry and break down barriers of specialization and isolation—to encourage researchers to "ask new questions" and spur communication that bridges languages, cultures, habits of thought, and institutions. Asked about the results of Keck Initiative-sponsored research, an interviewee explained that the potential for unpredictable breakthroughs is part of the appeal of IDR:

> *Within each scientific field, you tend to have a predictable, relatively iterative process of research discovery where each [research project] builds rather predictably on predecessor work. But when you go across boundaries, you end up with surprise outcomes—the potential is far greater for surprises and significant benefits to society in terms of the research outcomes.*

One external scientist shared his experience at MIT's Department of Material Science and Engineering, working with the Defense Advanced Research Projects Agency (DARPA) on advanced crystal group techniques and capabilities. At the time, the nature of crystal group research was that a faculty member would choose a piece of the problem to work on, and then go back to the ivory tower. As their results were published, other researchers would try to put together the jigsaw puzzle that resulted from independent research in related areas. The MIT group proposed forming a team to attack the work in an integrated way, including material scientists who understood controlled liquid-solid phase transformations, electrical engineers who knew how to make electronic devices from the wafers, chemical engineers who knew the control processes, and mechanical engineers who understood heat, mass, and momentum transfer. The interviewee said that although it took team members some time to understand the languages and perspectives of their counterparts from other disciplines, the end result was "an understanding of that problem unlike what any set of individual researchers had ever done."

Two Recurrent Themes

In sum, two key messages emerged from conversations with external interviewees. First, emerging areas of intellectual interest and practical importance in science today require holistic approaches with multiple perspectives and adaptive structures. IDR institutes and centers are the new "water coolers," not disciplinary departments. Second, interdisciplinary research is not an end to be pursued for its own sake—rather, it is a means to address complex questions.

Change in Science Policy and Practice

Underlying the paradigm shift described above is the general shift in science that occurred in the decades immediately after World War II, going from small-scale science performed by

individual scientists to "big science" characterized by large-scale projects funded by national governments. Inherent in the shift is that science as a pure quest for knowledge, often referred to as "blue-sky," or curiosity-driven, basic research, has taken backstage to some degree to more applied or "results-driven" science that considers how it can make substantial contributions to the well-being of the nation and the world. National research priorities and grand challenges established in a policy framework with science community input emphasize solving societal problems and global economic competition. One science administrator ruefully observed:

> *I wish we lived in a different era where pure research was appreciated for the sake of the knowledge base. It's hard for me to see us lose that; you can't get funding for it. … But that's the world we live in. Having us demonstrate the "why," rather than the wonder, is where we are, and that's a sad commentary on our society. Nevertheless, I don't see anyone getting money if they can't show some sort of applied relevance to [their work]. That's hard for scientists—particularly the older ones who were able to enjoy the last of that great era where our country was in a better position as a world leader than we are today.*

As an organization deeply associated with the former paradigm, the Smithsonian is bound to be affected by this shift. While some Smithsonian interviewees expressed consternation with the push toward more IDR (discussed in detail below), others insisted it is the future of the Smithsonian.

On a more practical level, some interviewees noted that shrinking resources for science research has necessitated a move toward more collaborative arrangements for use of laboratories, equipment, and support staff. A museum interviewee recalled the days when departments were a world unto themselves and each faculty member had a self-contained research lab. In those days, there were few common or shared facilities and little interaction among groups. The interviewee admitted that this model was "becoming increasingly outmoded—because of the cost of equipment and instrumentation, if nothing else."

IDR a Means to an End

A number of interviewees cautioned against promoting IDR for its own sake. For example, one scientist voiced this concern in the following words:

> *The current political mantra is that somehow interdisciplinary research has some virtue just because it's interdisciplinary. I would question that. The scientific question that one is [asking] should govern whether there are interdisciplinary approaches or not. It's nice to be able to have those approaches, and there are questions that are best*

approached that way. But then the converse is that some questions aren't interdisciplinary.

A science agency interviewee addressed the same issue from a management perspective:

I don't think you integrate for the sake of integration. You integrate in order to answer the questions. Scientists get that. … I think there was a misconception that you couldn't be as specialized if you did interdisciplinary [research], which is absolutely not true. It means you have to work with a team of other specialists.

Another scientist struck the same note:

Scientists like to be involved in something bigger than themselves. So it doesn't work well to push collaboration for the sake of collaboration—it's not effective or sustainable. But to the extent that you can inspire people to solve a big national or global problem and work on an issue that's bigger than themselves, it can make them gravitate more toward working with others and seeking others out to solve that big problem.

This view was echoed by Smithsonian science staff and managers. For example, one scientist warned against tying funding to massive, pan-Institutional initiatives in a "huge burgeoning field" such as nanotechnology, if the Smithsonian is not uniquely positioned to contribute to that field. Another said he was concerned that sometimes the goal becomes the interdisciplinary work itself, whereas interdisciplinary work "is just a place to look for interesting things to do; it is not an interesting thing to do in and of itself. In all of these things, we have to start out with a clear-eyed understanding of what it is we actually want to accomplish."

Smithsonian Science: Comparative Advantage and Relevance

This chapter examines the kinds of science research the Smithsonian does and its comparative advantages vis-à-vis other science research organizations. One of the assumptions underlying this study is that Smithsonian science needs to be more relevant. Discussions with interviewees were aimed at "deconstructing," to some extent, those perceptions if they exist. Relatedly, the chapter looks at relevance as a communications issue.

Smithsonian Science Has Unique National Value

As mentioned in the Introduction, Smithsonian science underwent in-depth external reviews by NRC and NAPA in 2002-03. The reviews were prompted by the Office of Management and Budget, which questioned whether the Smithsonian's Federally funded research was "inherently unique" and therefore eligible for direct appropriations not subject to peer-reviewed competition. The Smithsonian Board of Regents separately charged the Smithsonian Science Commission with reviewing the leadership, management, structure, and evaluation of science.

NRC concluded that the Smithsonian "plays an important role in the overall US research enterprise and contributes to the healthy diversity of the nation's scientific enterprise." The report stated that the research performed by three units—NMNH, NZP, and MCI (then the Smithsonian Center for Materials Research and Education)—is appropriately characterized as "unique" and as making "special contributions." Moreover, three units—SAO, SERC, and STRI—are "world-class institutions" whose combination of facilities, personnel, and specialized long-term research are enabled by the stability of Federal support. NAPA found that while the appropriation provides for researchers' salaries and core support, a significant portion of the actual research is funded through competitive grants and contracts (National Research Council, 2003; National Academy of Public Administration, 2002).

Smithsonian Science Strengths

> *SI research is unique in that it is aimed at deep understanding of natural phenomena and culture, and is not of the time-limited nature found in nearly all of the academic world. (From the responses to the Smithsonian strategic planning survey of staff)*

An important part of defining the proper role for IDR efforts at the Smithsonian is identifying the Institution's areas of comparative advantage vis-à-vis other research organizations—whether

universities, research centers, agencies, or other science research entities. The presumption is the Smithsonian would want to leverage its unique strengths as it expands its interdisciplinary research. The three external reviews cited above, interviewees for this study, and respondents to the Smithsonian-wide online strategic planning survey noted a number of specific areas where the Smithsonian can boast unique strength or potential.

Collections and Comparative Biology

Interviewees often cited the Smithsonian's collections—including the national biological collections—as having no equal. They contain an enormous wealth of information with which to pursue new questions and provide a springboard for collaboration with other research entities. NRC noted that NMNH's collections were vastly larger in size and scope than any comparable U.S. institution—four times the size of the next largest group at the American Museum of Natural history in New York—and, as such, were vital to the international natural science community and to answering questions related to such urgent challenges of our time as "rampant loss of biodiversity; global-scale degradation of water, the atmosphere, and soils; and the emergence of resilient and highly adaptive infectious organisms" (National Research Council, 2002). Brooks and Hoberg (2006) likewise stressed the crucial role systematic biology has to play in proactively addressing emerging parasitic and infectious diseases. Some interviewees saw foundational work in comparative biology as the Smithsonian's greatest strength:

> *We go out and document the occurrence and distribution of organisms and maintain vouchers for published science. There's not a single day that scientists from around the world aren't asking us to check on the identification of something cited in the literature. That's our strength. … But that isn't glitzy, and it isn't showing up on the front page of* The Washington Post *or the cover of* Science.
>
> *Certainly [the Smithsonian is] one of the half dozen or so biggest and most important institutions in the whole world [that provide] the base level [data] without which no studies of biodiversity or conservation or ecology can proceed.*
>
> *If SI doesn't do [taxonomy], who else is going to know and understand these elements of biodiversity? ... It is typical to look to SI for a long-term, lifelong expert on certain subjects.*
>
> *The taxonomic work isn't being done anymore at the universities. [SI is] keeping that alive … there's a tendency off in the university committee to go with what's flashy. So maintaining part of that basic national infrastructure … [SI] serves a really valuable role.*

Longevity and Long-Term Focus

One corollary of the focus on basic science is that, coupled with the Smithsonian's relatively stable funding base, Smithsonian researchers are able to undertake long-term, baseline monitoring studies such as the Smithsonian Global Earth Observatory (SIGEO), which grew out of the Center for Tropical Forest Science (CTFS) at STRI and now includes sites at CRC in Front Royal and SERC, as well as involving NMNH scientists. Such studies over long timeframes in stable locations are critical to answering big-picture questions and are now recognized as vital in understanding ecosystem processes and making informed policy choices, for example, about climate change, land management, and maintenance of surface and groundwater quality. Typically, such research falls outside the scope of grant-driven universities, question-driven research centers, and mission-driven agencies (National Research Council, 2002).

The Smithsonian has accumulated extraordinary, unique databases from its 150 years of research, and these are of interest across a range of disciplines and research areas. This makes it potentially a needed partner in wider collaborative efforts aimed at addressing complex issues—"these deep records (i.e., of changes in population dynamics of forest trees, tropical animals, or marine species) are extraordinarily valuable." Examples of important databases mentioned by reports and interviewees include:

- The NZP pathology department's archive of tissue samples and data covering more than 30 years
- Long-term research in marine science, going back 40 years at STRI; 32 years under the Caribbean Coral Reef Ecosystems (CCRE) program; 30 years on Florida ecosystems at the Marine Station at Fort Pierce, Florida,; and 39 years on coastal zone research at SERC
- The world's longing running field experiment on the effects of CO_2 enrichment on entire plant communities (SERC)
- Long-term research in cultural and archaeological materials and the instrumental neutron activation analysis (INAA) database

Breadth of Disciplines

The Smithsonian was said by some to bring global leadership to tropical biology, astrophysics, and the systematic study of biodiversity, and to list among its scientists a large body of specialists well-recognized among the scientific community.

Both internal and external scientists mentioned the biological sciences, including allied interdisciplinary fields such as paleobiology, as areas of great strength for the Smithsonian. Several people noted that the Institution as a whole has the largest corps of organismal biologists in the world—a fact that often goes unnoticed because of their dispersion across and within units. The biological disciplines found throughout the Smithsonian represent a comprehensive spectrum of evolutionary study, including paleontology, phylogenetics, bioinformatics, population biology, molecular genetics, human origins, and astrobiology (Erwin, 2004). Areas singled out by interviewees as having particular strength include conservation biology, marine sciences, invasive species, botany, paleobiology, ecology, human origins, the relationship between paleoclimate change and human evolution, and evolutionary and conservation genetic studies. Some interviewees thought the Smithsonian's corpus of knowledge would lend itself to rapid response work on crises relating to amphibians, birds, and invasive species.

The number of marine scientists was seen as a comparative advantage; some scientists thought that marine science was the closest to being a Smithsonian-wide activity, with scientists from multiple units involved in the Marine Science Network (MSN) (a pan-Institutional collaboration noted by the Science Commission), Sant Ocean Science Initiative at NMNH, and network of scientists involved with studies in the Pacific region. One person commented, "Taking advantage of staff expertise and the location of its field stations in marine environments, the Institution is in an exceptional position to conduct research on the responses of marine biodiversity to global warming." NRC noted NZP's pre-eminent and internationally recognized work in wildlife disease; assisted reproduction, cryopreservation, and endocrinology; population genetics and small population management; and zoo veterinary medicine. Further, it is a recognized leader in the study and conservation of certain species, among them golden lion tamarins, black-footed ferrets, Asian elephants, giant pandas, tigers, migratory birds, cheetahs, and amphibians. STRI is one of the few tropical research stations that takes an integrated approach to studying plant and animal ecological interactions in marine and terrestrial systems, and its tropical biology science is recognized internationally as outstanding. SERC, with its focus on the entire watershed of the Chesapeake Bay, is unique in its ability to conduct interdisciplinary ecological and environmental studies over a wide range of spatial scales and a variety of landscapes and ecosystems—watershed, marine, and terrestrial (National Research Council, 2002).

Areas of strength outside the biological sciences highlighted by external reviews and interviewees included astrophysics/astronomy, anthropology, materials research, and mineral, earth, and planetary sciences. For example, NMNH's Arctic Studies Center and the Archaeobiology program were seen as strong examples of synergistic, collaborative, thematically-based research; the National Anthropological Archives and Human Studies Film Archives were noted as unequalled anywhere in the world (Cordell, et al., 2007). Interviewees and respondents to the 2007 strategic planning online survey described SAO as world-class—

"Just about any job posting or post-doctoral announcement receives a huge number of top-tier applicants." CEPS's work on studying Mars is likewise highly respected.

Given the broad range of expertise that can be brought to bear on problems, interviewees and survey respondents thought the Institution was uniquely positioned to address questions related to global issues such as biodiversity loss and climate change:

> *The variety of biologists, paleontologists, and anthropologists assembled at SI puts us in a unique position to understand (1) how tropical diversity originates and is maintained; (2) the prerequisites, including the size of ecosystems, required to maintain relationships of interdependence …; (3) the impact of global climate change and how best to preserve biological diversity; (4) past episodes of global warming and other "biodiversity crises."*

To enhance IDR at the Smithsonian, interviewees mentioned the need for greater cross-unit collaboration and external partnering, which would allow the Smithsonian to bring critical mass to bear on important questions, including human ecology and human-environment interactions, astrobiology, microbial biology, Arctic studies, marine science/ocean conservation, water and water cycling on planets, bird research, amphibian decline, invasive species, and data synthesis such as the paleo database project.

Geographical Reach

Some interviewees saw the Smithsonian's research strength in regional rather than disciplinary terms, noting the Institution's extensive experience in regions such as the tropics (particularly STRI in Latin America), the North American coasts (SERC), Alaska, and Southeast Asia. One interviewee commented,

> *What is it that is unique about the science we do here? It is that, to a large extent, it's expeditionary science. … Given that, it makes sense to pick some part[s] of the world—or in the case of the STRI initiative, plots that girdle the world—and focus on those. We'll have overlapping datasets that will synergistically inform one another and produce a product far greater than the sum of the parts.*

Potential for Facilitating Scientific Dialogue

Owing to its reputation, location, prestige, and other scholarly assets, the Smithsonian is, in the view of some interviewees, uniquely positioned to draw together experts working on different aspects of complex research questions to synthesize and interpret data, identify gaps in knowledge, and formulate action plans to address those gaps:

Why not sponsor more symposia? Why not organize a big symposium around these issues, consisting of equal parts theoreticians and on-the-ground field biologists, that could then subsequently generate [new research] programs, or feed into [existing programs], or whatever?

Successes frequently cited are the public debate on the tropical extinction crisis held at the Smithsonian in January 2009 and symposia hosted by the Smithsonian in 2007 on marine science and polar science. Some interviewees who were enthusiastic about the Institution's potential in this area were, however, disappointed with its history:

The most effective thing [the Smithsonian] could do is put money into interdisciplinary working groups that are not just Smithsonian [researchers], but [include researchers from] other institutions. … An awful lot of people will come here because we're the Smithsonian. We've been remarkably absent from a lot of the … meetings bringing people together to worry about conservation biology and other issues. I guess people are afraid of the reaction on the Hill. The Smithsonian has an incredible position within the country, [but] we do a lousy job of capitalizing on it. Why don't we have international and national meetings here all the time?

Interviewees also noted that the Smithsonian has a reputation for objectivity and neutrality, making it a logical venue for discussions of sensitive issues.

It should also be noted that some research entities that convene workshops or symposia of experts provide mechanisms for supporting small groups of specialists to come together, for periods ranging from a few months to two years or more, to focus intensively on issues of interest. Others support geographically dispersed research groups that convene onsite once or twice a year.

Capacity for Professional Training

The Smithsonian offers exceptional educational opportunities for post-secondary students and post-docs/fellows, including in some relatively rare fields such as comparative biology, captive populations, and zoo veterinary medicine. In several fields, the Smithsonian is an extremely prestigious place to do graduate or post-doctoral work. Further, interviews made clear that there is a large unmet demand among Smithsonian scientists for more post-docs and graduate students, not only because of the research they do, but also because they tend to be more oriented toward collaborative work and bring new perspectives and knowledge.

Some interviewees also specifically commented on the Smithsonian's role in teaching students from countries around the world, noting that many will go back to their own countries and make a difference.

Smithsonian Science Weaknesses

The three review bodies that affirmed the unique status and importance of Smithsonian science in 2002-03—NRC, NAPA, and the Science Commission—also noted weaknesses. The Science Strategic Plan—*Science Matters: Priorities and Strategies 2005-2010*—and other changes in succeeding years have addressed many of these shortcomings. In addition, all seven science units included in this study developed their own strategic plans that flowed from the umbrella plan. Still, some of the weaknesses persist, and interviewees noted that they pose barriers to greater collaboration and IDR (and to science excellence in general) and hold the Smithsonian back from becoming a more prominent player on the national and international science stage.

The weaknesses are identified briefly here and discussed in considerably greater detail in subsequent sections dealing with leadership, culture, organizational structure, and funding.

Lack of Vision, Strategy, and Coordination

Those who reflected on the big picture of scientific research at the Smithsonian agreed that there is no underlying strategy driving it across the Institution. Despite many areas of world-class excellence, Smithsonian science does not add up to more than the sum of its parts. The blame for this tended to be placed squarely at the feet of senior leadership, which has not been up to the task of bringing focus to the collection of research projects by setting and funding strategic priorities. One Smithsonian scientist articulated this insight in particularly colorful terms:

> *The opinion of everyone outside the Smithsonian is that the whole is no greater than its parts. Until the administration looks in the mirror and admits it's doing an abysmal job at funding a historical [science] research agency, I don't think you can blame the staff for going off and letting a thousand flowers bloom that [do not have] any kind of rational relationship to each other. It is not a garden. Not even a cottage garden, with every plant doing its best. It's an abandoned lot.*

Several others echoed this view and pointed out lost opportunities to mobilize around large collaborative projects that address big questions emerging in ocean sciences, global change, anthropomorphic change, human impacts on the environment, and other areas.

Inflexibility

Several other interviewees pointed out that the Smithsonian does not have the ability to respond quickly to changes in its environment. The Institution has not built flexibility into its planning, systems, processes, structure, and—most importantly— culture. This lack of flexibility is part of the reason why large parts of Smithsonian science have not effectively responded to the shift

toward interdisciplinary, problems-based research. Although some units and centers have been relatively successful at adopting an interdisciplinary approach internally, coordination across science units to leverage Smithsonian resources has not been systematic or sustainable.

Poor Communications

Interviewees generally agreed that communications are poor among both Smithsonian science units and between Smithsonian science as a whole and outside stakeholders. The former means that Smithsonian scientists tend to be at best vaguely aware of what is going on outside their own unit (and in some cases, within their own unit). The latter means that potential funders and supporters in Congress, industry, and the general public usually do not appreciate the scope and importance of scientific research at the Institution. Underlying the situation is the inward focus that prevails at most Smithsonian science units, and often in parts within units. For example, some interviewees noted that two of the world's leading experts on carbon emissions—one of the most important science-based policy issues in a warming world—are located at SERC and STRI, yet the public is unaware of their contributions. Others noted that the Smithsonian is at a competitive disadvantage vis-à-vis other organizations with regard to raising funds, because Smithsonian science lacks the marketing, fundraising, and grant-writing support that is crucial to success in this area.

Inaccessibility of Data

As noted, the Smithsonian has accumulated unique and important long-term databases that cover a range of research areas and global science interests. As a matter of policy, the data are supposed to be highly accessible. In practice, however, access—particularly electronic access—is not always easy. In addition, many of the databases have not been synthesized, so the promise of an integrated picture (for example, of biodiversity in a specific area) has not been fulfilled. Lack of access and synthesis limits the impact and applicability of the data. As one interviewee opined,

> *The Smithsonian has collected a huge amount of data, [but some of it is just used for internal purposes]. If it were more open, there could be much broader analysis [that] would actually probably propel science forward much more rapidly. Also, when you take all the parts and put them together, you get a much stronger approach.*

Practical Weaknesses

In addition to the general weaknesses discussed above, which result from the basic culture and structure of the Smithsonian, Institution scientists face a number of more practical barriers,

including weak central administrative support, uneven management, and infrastructural elements (facilities, equipment, laboratory) that are not configured to support interdisciplinary research.

Implications of IDR for Smithsonian Science and the Issue of Relevance

In response to the statement that Smithsonian science needs to be more relevant, one interviewee asked, "Relevant to whom? Society? The scientific community? Congress? The readers of *USA Today*? Whom?" In the context of this study, one senior Smithsonian interviewee defined relevance as "addressing questions that people care about … if you're not seen as relevant, no one will want to fund you." External interviewees uniformly spoke of relevance in terms of potential impact on societal problems, for example, those contained in national research priorities and the grand challenges for science and technology developed in the policy arena with input from the scientific community. As one Smithsonian respondent to the online strategic planning survey said:

> *The current trend seems to be towards pragmatism and the unhappy belief that pure and applied science are somehow different, [even] exclusive endeavors, with the latter being intrinsically superior or more desirable. … The public will not support SI activities if the basic concepts that underlie research and their social benefits are not carefully and explicitly explained.*

For many interviewees, "interdisciplinary research," with its focus on bringing diverse perspectives to bear on solving complex problems, is one path to becoming more relevant. However, for others the term carries a more negative connotation. For example, one science administrator noted that scientists tend to think of IDR as contrasting with "cutting-edge" research:

> *It tends to be problem-driven. At best it's what they call Pasteur's Quadrant [research], which is basic research with a fixed practical outcome. Most people in the scientific community wouldn't call that "cutting edge." It's not the stuff that's going to [win] a Nobel Prize or anything like that. Interdisciplinary research has suffered on that score because that was the litmus test that traditional science has applied to it.*

This same interviewee added that in his experience, the term "has a sort of threatening tone to it of eroding existing disciplines, and more mature scientists are very aware of that and take it as a threat." The Gates Foundation, he noted, does not call its grants "interdisciplinary"—rather, it refers to them as "problem-oriented, difficult … complex." and frames them in terms of finding the right combination of researchers to solve a problem. However, other grant-making organizations, like the Keck Foundation, prefer the term "interdisciplinary."

So what is the implication of emphasizing more interdisciplinary research—often conflated with problem-oriented applied research—for an organization deeply identified with curiosity-driven basic research? A science administrator offered this observation:

> *There is a question of identity here, which is that those scientists have had a period of time, and it may vary from center to center, of having professional reputations equivalent to being a university professor. I don't know whether that's appropriate anymore, because a lot of factors go into sustaining the support and the leadership for the Smithsonian centers … you ask 100 different people, you'll get 100 different answers on that ... But it probably needs to be resolved in terms of really firmly sustaining those centers in this day and age, not in some romantic era of 10 years ago or 30 years ago or 100 years ago, but that's really sustainable today. That identity-tugging issue is a big one.*

Indeed, some interviewees were ambivalent about the idea of IDR:

> *I have a hostile reaction to the term "interdisciplinary studies."… The call for interdisciplinary [research] raises red flags in my view, because it doesn't look at the real benefits of being able to do scholarly research at your own pace, to do a really good job over a long period of time.*

In particular, scientists were concerned that increased funding for IDR projects would come at the expense of other "inherently non-interdisciplinary" research, for example, the museum biologists working in taxonomy and systematics who have traditionally worked by themselves and produced single author monographs. Mace (2004) raises the issue of the "funding and credibility gap" faced by taxonomic and systematic science, and asserts that it is impossible to develop the necessary plans and mechanisms for species conservation without adequate knowledge and description—effective conservation depends on a strong and well-funded science base in taxonomy and systematics. Brooks and Hoberg (2006) make the case that the crisis of emerging infectious disease stems from the absence of comprehensive taxonomic inventories of the world's parasites, which includes the world's pathogens. Interviewees similarly said that the greatest problem in biodiversity is the number of species that have not been well- studied or described and that that base level of knowledge is a prerequisite for any other studies. For example, one agency scientist pointed out the need to link the work of taxonomists and systematists to applied research in ecology and other areas. Without deep basic knowledge of the organisms at issue, there can be major blunders in applied work:

> *There are bandwagons to jump on of the moment—an environmental issue that makes splashy headlines. But the bottom line is that without the really basic boring research, you can't do that fancy stuff. Everything we do is a building block that provides the information for the glitzy stuff.*

An external museum interviewee said that he constantly struggles in the face of this stereotype to educate the administration that comparative zoology is a very modern discipline—"I couldn't do that if we weren't hiring the kinds of people … who use these new tools and take advantage of opportunities as they exist."

More generally, interviewees cautioned against losing sight of the importance of traditional curiosity-driven basic science and its ongoing validity. For example, one IDR center director explained that university disciplinary departments have very clear missions in terms of intellectual content, and if those departments become weaker because fundamental research is not being supported, interdisciplinary research will suffer as well—"There has to be quality and support for both things. If you don't have the disciplines, you can't do the 'inter-disciplines.' For me, the health of the departments is critical." The relevance of basic research was similarly addressed in a recent NRC report, *The Role of Theory in Advancing 21st Century Biology: Catalyzing Transformative Research*:

> *Biological science can contribute to solving societal problems and to economic competitiveness. Basic and applied research targeted toward particular mission is one way to accomplish this important goal. However, increased investment in the development of biology's fundamental theoretical and conceptual basis is another way to reap practical benefits from basic biological research. Theory is an integral part of all biological research, but its role is rarely explicitly recognized.*

A number of interviewees gave examples of instances where pure curiosity-driven research has resulted in unforeseen practical applications. CTFS/SIGEO was cited as a case in point . No one could have known when the program began in 1982 that the carbon storage data it collected would become critically important to understanding and managing the practical challenges of global climate change. In this way, much of the project's basic research work is becoming much more politically and socially relevant than previously imagined.

In the final analysis, said one IDR center director, the relative importance placed on IDR and the direction of Smithsonian science is a value judgment:

> *It's not the elimination of [individual curiosity-driven research]; it's that it is fundamentally a 19th century type of scholarship. And there is still room for it in the unexplored cracks and crannies. But most of the problems we are solving in the environmental sciences, they take multiple skills to resolve and usually require very large teams located over very large distances. Room for both, but what are the priorities of the Institution? That's a value question; it is not anything other than that.*

Many organizations have found this judgment a difficult one, according to one science administrator:

It's a bit of a dilemma, and a dilemma we feel all the time in trying to maintain the health of the research enterprise in this country. We obviously want to sustain the cutting-edge excellence of the American scientists, because they do fabulous work in their basic research. They have powered our society and the world to unimaginable heights. But everybody who has invested in it, whether it is institutions or the taxpaying public or whatever, needs to have a way of relating what those benefits are, and those benefits inevitably involve the translation, which is interdisciplinary. How that system links up … what that mix [of IDR and non-IDR] is and how they relate to each other is a very tough balance. Universities haven't figured out how to do this.

Communicating the Relevance of Smithsonian Science

In response to the premise that Smithsonian science needs to be more relevant, some interviewees suggested that the issue should be seen more in terms of better communicating its relevance to interested stakeholders than in terms of changing its modus operandi. For example, one Smithsonian scientist who saw the Institution's research orientation mainly in terms of curiosity-driven basic science argued that such science in fact can be of great interest to the public, but the Institution has not effectively capitalized on this:

The Smithsonian can be sold as something that addresses practically the problems of people, but we have a lot of agencies that are mandated to do that. So that's something we can do, but it is not our primary purpose. To me, a lot of people think the mystique of the Smithsonian is like a more rigorous version of National Geographic. … I don't think the Smithsonian has capitalized on that very well. ... One thing that captivates people is that Smithsonian science has people exploring the world in a very adventurous way. … We should retain that spirit, and part of that is the basic science, the curiosity-driven science. That stuff is really interesting to people; it is the stories we tell on our exhibit side. I don't think it should all be about studying global climate change. That's one way to sell science, but frankly everybody—every acronymic department in every agency in the world—is selling their science that way, and when you get on that bandwagon, it's hard to compete. But if you retain a certain amount of quirkiness about you, then people know that you are different. I think that would probably help fundraising in these recession-prone times—if you have ways of capturing people's imagination.

Others saw the communications question more in terms of informing stakeholders about how the science done at the Smithsonian ties into issues of practical concern, even if it is not specifically undertaken with these issues in mind:

You don't know how important some species may become down the road. I can understand the need and justification for conducting basic research without an identified

application. … If you frame the question … around the issue of a [policy] hotspot for which we need to know information, maybe that in turn will lead to increased congressional funding.

Another interviewee concurred, "There is a very interesting middle ground where we can be talking about areas of relevance of basic research, rather than research that's driven by a particular applied question." An external science administrator asserted that while

It's a very shallow society that wants to turn its back on new knowledge for its own sake, scientists might do more to explain the value of their work to those outside of their field: it can't just be "because I think this is an interesting snail"…. can there be a climate relevance to it? Can that serve as an indicator organism for the collapse of biodiversity in a certain ecosystem? To allow some of the 2008 relevance to sneak into the pie-in-the-sky curiosity-driven research—that would be pretty healthy. And you just want to be careful that you don't lose something very valuable because we don't understand why it's important today.

To get stakeholders, including funders and potential funders, excited about fundamental research would require different attitudes, approaches, and skills. Communication channels between scientists and support offices such as development and public relations would need to be strengthened. Additional staff would be needed with the skills to translate technical scientific information into layman's terms—a type of science journalism. As one interviewee commented, "It's not that tough to make the connection between the kind of stuff that goes on in natural history museums and societal needs. But museums have done a pretty lousy job I think of making that connection explicitly." Another Smithsonian interviewee agreed: "While I believe very strongly that the serendipitous side of science must not get lost, putting part of our energy into showing people why that serendipity is useful has to become part of what we do."

Two Smithsonian scientists in different units sounded cautionary notes. One said that "the world is going to eat this place up" if the Smithsonian cannot show the public and Congress why its research is relevant. The other referred to the academic culture that prevails at the Smithsonian as a barrier to such marketing: "Nobody here wants to do it. They want to do papers that will only be read by scientists—only five people in the world. That doesn't get resources to do big things. It's not the future—the future doesn't work that way."

Current State of Collaboration and IDR

This chapter discusses the current state of collaboration and interdisciplinary research at the Smithsonian, preceded by a brief look back at past experience with IDR programs and offices at the Institution. It then considers the inherent interdisciplinary nature of many areas of Smithsonian research, as well as the number and scope of current and proposed collaborative research programs and partnerships.

History of IDR at the Smithsonian

There has always been a great deal of interdisciplinary work at the Smithsonian; however, it has tended to be more informal in nature, flowing out of the shared research interests of Smithsonian scientists. For example, the Neotropical Lowland Research Program (1975-recent past) included entomologists, zoologists, botanists, and anthropologists who were interested in the flora and fauna of a particular environment. It did not have a separate office or staff, but coordinated fundraising and research through the Assistant Secretary for Science's office. Another example that began in 1988 and continues today is the Material Culture Forum, a quarterly meeting open to scholars and other staff from throughout the Smithsonian and other DC area organizations, where three or four scholars from different fields bring contrasting disciplinary perspectives to a selected subject of material culture. At the January 2008 meeting on the Smithsonian's founding donor, James Smithson, speakers included a biographer, physical anthropologist, historian of scientific instruments, and rare book librarian (Henson, 2008).

During the 1960s and 1970s and into the 1980s, a series of interdisciplinary pan-Institutional offices were created to stimulate and coordinate research in areas of importance to the Institution. The offices achieved some successes, but ultimately never integrated well within the Institution's structure and everyday workflows, and all were eventually abolished. Henson (2008) writes that there were several efforts to create new research units that addressed broad problems of contemporary interest, but their success depended on the presence of two factors—the availability of funding once the units were launched, and the traditional individualistic research of Smithsonian staff could be continued or redirected, but somehow also incorporated under the broad goals of the new units. These factors proved difficult to realize, and either the units' effectiveness was limited or they were closed (Henson, 2008).

- ***Smithsonian Office of Ecology (SOE) (and later Ecology Program under the Office of Environmental Sciences) (*1965-75).** The Ecology Office's mission was to help expand

research opportunities for Smithsonian scientists, stimulate research in ecology, and coordinate Institutional ecological work with other government agencies. Programs it and later the Ecology Program administered included the Chesapeake Bay Center for Field Biology, which ultimately became SERC; the Center for Natural Areas; and the Smithsonian-Peace Corps Environmental Program.

- ***Office of Oceanography and Limnology* (1962-75).** This office's functions included being a liaison with ocean-going vessels and scientists in order to collect biological materials; representing the Institution on committees and councils concerned with oceanography; and developing and operating the Smithsonian Oceanographic Sorting Center for marine biological and geological specimens.

- ***Center for the Study of Man* (1968-83).** The center was established in 1968 as a bureau-level organization to coordinate and carry out programs involving research, education, and services to facilitate the study of man on a worldwide scale.

- ***Office of Systematics* (early to mid-1970s).** The office had its genesis in the Summer Institute in Systematics, a series of teaching conferences in systematic biology. Its focus was convening a national conference and later committees, and overseeing the drafting of a national plan for the coordination of national systematic resources.

- ***Office of Interdisciplinary Studies* (1987-92).** The office succeeded the earlier Office of Symposia and Seminars and was designed to create opportunities for diverse audiences to discuss global concerns and debate significant issues in contemporary life. In the course of its work it produced international symposia, seminars, books, and educational materials.

Interviewees for this study recalled other, more recent attempts to coalesce Smithsonian talent around big interdisciplinary projects or better manage multiple disciplines working in a geographical region. One initiative was *New Research Initiatives*, set up with representatives from NMNH, SAO, SERC, and CEPS to realize synergy around the Smithsonian—"where we could really go in to make our own mark as an Institution, to go to NSF or other funding agencies around a multi-million dollar interdisciplinary study." The initiative never got going because of a lack of startup funds and time from scientists, who were too busy with their own projects.

Similarly, the *Institute for Conservation Biology* in the early 1990s sought to bring together conservation biologists from NMNH, NZP, SERC, and STRI for broad-scale, worldwide conservation ecology comparative projects. But, in the words of one interviewee, "it just kind of petered out." The Office of Biodiversity in NNMH served as a model for a number of years in providing logistical and administrative support to projects that cut across departments, for

example, BioLat (Biodiversity of Latin America); CCRE; Biological Dynamics of Forest Fragments Project (BDFFP); and Biological Diversity of the Guiana Shield Project. Interviewees commented that while these projects involved a number of different disciplines, they lacked an overarching perspective, and overall synthetic work never resulted from them. An interviewee opined that the end of the office came about due to perceptions that independence and individuality of projects were easier to maintain in departments.

A Thirst for IDR

Notwithstanding the skepticism about IDR of some Smithsonian interviewees, the study team encountered many who were already highly collaborative and interdisciplinary or who would like greater opportunity to be involved with interdisciplinary research teams tackling complex questions. As an example, a recent strategic planning exercise at NMNH that asked staff for "big ideas" produced 30 proposals, many of which were interdisciplinary to varying degrees. Over the course of this study, the OP&A team saw a number of examples of existing and proposed pan-Institutional programs and centers. The implication is that many staff understand the value of IDR, want to be involved in those types of projects, and have ideas about how such a program would operate within the Smithsonian environment. Some of the ideas are summarized below (see also Table 2):

- ***Smithsonian Center for Conservation Biology.*** Envisioned as a pan-Institutional center, it would foster interdisciplinary research on the biology and management of extinction-prone species. It would be both a location, e.g., at NZP or elsewhere, and a grouping of scientists who could leverage their interests to write grants for Federal or private sector support.

- ***Pacific Science Network.*** An existing consortium of collaborators from the Smithsonian and throughout the Pacific, it engages in studies of the forces of change in the Pacific—formation and change of islands, evolution and extinction of life, and interactions and impacts of humans. A proposal calls for a more effective, integrative, and interdisciplinary approach through a virtual center of current Smithsonian anthropology, biology, geology, and planetary science studies in the Pacific, with close to 100 collaborating institutions.

- ***Smithsonian Planetary Science and Education Center.*** Led by CEPS, this proposed virtual center would draw from all Smithsonian science units. Program and organizational elements include a highly competitive research program that could support large grants; post-doc and senior scientist fellowships and short-term visiting scientists; short-term employees, including engineers and computer programmers; a

Table 2. Smithsonian Partnerships, Networks, and Other Collaborations

Partnership Name	Who Is Involved?	What Do They Do?
University Partnerships		
Harvard-Smithsonian Center for Astrophysics (CfA)	Harvard College Observatory (HCO), Smithsonian Astrophysical Observatory (SAO)	Coordinate related research activities under a single director
Smithsonian-Mason Global Conservation Education Program	National Zoological Park Conservation & Research Center, George Mason University	Further the education of current and future conservation students and professionals
UMD/NMNH BEES (Behavior, Ecology, Evolution, Systematics) Program	University of Maryland, National Museum of Natural History	Train the next generation of scientists
STRI-McGill Graduate Program/Undergraduate Field Studies	Smithsonian Tropical Research Institute, McGill University (Canada), City of Knowledge (Panama)	Offer graduate research program to students interested in environmental issues in the Neotropics
Princeton Field Course	Princeton University, Smithsonian Tropical Research Institute	Educate students about natural history, ecology, and conservation in various ecosystems
STRI-Yale Environmental Leadership and Training Initiative (ELTI)	Smithsonian Tropical Research Institute, Yale School of Forestry & Environmental Studies	Enhance the capacity of key decision makers to better manage and protect forest ecosystems and biodiversity
Native Species Reforestation Project (PRORENA)	Smithsonian Tropical Research Institute, Yale School of Forestry & Environmental Studies	Demonstrate that ecological restoration in the tropics is feasible, financially attractive, and socially viable
Center for Tropical Forest Science (CTFS; see also SIGEO below)	Smithsonian Tropical Research Institute, Arnold Arboretum of Harvard University	Long-term tropical forest research using a set of permanent, large-scale plots established in forests that differ in climatic conditions, soil types, and disturbance regimes
Federal Partnerships		
USDA Systematic Entomology Laboratory (SEL)	Agricultural Research Service (U.S. Department of Agriculture), Department of Entomology (National Museum of Natural History)	Develop comprehensive global classification systems for insects and mites, furnish taxonomic services to state and private organizations
USGS Biological Survey Unit (BSU)	U.S. Geological Survey (U.S. Department of the Interior), National Museum of Natural History	Conduct original research on systematics, nomenclature, and biodiversity of vertebrates
National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Services	National Oceanic and Atmospheric Administration (U.S. Department of Commerce), National Museum of Natural History	Conserve, manage, and protect living marine resources

Walter Reed Biosystematics Unit	Walter Reed Army Institute of Research, National Museum of Natural History	Conduct lab and field research on systematics of medically important arthropod species
NMNH Feather Identification Laboratory	National Museum of Natural History, Federal Aviation Administration, U.S. Air Force	Bird strike analysis
Ocean Science Initiative (OSI)	National Oceanic & Atmospheric Administration, (U.S. Department of Commerce) National Museum of Natural History	Advance scientific understanding of the oceans and increase public awareness
Multi-Organization Partnerships and Programs		
Smithsonian Institution Global Earth Observatory (SIGEO)	Smithsonian Tropical Research Institute, other Smithsonian units, Federal agencies, and organizations around the world	Measure the effects of climate change using long-term global data from a set of permanent, large-scale plots established in forests that differ in climatic conditions, soil types, and disturbance regimes
HSBC Climate Partnership	HSBC Bank, The Climate Group, Earthwatch Institute, World Wildlife Fund, Smithsonian Tropical Research Institute, Smithsonian Environmental Research Center	Combat the urgent threat of climate change by inspiring action by individuals, businesses, and governments worldwide
National Ecological Observatory Network (NEON)	More than 50 U.S. & Canadian universities, laboratories, and scientific organizations, including the Smithsonian	Gather data and develop scientific understanding of pressing ecological challenges
Encyclopedia of Life (EOL)	Biodiversity Heritage Library, Field Museum, Harvard University, Marine Biological Laboratory, Missouri Botanical Garden, Smithsonian Institution	Develop an online reference database on all 1.8 million currently known species and stay current on new developments
Consortium for the Barcode of Life (CBOL)	More than 160 member organizations from more than 50 countries, including the Smithsonian	Explore and develop the potential of DNA barcoding
Integrated Taxonomic Information System (ITIS)	Agriculture and Agri-Food Canada (CONABIO), National Biological Information Infrastructure (NBII), NatureServe, National Oceanic and Atmospheric Administration (U.S. Department of Commerce), National Park Service (U.S. Department of the Interior), Smithsonian Institution, U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Geological Survey (U.S. Department of the Interior)	Create an easily accessible database with information on species names and classifications

Conservation Centers for Species Survival (C2S2)	San Diego Wild Animal Park (CA), Fossil Rim Wildlife Center (TX), The Wilds (OH), White Oak Conservation Center (FL), National Zoological Park Conservation & Research Center (National Zoological Park)	Study and create self-sustaining populations ex situ and in situ
Mars Express Mission	National Aeronautics and Space Administration, European Space Agency, Center for Earth and Planetary Studies (National Air and Space Museum)	Gain a better understanding of the geology, surface, atmosphere, history, and water on Mars
National Astrobiology Institute (NAI)	National Aeronautics and Space Administration, National Air and Space Museum, Massachusetts Institute of Technology, Harvard University, CalTech, University of California-Los Angeles and Berkeley, Dartmouth College	Draw scientists together to answer questions such as: "Is there life anywhere outside of Earth?"
India Science and Technology Partnership (INSTP)	The Indo-US Science & Technology Forum (IUSSTF), Smithsonian Institution	Promote the interaction of government, academia, and industry in science, technology, and health
Biological Dynamics of Forest Fragments Project (BDFFP)	National Institute for Amazonian Research (INPA) (Brazil), Center for Tropical Forest Science (Smithsonian Tropical Research Institute)	Study plant and animal communities and ecological processes in forest fragments before and after deforestation
Camisea Project (Peru)	Shell Oil Prospecting & Development, National Zoological Park	Assess possible environmental impacts of extracting gas deposits
Gabon Biodiversity Program	Shell Oil Prospecting & Development, National Zoological Park	Increase understanding of biodiversity and energy resource development in Gabon
Moorea Biocode Project	University of California-Berkeley, SNRS-EPHE (France), Smithsonian Institution, Florida Museum of Natural History, French Polynesia (Research Department), IRD (New Caledonia), Association for Marine Exploration (Hawaii)	Genetically barcode the first complete tropical ecosystem
Biological Diversity of the Guiana Shield (BDG)	Department of Botany (National Museum of Natural History), Departments of Zoology, Entomology, and Anthropology (National Museum of Natural History), scientists from other Smithsonian units and external organizations	Study, document, and preserve the biological diversity of the Guiana Shield area of northeastern South America
The Indo-Pacific Conservation Alliance (IPCA)	Bishop Museum, Smithsonian Institution, World Bank, other organizations	Promote conservation and biodiversity in tropical Indo-Pacific

Panama Amphibian Rescue and Conservation Project	National Zoological Park, Smithsonian Tropical Research Center, African Safari Park, Cheyenne Mountain Zoo, Defenders of Wildlife, Houston Zoo, Summit Municipal Park, Zoo New England	Joint venture to save amphibians from the brink of extinction in the eastern region of Panama.
Multi-unit/Organization Laboratories and Instruments		
Laboratories of Analytic Biology (LAB)	National Museum of Natural History, other Smithsonian units and external organizations	Support molecular research at Smithsonian, mainly National Museum of Natural History
Genetics Laboratory	National Zoological Park, National Museum of Natural History	Support molecular genetics studies with people inside and outside Smithsonian
MMT (Mount Hopkins, AZ) **Magellan Telescopes (Las Campanas, Chile)**	MMT: Smithsonian Astrophysical Observatory and University of Arizona Magellan: Carnegie Observatories (Carnegie Institution for Science), Harvard University, Massachusetts Institute of Technology, University of Arizona, University of Michigan	Study basic physical processes that determine the nature and evolution of the universe; MMT and its twin Magellan Telescopes have been crucial to many Harvard-Smithsonian Center for Astrophysics discoveries
Submillimeter Array (SMA), Mauna Kea, HI	Smithsonian Astrophysical Observatory, Academic Sinica Institute for Astronomy and Astrophysics, University of Hawaii Institute for Astronomy	Study planetary systems, asteroids, comets, planets in our solar system, dying and newborn stars, redshifted radiation from the most distant/oldest objects in universe, radiation from Big Bang
Very Energetic Radiation Imaging Telescope Array System (VERITAS) (Mount Hopkins, AZ)	Smithsonian Astrophysical Observatory, National Science Foundation, U.S. Department of Energy, several colleges and universities worldwide	Study "Cherenkov radiation" phenomenon, a shower of charged particles caused by gamma ray bursts in space
Chandra X-ray Observatory	Smithsonian Astrophysical Observatory, National Aeronautics and Space Administration	International facility that carries out observations, spanning the gamut of astrophysics from planets to clusters of galaxies, for hundreds of government organizations
Spitzer Space Telescope	Smithsonian Astrophysical Observatory, National Aeronautics and Space Administration	Infrared Array Camera that penetrates dense clouds to view the birth of stars and planets and study the distant universe
Pan-Institutional or Multi-unit Programs and Symposia		
Marine Science Network (MSN)	National Museum of Natural History, Smithsonian Environmental Research Center, National Zoological Park, Smithsonian Tropical Research Institute field stations	Advance marine science objectives

Smithsonian Ornithology	All ornithologists across Smithsonian	Provide educational resources and references on birds to the general public
Caribbean Coral Reef Ecosystems (CCRE)	Various scientists at National Museum of Natural History and Marine Science Network	Study reef, mangrove, sea grass meadow, and plankton community in Carrie Bow Cay, Belize region
Amphibian Working Group	National Zoological Park Amphibian Conservation Program, Smithsonian Tropical Research Institute, National Museum of Natural History	Understand and prevent amphibian decline
New Threats & Realities in the Tropical Extinction Crisis	Office of the Under Secretary for Science, Smithsonian Tropical Research Institute	Symposium January 2009
Marine Science Symposium	Office of the Under Secretary for Science, Marine Science Network	Symposium November 2007
Smithsonian at the Poles-International Polar Year	Office of the Under Secretary for Science, National Science Foundation	Symposium May 2007
Proposed Pan-Institutional Initiatives		
Smithsonian Center for Conservation Biology	National Zoological Park, eventually Smithsonian-wide	Collaboratively promote conservation worldwide through scientific research, education, and professional training
Smithsonian Network for Human Ecology Research and Education	National Museum of Natural History, Smithsonian Tropical Research Institute, National Zoological Park Conservation & Research Center, Smithsonian Environmental Research Center, National Museum of the American Indian, Center for Folklife and Cultural Heritage	Collaboratively understand and promote ecology studies
Pacific Science Network	National Zoological Park, National Museum of Natural History, Smithsonian Tropical Research Institute, National Air and Space Museum	Create an organizational and physical framework for future research in the Pacific
Smithsonian Planetary Science and Education Center	Center for Earth and Planetary Studies (National Air and Space Museum), National Museum of Natural History, Smithsonian Astrophysical Observatory	Collaboratively understand and promote exploration of the Earth, moon, planets, and exosolar planets
National Center for Synthesis in Biological Evolution	National Museum of Natural History, external scientists, local universities	Address the fragmentation of knowledge within evolutionary biology and apply its concepts and methods to questions of public concern

Tarahumara Indian Project in Mexico	CONABIO (Mexico), Departments of Anthropology, Entomology, Botany, and Vertebrate Zoology (National Museum of Natural History)	Conduct a multidisciplinary, bio-cultural study in Chihuahua, Mexico

Sources: The information in the table comes from websites and interviews.

pan-Institutional education initiative, online magazine, and public website; and an internal board of researchers from Smithsonian units, as well as a national board of prestigious external citizens who support earth, planetary, and space science.

- ***Smithsonian Network for Human Ecology Research and Education.*** Modeled after SIGEO, the network would offer a broad framework for linking parts of the NMNH Anthropology Department with other Smithsonian staff focused on biodiversity and sustainability issues, e.g., in other NMNH departments and at STRI, NZP/CRC, SERC, NMAI, and the Center for Folklife and Cultural Heritage. The organizing principle is that sustainability needs to be considered not only from the point of view of the environment, but also of the people trying to maintain their way of life within these environments. The initiative would include cross-departmental hires in human ecology.
- ***National Center for Synthesis in Biological Evolution.*** This submission to NSF proposed an integrative center under NMNH to foster and facilitate a wide range of synthesis activities in evolutionary biology. The center would address the fragmentation of knowledge within evolutionary biology as well as apply its concepts and methods to questions of public concern. Primary venues for center activities would be working groups, workshops, and conferences.

Inherently Interdisciplinary

Some areas of Smithsonian science are, by their nature, more likely to involve collaboration, interaction, and integration across disciplines. While not intended to be comprehensive, the following list of areas came up frequently in interviews as ones where working across disciplines is commonplace and necessary.

Astronomy, Astrophysics, and Planetary Science

The physics and astronomy communities have a long history of collaboration, since the complexity of the research questions—and of the facilities and instrumentation required to address them—require expertise not only from these disciplines, but also from engineering, computer science, and other areas. The term “interoperability” is used within the fields of

astronomy and astrophysics to describe the integration of different types of data (taken at different wave lengths—for example, x-rays, optical, and radio) on a given object in the sky, because these different types of data come from different communities with different ways of doing things. Further, some of the facilities, equipment, and instrumentation involved in this field are extremely expensive, necessitating a certain level of sharing among organizations.

Likewise, planetary exploration missions are by definition multidiscipline, multi-institution, big-dollar projects. One interviewee explained, "If you are looking at things like choosing landing sites for spacecraft, that involves engineers, finance people, and meteorologists to tell you whether or not the winds are going to blow you off course if you are coming down on a parachute or something."

Working within the broad field of planetary science are physicists, chemists, engineers, material scientists, geologists, instrument builders, and many other specialists. According to an interviewee in the field, it involves "All people who look at planets in one way or another. There are people that I struggle to have conversations with, because their expertise is so different from mine. You bring all those people together."

Environmental and Conservation Sciences

As one person commented, "Environmental studies demand interdisciplinary collaboration." NZP, SERC, and STRI interviewees typically described their conservation biology and ecology work as inherently interdisciplinary. At SERC, for example, collaboration is required to address large-scale ecological problems at the level of ecosystems, landscapes, and even continents or whole globe: "Ecology by definition is multidisciplinary, so to address big problems you need to have teams of people working together, and it's helpful to have interdisciplinary members of those teams." SERC teams often include different levels of expertise—students, technicians, post-docs, and senior PIs. Together, they address a range of separate but interrelated tasks such as data collection, data integration, standardization of measurements with other monitoring networks, and communication of results to management. One scientist described the variety of specialists working on reef ecosystems who were gathered at a recent professional conference—not just the expected ones such as invertebrate zoologists or botanists, but also people studying water movement, chemists, and generally "a tremendous number of people trying to understand the whole ecosystem."

Several Smithsonian scientists suggested that extensive rethinking of traditional disciplines would be needed if the Smithsonian is to move with the current trend from observation of ecosystems to conservation action. For example, a Zoo scientist working on amphibian decline said,

If we're going to save amphibians, we're going to need people who know how to do education. We're going to need to embrace the geneticists who can tell us how to identify this chytrid fungus that's wiping out half of the amphibian species in Meso-America. We're going to have to speak with the climate change people. We're going to have to speak to all of these people and work out what are the various conservation actions that we can take.

An issue raised by both internal and external interviewees is the need to bring the human dimension—such as policy, social science, economics, and politics—into the environmental and conservation science equation. One example is the proposed Smithsonian Network for Human Ecology Research and Education described above. According to Hellinger and Hellinger (2008), it is essential to view humans as an integral part of the ecosystem—not to treat populations living in or near wildlife habitats as part of the ecosystem is to lose a critically important potential partnership for sustainable habitat conservation. Likewise, failure to consider the political economy that has shaped current circumstances and to involve local communities in finding solutions will compromise sustained success.

One Smithsonian interviewee spoke of the broadening of what the Migratory Bird Center does from a narrow focus on species and morphological research to looking at issues such as land management, which is intimately tied to biodiversity preservation. This person noted that while the biologists look at "shade-grown" techniques for coffee cultivation in terms of the implications for biodiversity, the center also comes at it from the standpoint of socioeconomic benefits to the growers. Looked at from these two different perspectives, shade-grown coffee can be seen as part of the solution to problems that are both environmental and socioeconomic in nature.

Similarly, some areas of interest—such as wildlife disease and emerging infectious diseases—involve the intersection of wildlife, domesticated animals, and human biology and society. In general, however, the Smithsonian has not integrated the social sciences and like fields with natural sciences in any major way. An interviewee lamented, "There is nobody on the social science side. The anthropologists are looking at past culture, [but] there is nobody looking at contemporary cultures or societies."

Archaeology

Archaeologists at the Smithsonian described their modus operandi as developing the research questions and obtaining samples, then partnering with experts from other disciplines to analyze them—"Geologists to figure out elevation from the shell samples and associated peat and wood samples; pollen experts to look at climate change and vegetation's response to it, and how forest and tundra boundaries change. So that kind of work just goes on and gets folded into your

perspective." The archaeobiology program at NMNH was explicitly started as an interdisciplinary program that could bring together botany, biology, and anthropology to study the interactions of humans, plants, and animals.

Material Science

MCI is one of a few places in North America—others are the Metropolitan Museum of Art, Getty Conservation Institute, and Canadian Conservation Institute—that has scientists and conservators working together. The scientists come from engineering, archaeology, chemistry, and biology; the conservators have art history, collections, and science backgrounds. Interviewees explained that each discipline "has a little different take on how they operate" and interpret the same data in different ways. But when they mesh their different observations, the results are "very good communications, better studies, better understanding of what the studies mean, more relevant applied research ... a strong publication."

Smithsonian Partnerships and Other Collaborations

Collaborations that involve multidisciplinary, interdisciplinary, and even transdisciplinary team approaches generally involve research that is broader in intellectual or geographic scope than traditional discipline-based work. Such collaboration is also a means to tackle complex questions that cannot be effectively addressed by a single investigator or collaboration among peers in the same discipline.

Table 2 lists some of the major Smithsonian partnerships and other collaborations—university, private sector, multi-organization, and pan-Institutional currently underway or proposed—that arose during the interviews.

Despite the number of collaborations in which Smithsonian science units are engaged, it appears that the Smithsonian is not involved, particularly in terms of Institutional or unit-level partnerships, on anything like the scale of some of the organizations the OP&A study team spoke with. For example, the National Institute of Standards and Technology (NIST), an agency roughly the same size as the Smithsonian, counts 2,600 associates and facilities users—"We have more technical partners than we have technical staff." A USGS interviewee explained that the agency "does not farm science out, we form partnerships." While a much larger agency, USGS has approximately 2,000 partners ranging from state and local governments to university systems.

In many instances interviewees suggested that the Smithsonian could do much more through increased partnerships to leverage its resources and contribute to larger scientific endeavors.

They often mentioned Federal science agencies and local universities as likely places to cultivate collaboration. SAO was held out as a model:

> *Partnerships such as the Harvard-Smithsonian Center for Astrophysics should be replicated with other schools and research labs, and maybe even with private corporate scientific research centers, so SI may foster a moderately large network of research initiatives, aggregating talent and leadership in a wider spectrum of scientific subjects and areas of current concern.*

One respondent to the strategic planning online survey urged the Smithsonian to be cognizant of emerging areas that are ripe for partnerships:

> *We find ourselves on the edge of a new frontier in technology—renewable energy [and other technologies for] reducing our carbon footprint and saving our planet from environmental disaster. These areas will generate research and development funds/grants, producing employment and economic/educational opportunities for the world. The Smithsonian should position itself as a major player in the development of partnerships for these new frontier areas.*

(A diagram of different types of collaboration mechanisms and their degree of formality, ranging from the proverbial "handshake" between individuals to a formal contract can be found in Appendix D.)

Co-authorship Data

To get an idea of the degree and extent of internal and external collaborative activity of Smithsonian researchers, as measured by joint publications, the study team examined co-authorship data contained in the ISI Web of Science database.[4] Both the OP&A analysis of years 2004 through 2008, and a prior review done by Thomson Scientific for OUSS of years 2001 through 2005, corroborate the Smithsonian Science Commission's observations based on

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[4] The *Web of Science*® bibliographic database, a product of Thomson Reuters, is widely used in the university community to measure productivity and collaboration. However, because the database does not include many of the biodiversity and other publication venues used by Smithsonian researchers, several fields of Smithsonian expertise such as taxonomy, paleontology, and anthropology are underrepresented. In addition, undercounting may occur because of the way Smithsonian authors sometimes identify their home organization, e.g., using an acronym, department name, or variation of their organization name rather than a standard one. During the 2006 analysis of *Web of Science* publications data for seven Smithsonian science units conducted by Thomson Scientific for OUSS, it became apparent that the search missed some of these variants of names. The report noted that the diversity of Institutional affiliations used by Smithsonian scientists is a challenge.

anecdotal information—Smithsonian researchers are collaborative, but are most likely to interact with researchers outside the Institution and, of those, most frequently with university-based researchers. The number of cross-Smithsonian unit papers as a percentage of all co-authored papers is miniscule. While science managers acknowledged that there are a variety of legitimate reasons for Smithsonian researchers to seek external vs. internal partners, they also recognized that there were lost opportunities to be realized through leveraging resources, responding to urgent scientific questions, and applying for large grants that required pooling of talent from dispersed Smithsonian science units.

Leadership

> *Organization leaders must do "adaptive" work, not only "technical" work, to keep up in a turbulent environment where new technologies are changing how work gets done, demographic shifts are roiling talent pools, and market demands are increasingly dynamic (Heifetz, 1994).*
>
> *The challenges that are most likely to require an adaptive approach are those that are unfamiliar, complex, and require a combination of disciplines to address (Snyder and Briggs, 2003).*

The critical need for effective, committed, sustained leadership emerged in the interviews and literature, particularly when an organization is contemplating new directions or emphases that require major changes. Strong leadership is required not just at the top, but at all levels. As one interviewee said, "The message has to come down from the very top and [be] encouraged at every level through the organization" down to the project team. Smithsonian interviewees emphasized several leadership issues specific to the Institution:

First, excessive turnover of leadership has resulted in constant changes in direction and priorities. Said one person, "Over the last couple of years there has been enormous turnover in our senior staff at the Smithsonian. You get someone who is really interested in [collaboration] and they want to help, and then they leave."

Second, leadership at all levels has been unwilling to make hard decisions or to follow through on ones they have made, ending up instead trying to please everyone. For example, leaders have spread funds thinly but equitably for fear of alienating a particular group or unit, instead of focusing resources on priorities—with the ironic result that everyone feels they are not getting enough. One interviewee quipped, "The Smithsonian could be transformed, I don't have any doubt about that, but it will take somebody who is willing to break some china."

Third, the selection of leaders has been weak. Leaders are often chosen not for their leadership or management skills, but for reasons such as politics and academic stature. With respect to science leaders specifically, an interviewee noted,

> *Leadership is very uneven across the Institution. Some [science leaders] are just not … people who have good interpersonal skills or can get people to work together,*

[although] they may be very good scientists. We tend to put scientists in leadership positions, and that works maybe 30 percent of the time.

New leaders, particularly inexperienced ones or those coming into the Institution from the outside, are not provided with the mentoring they need to get up to speed. As one interviewee lamented, "It seems like we always end up pulling in people who don't fundamentally understand enough about the Smithsonian to make good decisions. Or they are political types who want power and money."

The interviewees and literature pointed to several critical elements of effective leadership when it comes to carrying out major initiatives that involve significant organizational change and a challenge to the prevailing organizational and scientific culture.

The Starting Point: A Value-Driven Purpose

The starting point is for the leader to articulate a persuasive case for the new direction or initiative. With respect to the Smithsonian, one interviewee made this the point:

What are you doing that couldn't be done with a bunch of individual investigator grants? … What are you trying to produce in the end? That drives how you want to integrate [your research efforts]. The challenge is finding the right niche for your organization and not overreaching at the same time. I see a lot of different agencies and organizations claiming they can do all this stuff … [But] they will never have the capacity to do it on the scale necessary. The Smithsonian—you have real legitimacy if you choose those [research] areas … and partnerships wisely, building on the capacity you have in place, your educational mission.

Another interviewee offered similar observations:

If we start with what we want to achieve—what [we want] our impact [to] be—then you can say, "All right, what do we need from the various disciplines to get to that point?" We're not going to get anywhere if we just start with the objective of bringing disparate perspectives or disciplines together [without asking] "Why are we doing that? What's the purpose?

For example, Duke University's new strategic plan in 2006, entitled, "*Making a Difference*" (http://stratplan.duke.edu/), strongly affirmed the centrality and importance of interdisciplinarity and knowledge in the service of society, often the product of interdisciplinary scholarship. It reflects a belief that the university has the power to produce knowledge that can improve the world by collaboratively tackling the true complexity of societal problems.

Key Starting Point Questions for the Smithsonian

As Janelia Farm was in the planning stages, its organizing question was "what important biological problem would you tackle if you could assemble 100 people for 10 years with generous funding?" (Rubin, 2008). With a mission as broad as "the increase and diffusion of knowledge," one external interviewee saw defining the basic purpose of collaboration and IDR at the Smithsonian as a challenging but essential task:

> *The overall goal of the roadmap [at my agency] addresses difficult questions. But they're limited; they're not open-ended … If you don't have these unifying questions, you have a difficult time coming up with an IDR approach. When I look at the diversity of what the Smithsonian does, I think, "My God—what are the questions? What do the environmental folks, or the archaeology folks, have in common with the people at the Zoo, or the geologists?" … That's why I think your task is difficult.*

As discussed in the section on the relevance of Smithsonian science, interviewees raised several fundamental and long-standing values questions that they thought needed to be considered when contemplating how collaboration and interdisciplinary research fit into the big picture of science at the Smithsonian, and that, if not addressed, could undermine any change process.

What does interdisciplinary research mean to the Smithsonian? A fundamental question is whether the Smithsonian wishes to orient itself more toward areas of research in a true interdisciplinary sense, or to continue to work primarily in its traditional areas of disciplinary strength. One interviewee posed this question, "Are you just looking for more collaborations? Or are you looking for true intellectual interdisciplinary [engagement]?" In other words, is the image of collaboration at the Smithsonian merely one of scientists from different disciplines working alongside one another—for example, doing field work at the same location? Or is it a vision of integrated research that brings different disciplines into a dialogue that produces a whole that is greater than the sum of its parts?

What is the role of curiosity-driven research at the Smithsonian? One external interviewee asked whether the Smithsonian saw itself as "a science-for-science's-sake organization," where inquiry is driven by individual scientists' interests, or as an organization that tackles complex scientific questions and challenges that are likely to require contributions from multiple disciplines and that have a more immediate practical focus.

As noted in the discussion of Smithsonian science's relative strengths, a number of interviewees held that foundational work in comparative biology is the Smithsonian's greatest strength. Because this type of work often involves a single discipline and can frequently be done with little collaboration, the implication is that IDR would at best have only a supporting role in Smithsonian science. Others disagreed. One Smithsonian interviewee thought that maintaining

a focus on foundational work in comparative biology amounted to living in the past and is one reason the Smithsonian has been overtaken by other research organizations: "To say that we are the engine for basic research is nonsense; we're a very small player, very far behind. The question now is, what role does the Smithsonian play, given that we're a mid-sized tree growing in a stand of [giant] redwoods?"

Should the Smithsonian focus on global societal concerns? As noted, some interviewees believed that the Smithsonian, by virtue of its status as a largely taxpayer-supported organization, has a responsibility to play a role in finding solutions to major global problems where it has particular expertise, such as climate change and loss of biodiversity. Others thought that the Smithsonian's formidable biological collections and long-term databases established over many decades put it in a unique position to contribute to this scientific effort. Pragmatism also enters into the debate, with some interviewees believing that, to some degree, the Smithsonian needs to follow the money. One person described a former central manager who was successful in raising money from Congress and elsewhere as having "a good ear for figuring out the latest science trend and how to fit existing programs into that theme," and then packaging the budget in a way that could be sold to Congress.

Some questioned whether it made sense for the Smithsonian to blindly jump on the bandwagon along with the many other organizations currently trying to justify themselves in terms of contributing to the today's environmental and policy issues. One person saw political reasons to stay away from a "big questions" approach to research, noting that these questions "by their very nature are [entangled] in politics, [and] you can end up cross-wise with the politicians, depending on where they are on that issue at the moment." Others said it is always possible to imbed big question research in broader, more neutral-sounding programs that appear less sensitive, e.g., "long-term impacts on terrestrial ecosystems." Topical and politically sensitive issues like climate change would fit easily under that heading, as would projects such as SIGEO, National Ecological Observatory Network (NEON), and long-term monitoring studies of forests by STRI and of marine ecosystems by SERC—projects that have scientific value independent of current policy concerns, and are unlikely to arouse political passions. The Smithsonian's reputation for objective research and people's perception of it as a neutral party would also mitigate against political reactions, some interviewees thought.

Vision

Beyond that starting point, several interviewees talked about the importance of leaders with vision. For example, the director of an external organization that conducts scientific research described his role largely in turns of articulating, promoting, and supporting a vision with staying power:

I spend a lot of time on internal management issues to build a culture and to demonstrate [the vision] to people. If scientists understand the value [of] the vision, I think they'll do it. You [also have to] get the bureaucracy off them, give them reasonable rewards [for supporting the vision], and [convince them] it's focused and long term … so they don't think we're going to do this for two years and then do something else.

Several interviewees discussed the possible need to reallocate resources and change organizational structures to support a vision. One noted that senior leadership must be willing to say, "This is our vision, this is where we are right now; and because of this, we need a big chunk of funding for these two units this year." Another suggested that pulling some facilities and programs into the Castle "would be a good thing, if the Castle were able to articulate and implement a vision that we could move with, independent of players and bureau politics."

Strategic Research Direction

Any institution that doesn't develop new bold major initiatives won't get the resources to do science … identifying big cross-cutting initiatives is the duty of the Under Secretary's office, to knock people's heads together. I guess what I was reacting to in the whole process is that you don't want to throw the baby out with the bath water. Almost all of the really good ideas that are now scaled up to be big started out as small ideas that individual scientists came up with.

In setting a strategic direction and deciding what questions a science organization should address, one of the prevailing messages from both internal and external interviewees was the need for a bottom-up process—but also the importance of a strong leader willing to make a final decision and stick with it.

Former NIH Director Zerhouni described his primary leadership role as thinking strategically—"Where does the agency need to go? How do we organize and manage the agency in a way that's most effective? How do we communicate with the many constituencies?" Within weeks after accepting his post as director, Zerhouni organized a series of meetings with both the outside scientific community and the scientific community within NIH—

Everyone came to the table, and I said, you know, the first thing we have to do is we need to know where we're going in this early part of the 21st century ... and within a year, we came up with a major initiative called the Roadmap for Medical Research in the 21st Century, which is the first trans-NIH, cross cutting, cross institute vision about where medical research, biomedical and behavioral research, need to go and how you get there (Zerhouni, 2005).

At USGS, a decadal plan (2007-2017), organized around six new strategic directions, recognized the need to transcend the traditional USGS structure and to engage in broad interdisciplinary thinking and action (U.S. Department of the Interior, U.S. Geological Survey, 2007a). The director held many meetings and discussions to convince scientists of the strategy's importance—"its relevance and the fact that it's filling gaps that no one else is doing right now effectively." The agency's strategic plan was then developed internally so that the scientists "own it"—"It requires the scientists to take risks, to get outside their comfort zone. So they had to have confidence we were going in that direction." The plan was vetted through the scientists, and the agency committed to it.

In setting its research direction—a "roadmap" process to facilitate multi-university planning—one NSF-funded multipurpose, multidiscipline university research center (MMURC) held an annual retreat to ensure a participatory approach to talking about and revising the roadmap—"We do not accept a dictatorial approach" (Bozeman and Boardman, 2003).

While providing an opportunity for creative ideas and innovation to "bubble up" and for participants vested in the outcome to have input is crucial, ultimately it is leadership's responsibility to decide what questions the organization should be addressing in its science and what impact its science can and should deliver. Not only should the organization start with a clear sense of what it wants and can accomplish, but it also needs to be able to articulate why it could not be accomplished equally well by other organizations or through other means. Further, the specific research areas in which an organization undertakes to work need to reflect its comparative strengths and resources. That is, it has to be able to deliver what it promises.

Setting Priorities

Interviewees suggested that Smithsonian leaders need to face up to some hard decisions about Institutional priorities, and stand by those decisions in the face of resistance. One interviewee noted,

> *If the Under Secretary says [collaboration] is important … the Under Secretary should also say, "Yes, you will. And if you don't want to and we dissolve this thing, I'm taking that FTE [position] and moving it to this other unit, because we are not going to destroy their productivity because you did not want to go along with what was best for the Institution."*

One frequently mentioned obstacle to setting priorities at the Smithsonian—and to good decision making more generally—is the quagmire of consensual, committee-based decision making. Interviewees stressed the need for leadership to curb the Institution's propensity for excessively

collegial decision making, which they saw as stultifying the setting of strategic directions and priorities. As one scientist said:

> *While [participatory decision making] brings diverse perspectives to the table, the decisions that emerge meet [only the most] minimal demands. They generally reflect the interests of everyone, [so] they are never the optimum choices, or even [the choices that] satisfy the majority. Generally, they are self-serving, and are arrived at to end a series of meaningless discussions.*

Interviewed scientists uniformly wanted continued opportunities to provide input, but many also recognized that someone at the top ultimately has to make the hard decisions:

> *Being steered by a committee, from what I've seen, results in anything from an argument to a "gentleman's discussion" about how to divvy up the available funding—instead of [discussions about] where a program can go that would bring prominence to the Smithsonian's capabilities.*

Follow-through

Smithsonian interviewees cited a lack of follow-through by leaders on decisions as a major problem. They saw follow-through as at least as important as setting an initial direction. The study team noticed that a pervasive characteristic of successful external IDR organizations was ongoing commitment from leaders to carry out decisions, based on a pragmatic action plan and within a defined timeframe. As one external interviewee said, "Building credibility takes time. You're asking [the scientists] to take on a fair amount of risk, both personally and for their part of the organization. So they've got to believe you're going to carry through with it."

The lack of follow-through has included failing to champion initiatives announced by leadership, adhering to hiring criteria they establish, and carrying out strategic plans they issue. As one interviewee put it, Smithsonian leadership has had "a great capacity to just go limp." A particular concern was the failure to provide funds for approved initiatives. A Smithsonian interviewee commented on the problem:

> *I have never been able to get the Under Secretary's office to think strategically about the application of their financial resources. [They seem to expect] that the PIs will go out and get the money. But we need to support the capacity for them to do that, to sustain them and stabilize their long-term research.*

An interviewee from an external agency talked about a specific instance of this problem at his agency:

No one disagreed that [the initiative in question] was a great idea, but … they already had programs running in their offices and agencies. Who is going to provide money for these new things? If it doesn't come from within your organization, it's not going to happen … If you are talking about a grand new effort, either Congress has to decide to allocate new money for it, or the agencies involved have to say that it is so important that they are going to end other things they are already funding and invest the money there. People don't usually like doing that.

Several interviewees lauded a former senior manager for his ability to think strategically about the allocation of funds, and to get others to buy-in:

He would say "Okay, for the next three years, our 'theme push' is going to be this," and he would pick a theme he felt was saleable. … [For example, he would say that] this year, SAO is going to get the telescope, [and] when they have their telescope, then STRI gets its new big push. … People trusted him; they believed him. … He was really good at packaging Smithsonian science across the bureaus, not just creating a gazillion little tiny requests. … He would come up with the intellectual argument for [the focus initiative] and the research argument for it, and make it the centerpiece of what we were doing.

Sustained Commitment

Interviewees and the literature brought out the point that measures must be taken to ensure that priorities remain essentially intact, even when leaders change. Smithsonian interviewees expressed frustration about the lack of continuity in leadership, a recurrent theme that was a point of emphasis in the recent Smithsonian strategic planning survey. An interviewee gave an example of the impact of turnover in leadership on a key initiative:

All of a sudden, there was nobody in the Under Secretary's office to say … "This is an Institutionally important program. It was endorsed through this Office, and I want it to occur. … I'm going to move resources around and make it happen." … That's a perfect example of [an initiative] that should be heralded as a huge success, but is suffering because of pettiness over territoriality and [people who] don't want to contribute their share of the thing

One person noted that while continuity in leadership personnel is ideal, "even a stability of philosophy would be beneficial … so radical change doesn't happen with the change of a key person."

Absent sustained commitment and support, staff tend to draw back from collaborative initiatives—or, for that matter, from anything that involves risk or deviation from the status quo.

One interviewee observed, “There are an awful lot of people who don’t want to do anything interdisciplinary, because the best thing they can do is keep their head down.” Another said, “If I’m going to commit to long-term research, I want to have confidence that [the project] is going to be in existence in two or four or ten years.”

One practical suggestion for dealing with leadership turnover was to

> *Have some kind of ongoing advisory group that would both run and advise the [collaborative] project. My concern is that as soon as you have a leadership change, somebody may want to go in another direction unless you have some stability to keep things on track. Have some type of restricted endowment, [with money that will] always be there—not something someone can siphon off, which is what happens consistently here.*

Communication

Another major leadership responsibility is communications. Zerhouni said that a full 25% of his job [was] taken up with communications—with Congressional committees, other science agencies, the patient advocacy community, the university community and so on, as well as internally with NIH scientists. With a knowledge-based workforce, he said, the only way you can truly lead is by bringing knowledge to the forefront and having an open environment where you share information—

> *My experience with this myriad of highly intelligent people is that if you do not bring intellectual horsepower on the table in facts, then you really can’t lead that organization. Organizations like this need to be convinced, and 95 percent of the time if you bring data—they're data driven—people will converge towards an optimal solution.*

Relatedly, Zerhouni brought up the importance of honesty. Candor is an instrument of leadership, because candor generates trust—“they have to know that they can trust you and that if things get rough, you will honor your side of the bargain” (Zerhouni, 2005).

Hiring the Best

Leadership must be able to recognize key attributes and recruit good science leaders and managers. Quoting Zerhouni again:

> *One thing that I consider the most important part of my job is recruiting the best and brightest people I can recruit. So, since I've become director, I've recruited eight new*

directors of institutes since 2002, and I consider that the most important job for the NIH director, to get the best (Zerhouni, 2005).

One university administrator cautioned that "just getting people involved doesn't guarantee that really top people will be involved or that you've created an organizational or institute forum that has the really big brains at the table who have something important to say and do." It is leadership's responsibility to decide, "who do you want at the center who are really productive, really dynamic, at the cutting edge, National Academy members, whatever you want to use as your criteria."

Inspiration

The Smithsonian's record of failed attempts at relatively modest change—let alone major transformation—has engendered tremendous skepticism that will require inspirational leadership to dislodge. When faced with talk of change and transformation (particularly change with which they do not agree), many Smithsonian employees reflexively hunker down:

They see a guy who's 65, who's probably going to be Secretary for five or six years. Of those five or six years, it will take him at least a year to figure out how the place even works. … [The likelihood of] anything happening is sufficiently indistinguishable from zero as to not make it worth their time to do much. … Even if [the Secretary] does try to do something, people won't get that upset because they figure he'll be gone before long.

Less cynically, another interviewee noted that it is intrinsically hard to get busy, possibly overstressed people excited about something bigger than themselves, their department, or their unit, and that the Smithsonian's leadership in recent years simply has not been up to the task of convincing them: "We haven't had dynamic leadership that shows the way … [to accomplish] some of these really complex interdisciplinary works. I just kind of do my thing, and enjoy doing it, and for the most part I don't want to think about [bigger things]."

Advocacy

Interviewees spoke of the importance of having a champion for specific initiatives, as well as for Smithsonian science overall, high up in the chain of command:

Having a strong proponent for science in the Castle is very, very important. What it takes is will power on the part of the people leading. It is a lot of work. Someone has to be laser-focused on making the [individual science units] actually spend their research budgets in concert, so the whole is more than the sum of its parts. That would take the

Secretary, the Under Secretary for Science, or someone [at that level] to do it. They could do it. They don't need a report. They just need the nerve to decide that's how it's going to be.

Management

> *The biggest struggle obviously is the leadership and the management of the center, making sure it's a center … it's very difficult to get people to cooperate and do things in a certain way. So management is a big risk for us. At least one of the two centers closed early because of leadership and management. They were great researchers, but they didn't want to play in the same sandbox. (Interviewee from a Federal agency)*

> *Typically scientists have a very narrow view of management—direct research, assist students, [and] monitor the quality of output (Epton, et al., 1983).*

While management issues did not come up often, some interviewees, principally external ones who had run or participated in organizational change involving collaborative and IDR science, were very conscious of the critical role that managers play, and they shared their experiences. As one interviewee said, "part of it is just a decision about why you have the program in the first place, then deciding how to manage it so that you achieve that." Key themes to emerge from the interviews were treating management as a distinct function requiring special abilities and skills, the importance of investing in qualified managers, choosing the right strategies to accomplish organizational change involving scientists, emphasizing boundary spanning, creating a positive work climate that promotes and sustains this type of research, and holding the organization accountable for desired results.

Investing in Qualified Managers

A number of interviewees commented that management at the Smithsonian was sometimes treated as a collateral duty and did not take into account the distinctive features of collaboration and IDR. In contrast, strong management has to be a specific focus of any effort to move forward with a major initiative that emphasizes collaboration and IDR. That managing collaboration and IDR is different from traditional management was a clear refrain. Often the organization didn't recognize that and assigned people to be managers who were destined to fail. Said one interviewee,—"that unique kind of talent, it is rare. And the effort at IDR can fail very, very easily when they just pick the senior scholar [to manage it]." In recognition of this fact, one interviewee's university was developing a Collaborative Leadership Series—

> *assuming that we need to prepare people for competencies they weren't prepared for in the past. Those [competencies] include conflict resolution, team building, knowing*

intellectual property law in terms of how collaboration works, and a host of other things that are not what is ordinarily taught … Often there is a mentoring committee set up that is interdisciplinary, again because somebody comes in in one field, but their appointment is in another department. You can't just stick them somewhere. The junior faculty really have to be followed and mentored. There has to be a kind of sophistication and commitment on the part of the senior faculty.

An interviewee recommended looking for scientists to be managers who had made their mark and were toward the end of their research careers. They don't have conflicts of interest between building their reputation as a researcher and spending time on management, and they are better able to cope with the time-consuming paperwork, meetings, marketing, etc.

It's not hiring that big guy in the field, although you might want him on your team. It's hiring the senior, a little bit past prime in the sense of having to prove him or herself, eager to mentor more junior colleagues, to coalesce a set of talents, as opposed to "three big tenors," and each of them sings really well. [That] doesn't work because the work of team building, of building a collaborative organization, is fundamentally unlike most academic careers, which are solo or which are strongly hierarchical in a lab setting.

Saxberg and Newell (n.d.) similarly pointed out the continuous internal conflict between the demands of management and of research in IDR. Whereas scientists focus on retaining credibility and respect in their disciplines and staying abreast of progress in their fields, managers must move more toward being a generalist than a specialist and being more oriented toward application. They "can lead by stepping down from the top and being a facilitator to enable the team to realize its potential."

Bozeman and Boardman (2003), in describing management of MMURCs, reported that the smoothest running ones were those that clearly delineated between the managerial tasks of the center director and an administrative director. The center director focused on issues related to research direction, linkages, and procurement of funds, while the administrative director saw to tasks that did not require scientific knowledge and expertise, such as budgets, NSF reporting requirements, and logistics for events like workshops and conferences. In addition, hiring a research general manager with, for example, a MBA or comparable degree, can facilitate interdisciplinary research activity by overseeing coordination and accountability of researchers, said the authors. If an administrator is dedicated to coordinating scientists from disparate fields, he or she is more likely to recognize emergent problems and quickly take remedial steps.

Advisors can also be helpful—said a Smithsonian scientist, "When you've got everything set up, you can pull these guys in with great expertise for targeted, focused episodes, and take advantage of their skills and interest."

Other points made by interviewees included:

- "[H]ire the best people you can, you do everything you can to support them, then you just get out of the way if you are an administrator. If those researchers are good and productive and well-regarded in their field, they will do collaborative kinds of things."
- "The glue people. You need the people who can see across and reinterpret" and who are able to speak with both scientists and stakeholders. Another type of glue person is the boundary spanner or broker, discussed below.
- Management is a full-time job, not a collateral duty—or, as one interviewee put it, "100 percent managing the center. It's not the leadership, not the vision, but making sure that everybody gets together to do what's right." Said another, "We have learned that you need a dedicated position to make it easier for everybody to do things and to make sure they do what they are supposed to, rather than having scientists manage, because most of the time they can't manage well." Bozeman and Boardman (2003) also spoke to this issue, recommending that organizations should strive to "minimize double duty." They explained,

  > *Many of the faculty researchers we interviewed lived two interesting lives—one as a traditional academic, teaching and publishing in the discipline's refereed journals, and another working on the center's applied research and technology problems … The chief point is … [to] recognize the dual life and set expectations accordingly. Center researchers are "jugglers" with many balls in the air, and the price of the current organizational design is that some of those balls will occasionally come crashing down.*

Decision Making

A number of interviewees commented on the nature of decision making at the Smithsonian. A major driver of decisions is the need for consensus and equity, which can also be interpreted as avoidance of conflict. For example, when new funds become available, they tend to be divided across the units, with the resulting amounts too small to have much impact. Committees are often set up to recommend decisions, and the goal of consensus leads to results that are "lowest common denominator." Interviewees also noted a lack of decision-making guidance in the form of priorities or cost-benefit analysis.

In their study of MMURCs, Bozeman and Boardman (2003) found a variety of approaches to decision making, but found the description by one center director to be fairly typical—

We make decisions by our executive committee, setting out with our strategic plan. I try not to do this [strategic planning and decision making] all myself. The executive committee sets out criteria that suggest contributions and potential contributions not only in research, but also education and outreach. Then we solicit proposals for not only research but also education and outreach.

One MMURC director talked about how he allocates research funds:

I want to empower the people that run the programmatic areas and trust them in terms of making intellectual decisions … we have an all-day meeting to see what will be funded … projects [using center funds] are funded to be in line with the strategic plan that is devised by the leaders of the programmatic areas. So we try to create some integration with center research goals, even if an individual project is just a professor with a student.

Another director described a slightly different process:

[With this input] we develop a final executive proposal. This is top down. We decide what problems we need to resolve … Once the road map is defined, the research proposals must adhere to the road map. If a proposal deviates too far from the road map, I turn it down. I feel strongly that we have to do this. … The road map is decided on by all … we do not accept a dictatorial approach. That is one reason we have an annual retreat.

IDR Skill Building

Graduate schools and centers are still looking for the right ways to train a new generation of interdisciplinary scientists who can both speak the language of multiple fields and maintain enough expertise to take on cutting-edge problems (Vastag, 2008).

As a result of cognitive, subject matter and normative differences, scientists of different disciplines may have difficulty agreeing upon appropriate sets of goals, an appropriate framework for pursuing those goals, and an appropriate evaluative framework (Epton, et al., 1983).

An issue raised by some interviewees was how to bridge the differences in communications, methodologies, standards, philosophical context, etc. of different disciplines. "How to work together, that's huge, because the [traditional] model for training a scientist is self-sufficiency," said one person. A university IDR center director explained,

[It is] like learning to speak each other's language or even developing the self-awareness to know what you don't know—I am the outsider and how do they behave here. And not personalizing it, but seeing it as a sociological problem, and so on—developing greater facility with doing the translational work, but also in terms of setting methodological standards or units of analysis or all kinds of things like that.

Interviewees provided some very concrete examples of the communication and cultural problems that can arise in interdisciplinary projects. An interviewee spoke of one project where they made a very conscious effort to eliminate disciplinary niches and use very broad labels that would encompass scientists in many fields, using terms like "global connections," "frontiers of science," and "discoveries." The project team soon learned that even broad terms fell short. The social scientists said of the word "discovery,"

No, it doesn't apply to us. We do not operate this way; we do not operate with the term "discovery." Someone's discovery is another person's daily life. I go to the communities, I stay with them, I talk to people. What is my discovery? The discovery that they do something this way, or talk about something another way? That's not a discovery. The very idea of new or unknown or original, in this context, is very different from when you go, say, under the ice or to the highest mountain. We don't discover new species, we don't discover new languages or new practices—we are trying to understand people's lives; this is really different.

Another interviewee described her experience with crossing disciplines:

We have one engineer, and sometimes we [natural scientists] just look at each other and say, "They are different. Their training is completely different … there's a different way to use evidence." … Our doctorate is not in science facts, it's in philosophy. We spend all of our professional training learning how to speak about uncertainty and learning about the formalities of what you can and can't prove. Engineers don't learn any of that. They learn how to operate the slide rule and get the number 42. They think, "I have calculated it based on the set standards in my field, and there is an answer … [when natural scientists are asked for an answer], we would say the stomach contents are consistent with them having eaten a mouse. And then someone asks, 'does that mean they ate a mouse?' Well, we don't know, but it's consistent with it.

A younger scientist at the Smithsonian talked about the lack of preparation he got for the non-research aspects of IDR:

From an academic perspective we're not well-trained to do conservation. I've been in biology departments my whole life, but when you come out of school, you don't know how to do conservation policy. You don't know how to raise funding. You look at one of the

most critically limiting factors for conservation scientists today, it's conservation funding. Those people who are effective at raising money tend to be effective at conservation. You start looking at some of these other conservation actions that involve capacity building or policy making or education—stuff that seems to be the realm of someone else's discipline, not a research scientist's discipline.

Another interviewee discussed the value of some kind of training on collaboration that involves different disciplines, since a culture of scientific cooperation does not currently exist at the Smithsonian and such cultural changes do not arise spontaneously:

Collaboration and interdisciplinarity are not innate. They have to be learned, much as we learn to walk, write, or type on the computer—and often we learn the very hard way. We are not trained [to collaborate], except for some programs. (I would say that geography is one of the few.) Many disciplinary educational programs do not train people in collaboration and interdisciplinary work.

The Urban Ecology IGERT program at the University of Washington uses a variety of methods for IDR skill building, which it describes as the "mental effort necessary to rigorously explore interdisciplinary topics while also addressing the interpersonal dynamics intrinsic in groups." Interventions are designed to overcome barriers to collaboration that result from miscommunication, lack of accountability of team members, or divergent expectations among faculty and students. One method it uses is to hire a professional group dynamics facilitator to conduct workshops—attended simultaneously by faculty, students, and staff—on group management skills, interpersonal communication strategies, and creative problem solving. Institutional support includes the ability to access faculty in multiple departments and to develop PhD committees comprising multiple disciplines. Chances of success of an IDR program are increased with:

- Greater *flexibility* regarding logistical issues such as short- and long-term structural arrangements, group dynamics, and variable schedules;
- A *commitment to curiosity* about different disciplines' contributions to an interdisciplinary endeavor that is a prerequisite to understanding and appreciating different world views; and
- *Appreciative inquiry* that counteracts academia's culture of cross-disciplinary criticism (Graybill, et al., 2006).

The difficulty the Smithsonian has with reviewing interdisciplinary proposals and performance came up frequently, as noted. To deal with this issue, the NSF has taken a formal approach:

We do [interdisciplinary review] panel orientations and that sort of thing, and really emphasize the importance of wearing multiple hats and not being parochial … [For site visits] we bring maybe 8-10 external reviewers and a few people from NSF, and maybe one from anthropology, and maybe someone in philosophy, and the rest may be engineers. We spend time before they do that site visit [to get to know each other] ... Once you get to know people and learn your strengths and weaknesses and what are your concerns about the proposal, then you are kind of leveled off. You may be speaking different languages, but you are talking about the same thing.

Brokering Knowledge

At the heart of interdisciplinarity is communication—the conversations, connections and combinations that bring new insights to virtually every kind of scientist and engineer (National Academy of Science, 2004).

Many challenging, urgent, and complex problems are inherently interdisciplinary, and addressing these problems requires, as noted, breaking down barriers between disciplines and organizations, sharing knowledge, and forging connections. A number of interviewees shared their experience on how to link people together and form interdisciplinary teams.

Restructuring the Traditional Academic Model

Over the past half century, universities, research centers, and pharmaceutical companies have increased in number and become more bureaucratic and fragmented, with huge departments constructed like silos. As a result, many scientists find it difficult to communicate across fields (Hollingsworth, Muller, and Hollingsworth, 2008). Following this system, graduate education tends to direct graduate students into discipline-specific academic departments, where they are judged and influenced by faculty members trained in an earlier day when cutting-edge research meant working individually or in small groups on highly specialized, narrow research areas. While, as noted throughout this report, there has been movement away from this model, most research at universities continues to be structured along departmental lines, and faculty often regard interdisciplinary programs and centers more as places for pre-professional training than places where the next generation of researchers is cultivated. In addition, departmental culture tends to place value on stability and to have a short-term outlook that is driven by near-term considerations of budgets and funding. Different departments are often sealed off from one another, and often regard each other as competitors for funds and central administration attention. The departmental structure of Smithsonian science units reflects the traditional academic model, and several Institution interviewees cited this fragmented structure as a source of miscommunication, lags in communication, difficulties in accessing information, inter-unit

(and interdepartmental) competition, and lack of interchange and feedback among Smithsonian scientists and between Smithsonian scientists and peers at other organizations.

A number of universities, such as Minnesota, Washington, Wisconsin, and North Carolina, have taken active measures to restructure their academic recruitment, hiring, and promotional policies and practices to facilitate interdisciplinary work. Several have created offices tasked with breaking down departmental boundaries, improving intra-university communication, and promoting collaboration within and outside the university. A group of ten research universities led by the University of Minnesota's Office of Interdisciplinary Initiatives make up the Consortium on Fostering Interdisciplinary Inquiry, which has developed a self-assessment tool to identify problems and share best practices. In these cases, frequent face-to-face communication among researchers across disciplinary boundaries is often cited as a key to success.

The literature discussed several informal structures that lead to greater knowledge sharing, including networks/communities of practice, expanded peer groups, and greater openness and problem broadcasting. Researchers who divide their time between traditional disciplinary departments and IDR programs often formed "networks of practice" that yielded important outputs that went beyond publications in academic journals, for example, Congressional testimony, public policy initiatives, mass-media placements, and alternative journal publications (National Academy of Science, 2004). Organizations that supported "communities of practice"—groups that are informally bound by shared expertise and passion for a joint enterprise—found that essential information was shared more readily across organizational units (Ackerman, et al., 2003). Sharp (n.d.) called for a redefinition of professional peer groups to include larger networks of people pursuing work in related or potentially related fields. One mechanism to achieve this was to involve an expanded peer group in annual performance evaluations and in review of proposed new areas of research (Sharp, n.d.). In an interview with Martha Lagace, Karim R. Lakhani spoke about drawing on the practice used in open source software development of "broadcasting problems" to explore a model for encouraging large-scale scientific problem solving to "open up your problem to other people in a systematic way. A problem may reside in one domain of expertise and the solution may reside in another" (Lagace, 2006). Lakhani, based on a study he conducted with other researchers (Lakhani, et al., 2007), that solutions most often came from outsiders who reconceptualized the problem. The challenge was to find innovative ways to exploit open source principles and at the same time minimize the risk of loss of intellectual property.

The proposal NMNH submitted to NSF for a National Center for Synthesis in Biological Evolution included a range of "synthesis activities" to address fragmentation of knowledge, including working groups, research fellows, a full-time resident informatics team, annual meetings and workshops, electronic tools and research resources, a strong web presence, and a significant public and professional outreach component (Erwin, 2004).

Some examples of recent efforts at the Smithsonian to forge stronger connections provided by interviewees included the following:

- One Smithsonian scientist created an international listserv to facilitate intellectual exchange; what began with just 10 people grew to 620 over seven years, and has led to joint research and publications.
- A Smithsonian biologist is actively involved with the Society of Conservation Biology, a professional association of 3,000 members who include social scientists as well as researchers in various areas of the natural sciences.
- Recently three departments agreed to share a post-doc; this joint appointment facilitated the flow of communication among scientists in these departments and fostered joint publications.
- STRI has appointed two knowledgeable liaisons—one located in Washington, DC and the other in Panama—to enhance exchanges among researchers and external partners.
- SERC is integrally engaged in a diverse array of research and advisory networks and was lauded in a 2005 external review for its broad-scale approaches to environmental issues and collaboration among scientists who are widely dispersed geographically.
- Publications such as the *Atoll Research Bulletin* (now available digitally), *Inside Smithsonian Research*, and *Listings of Fellowships* are useful sources of information for those seeking a sense of research developments across disciplines and departments, as well as opportunities to work together.
- The research tent at the annual Smithsonian staff picnic promoted a better appreciation of the scope of research at the Institution, and personal contacts made in this venue sometimes led to further communication and exchanges.
- Presentations and discussions hosted by the Congress of Scholars and Senate of Scientists are useful means of sharing information and promoting discussions.
- Looking to the outside for new ideas—"we've organized a number of broad workshops using people from the broad community, not just people we fund. Those are very useful to find out what is going on and get new ideas in certain areas."

Dedicated Boundary Spanners

A number of interviewees thought the Smithsonian needed to go beyond those individually-initiated efforts. Encouraging work across different domains could better be accomplished

through dedicated boundary spanning or knowledge brokering mechanisms and personnel. Boundary spanners in research organizations typically operate by facilitating communications and exchanges among staff internally and with people in other organizations. In some parts of the government, boundary spanners are well-established. For example, the National Security Council has staff charged with gathering information from agencies and organizations such as the State Department, multinational corporations, think tanks, and foreign governments, and transmitting it to various agencies for which it may have relevance. Several high-profile research organizations, both public and private, maintain boundary spanner positions. One is the California Institute for Quantitative Biosciences (QB3), a cooperative effort among three campuses of the University of California and private industry; it employs four former research scientists whose sole responsibility is to broker internal and external connections.

The literature points out the importance of selecting the right people for this role:

- Boundary spanners need to be deeply knowledgeable about both their organization's internal environments and the complexities of the external environment in which it operates. This may involve reading and traveling widely to keep in touch with advances in a number of fields.
- They need to possess expertise in gathering, filtering, interpreting, and transmitting information in written and verbal form, so that it gets to its intended audiences in a usable manner that leads to the desired result.
- They need to be self-assured, flexible, curious, supportive, discreet, and likable; information is less likely to be heeded if transmitted by personnel who are perceived to be biased, untrustworthy, or unreliable.

An interviewee who was a boundary spanner in a government research facility summed up what it takes to be an effective boundary spanner—"Generally, they have been employed as researchers and have developed extensive networks. A key attribute that aligns with extensive professional experience is trustworthiness. It embodies legitimacy, reliability, acculturation, and maturity."

Boundary Spanners at the Smithsonian

That same interviewee added that

> *The Smithsonian needs a different way of communicating its research, or its importance will inevitably lessen. Arguably, a critical communication element is knowledge brokering. In the absence of two-way channels that receive and transmit information vertically and horizontally, externally and internally, the Smithsonian may end up as a*

bunch of uncoordinated subsystems that do not draw upon its vast resources to help solve serious societal problems that are confronting us today.

Periodically, the Smithsonian has attempted to use boundary spanners to facilitate collaboration. In almost all cases, however, it did not establish dedicated boundary-spanning positions; rather, that task was assigned as collateral duty, which decreased the effectiveness of the effort. Further, achieving buy-in was difficult; to many researchers at the Smithsonian, the boundary-spanning role suggests the kind of top-down direction that is anathema.

The Institution has had more success with informal boundary spanners. One interviewee recalled that former Secretary Dillon Ripley played a useful knowledge-brokering role. He frequently visited the units and asked scientists about their research, sometimes suggesting connections and cross pollinations, and gained a reputation as a champion of collaboration. The interviewee noted that Ripley "had an enthusiasm for knowledge and [an appreciation for] diverse perspectives," and suggested that Secretary Clough should follow his example and talk directly to scientists.

Several Smithsonian interviewees also mentioned that Scott Miller, currently Senior Program Officer in the OUSS, and former STRI Director and Acting Under Secretary for Science Ira Rubinoff have been effective *de facto* information brokers. At the same time, interviewees pointed out that the Smithsonian has never regarded boundary spanning as a critical organizational strategy.

Some interviewees who had had no experience with boundary spanners were unsure how these would benefit them. Some thought that the concept of boundary spanners appeared useful in the abstract, but expressed doubts about whether a person—or even several people—could master the job at the Smithsonian in the face of organizational impediments such as funding constraints, the culture of autonomy, an inflexible bureaucracy, distrust of the central administration, competitiveness among units, and deep suspicion of anything that promises to create more paperwork. One person suggested that the Congress of Scholars and Senate of Scientists could be adequate boundary-spanning mechanisms, but acknowledged that their workings could be improved.

Creating a Positive Work Climate

Basically [you need to find] positive ways of breaking down barriers and making it possible to do these things and creating the situations where people will.

In some ways the biggest reward for an investment [of time] is helping the overall atmosphere of the place, being more encouraging and just to strike more sparks

through having more people with more diverse expertise and outgoing, intellectually willing to be engaged with others. Give them reasons to talk to one another, and hire people who are inclined to do so.

What did interviewees say about what constitutes a congenial and personally satisfying work climate, one that fosters and supports collaboration and IDR? Obvious points were financial rewards, good salaries, and potential for promotion. This section looks at some of the more intangible factors that came up, such as academic freedom, compelling research opportunities, the personal satisfaction of teaching and mentoring younger researchers, the professional development that occurs from working with interesting and knowledgeable colleagues including post-docs and other non-employee researchers, and having a voice in planning and programming decisions. (Some of these factors are elaborated further in the following two chapters that catalogue the reasons that interviewees gave and what the literature reveals about why researchers do or don't collaborate).

- ***Academic freedom.*** The importance of academic freedom ranked high on the list of factors that make up a good work environment.

- ***Interesting research opportunities.*** Many interviewees emphasized the role of interesting research opportunities and agreed that compelling research questions can be a strong motivator to bring researchers on board with new initiatives. Here, too, post-docs were seen as a foremost driver in the development of innovative and exciting research projects.

- ***Meeting people on their own "ground."*** An interviewee from a university IDR center talked about the need to meet students where they were:

  My team thought we ought to put something on the Web … with the force of the '20s-something view of science, which is rather different than the '50s-something group of scientists that I represent … It speaks to a wider, more informal side of what my research group does than my [formal university] site.

  Another external interviewee, also referring to a university setting, talked about empowering young scientists:

> *[W]e do know that students learn best from students. Collaboration on the student level is much easier than on the faculty level … students from one institution work with those from another, from one discipline with the other ... For the first time this year [we are sponsoring] a student leaders' meeting [at our annual program review meeting]. That's going to be interesting. If that really takes off, what we are going to see [is] the best practices regarding students.*

Younger students are highly creative, and "You have to allow some risk-taking. Some of these things are going to fail. It's all going to be pretty boring if you only do the ones that you think are sure-fire."

- ***Opportunities for input.*** Interviewees wanted to be involved in decisions that affected their work, such as the formulation of directions and programs. To a person, interviewees involved in moving an organization in a new direction talked about the importance of a bottom-up approach—providing scientists the chance to give input—although with the top having final control. This point went hand-in-hand with not forcing scientists to do something—"it is that kind of more encouraged from the top, but let the juices flow from the bottom. That is more likely to lead to much more successful collaboration."

- ***Professional development.*** Interviewees wanted not only opportunities to stay abreast in their own areas of expertise, but also to expand their knowledge of other fields and ways of doing research. Having access to new and varied people, particularly post-docs, emerged as critical in this regard. "That's where the ideas come from—talking with people about what you are doing."

- ***Rewards.*** Funding for research projects emerged as the key incentive for collaboration and IDR. However, interviewees spoke of other rewards that contributed to a positive work climate, such as awards for exceptional performance, dissemination of important research results to peers and the public, nominations of scientific staff for external rewards, sabbaticals, and priority in getting post-docs. One study found that at NSF centers, researchers reported publications as a less important benefit than the intellectual change they were experiencing (Vastag, 2008 with reference to a study by Rhoten [2003]).

- ***Opportunities to do things that are personally satisfying.*** For some scientists, being able to educate younger scientists and see them thrive on their own in part because of the researchers' contributions was very important. Similarly, the study team noted a number of researchers who initiated "side" projects on their own time—interdisciplinary coordinating groups being a common one—to meet needs in areas related to their research and issues they were addressing. Unfortunately, many noted that a lack of

support and formal recognition made these efforts, even if worthwhile, very difficult to sustain alongside their regular workloads.

- ***Accommodating the realities of IDR.*** As noted, many interviewees saw the Smithsonian as more of an obstacle to collaboration and IDR than a facilitator. To a large extent its systems were not designed to accommodate how collaboration and IDR are practiced. One university, recognizing this, took a major step to better align itself—

  > *we passed policies just this last year to allow dissertations and theses to have multiple authors because … there will also be integrative works … And so we've teased out the part of the dissertation, where you must make an original contribution to knowledge, but we've stopped conflating it with an individual contribution.*

Accountability

> *Everything has to be evaluated all the time—is this going in the right direction?*

Interviewees spoke of two levels of accountability. One took place at the individual level, and is discussed in the workforce section. The other, discussed here, occurred at the unit, department, program, and project levels.

Many interviewees noted the importance of regular assessments of the programs and projects within them because "Things can get stale or can no longer have the driving need they used to have." There were different levels of assessment, as one external interviewee noted. While annual reviews provided "familiarity with the program," deeper reviews were needed at longer intervals to "judge the value" and determine if changes were needed. The "very substantial reviews" performed by external committees of scientists could result in a recommendation to "end programs."

Assessment processes sometimes involved bringing operational managers together to discuss initiatives, confront issues, and deal with program needs. Another approach was periodically to convene a scientific advisory committee, comprised of the directors of the host institutions and their scientists and colleagues. Universities and research organizations, however, typically used external reviewers. The National Research Council, in its 2003 review, *Funding Smithsonian Scientific Research*, recommended that "Regular in-depth reviews by external advisory committees are essential for maintaining the health, vitality, and scientific excellence of the Smithsonian Institution."

An external interviewee talked about the importance of the five-year reviews at his agency, "where we ensure the relevance of our research, its quality, and its impact." Someone from another agency commented on one role of its full reviews, which also occurred every five years:

> *If a problem [on which we're working] has been solved or is no longer an issue, then we may need to start on a different project with totally different objectives. If it's something that's longer term in nature, it can be that we just need to continue it or expand it or take it into a slightly different direction. All those different possibilities are there because it's research, and you can't really predict the future and where you're going to go, what new technological developments may occur.*

Some Smithsonian scientists believed that that type of review was missing at the Institution—"there have been sort of straight allocations [of funds] and not much review about whether programs work or if they don't. At some point, hopefully, we will have a structure where we can say where our really successful programs are, working with our strategic plans and so on." One of the reasons the Smithsonian-wide science strategic plan had gone nowhere, thought a scientist, was that the Smithsonian "never collectively went back to measure ourselves, so what's our progress?" Another scientist explained why there is resistance to that approach—"resources are short, and people sort of cling on to that [program] … If you allow change to happen, you don't really know if you will come out the other end … There is kind of this tension between moving on to logically good and strategic goals and clinging on to the status quo because of the budget."

An interviewee from an external agency talked about the delicate balance between good oversight and micro-management:

> *[The field] is still going to be answerable to a review committee every three years, and they are still going to have to provide us with annual progress reports, at which time we can say, 'Whoa, you are really getting off target here, we need to talk about it.' Or, if they want to do something radically different, they need to check with us first … but, we're not micromanaging.*

Why Researchers Collaborate

This section summarizes the motivations and incentives to collaborate as described by interviewees and discussed in the literature. Some apply to science research in general while others are more specific to the Smithsonian. What emerged as perhaps the strongest incentive to collaborate—research funding—is addressed in greater depth in a later chapter of this report.

Reasons to Collaborate

Self-interest

Collaborations happen when scientists want or need them to happen. A university center director explained that they have had a lot of "meet and greet" gatherings and similar exercises, but top-down efforts to foster collaboration do not generally result in lasting linkages if you simply "put everybody in the same room and see if something happens." Rather, it comes together when you find people who have a common research interest or a complementary set of skills, and who can promote their own self-interest through collaboration.

Collaborations have to offer a win-win situation, which most often involves a related research interest or funding opportunity:

> *[Collaboration] is perceived as being a priority if there is some funding for it and if it meshes with what enough people actually want to do.*
>
> *Does it take me where I want to go? Is there enough money to really allow me to do something different than what I am doing already? Does it have the opportunity to grow into something different, new? Is it a good investment, in other words?*

Increasingly, an important part of this self-interest boils down to dollars and cents: researchers are interested in projects for which there is money. It's the *Field of Dreams* idea—if you build it, they will come. For example, an interviewee noted that MSN works because of its endowment. Base erosion in funding for research has forced Smithsonian scientists increasingly to look outward for support, and much collaboration today is defined by the search for money. One Smithsonian interviewee talked about some areas of collections research at the Smithsonian that would not be possible without funds from outside the Institution:

We don't have anyone to do [this species program], and absent an increase in the budget, no money to do it. It's an open invitation [for outside collaboration] at this stage. We've worked out the methods and can provide the infrastructure, and [scientists from another organization] want to do it and have the funding to be in the project.

Scientists often band together because collaboration and IDR allow them to go after big pots of money.[5] A number of interviewees commented that if Smithsonian scientists were more collaborative, it could compete more effectively for large grants—"My experience with fundraising with foundations and others is usually the bigger [the project], the easier [the funding]." Sometimes collaboration or IDR is a requirement of the grantor or funding body. For example, at HHMI's Janelia Farm, funds are available only for collaborative projects.

Interviewees sometimes expressed concern that the Smithsonian was "missing the boat" in terms of strategically exploiting collaboration to secure grants and funding. One noted that the Smithsonian is not structured in a way that encourages organizing for interdisciplinary initiatives, and such initiatives only seem to work when entirely new money is available to do them. Some suggested that hopping on the IDR train is crucial if Smithsonian science hopes to thrive in today's world. As a younger scientist said:

[Uncertainty about year-to-year funding] seems to be looming large in your ability to project what you can do in a larger perspective. But there are ways around it … [through] these large, collaborative fashions. You have things built into the system, rather than these piecemeal, single-PI things. … You can't survive anymore without doing it in that way.

Expanding Research Horizons

Collaboration and IDR allow both individual research organizations, and the scientific enterprise as a whole, to grasp hitherto missed opportunities and expand their horizons. From the perspective of the scientific enterprise as a whole, many potentially fruitful areas of research fall into gray zones between traditional disciplines. One Smithsonian interviewee commented, "The motivation in general for doing interdisciplinary work is the perception—which is mostly correct—that there are a lot of opportunities in the gaps between disciplines that might be overlooked because existing structures don't naturally support them."

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[5] Some interviewees lamented this trend, because it means that scientists are compelled to work on the questions for which there is money, which aren't necessarily the ones they are most interested in. Another noted that there will always be some researchers "who are not going to be interested in interdisciplinary, it doesn't matter how much money you put on the table."

From the perspective of individual researchers or research organizations, collaboration/IDR provide a way to bring in the skills and expertise needed to effectively pursue certain interesting research questions:

> *You can address multiple aspects of an important project by pulling in people that have the kind of expertise that you need to put the pieces together, and no institution is going to have all of the right people.*

> *I collaborate with people who provide the kinds of data that either make what I study more complete or lead to a greater understanding of what we're doing.*

> *Usually [I work with] someone who has skills in some other area that are complementary to mine. They either know about something I don't know, or they are better at writing or better at math or whatever.*

One Smithsonian scientist said he viewed himself as a facilitator, trying to get specialists from across a range of disciplines interested in the species that were his area of expertise, in order to deepen their collective understanding of that species, its environment, and its value: "If I see a possibility that the [species] might be of interest to you, then I will try to convince you that you should work on it. I'm trying to encourage ecologists and chemists and all kinds of people to look at this."

Addressing Big, Complex Issues

As emphasized earlier, a number of global issues of great concern today—climate change, loss of biodiversity, spread of infectious diseases, population pressures, degradation of the oceans, and so on—cannot be addressed successfully without the involvement of multiple research perspectives and disciplines, not only from the life sciences, but also the social sciences. But in many cases of curiosity-driven basic research, obtaining the big picture of how parts of a system fit together also requires contributions from a range of discipline, skills, and perspectives.

> *My expertise is in [species] classification, but I really want to understand the broader issues about evolution and biogeography, population, speciation—many of those questions are more complex than what my expertise allows for.*

> *The rock turns to soil, the soil has the nutrients for the trees, and the trees provide the architecture and food for the beetles. It will take different specialists in each of those components working together to understand how life is assembled. That's our root question.*

It is a natural happenstance of the type of science that you are doing. In planetary sciences, all of us may write individual scientific papers on some aspect of something, but we are all probably involved with other people, usually from someplace else, in looking at the larger ramifications of that.

Leveraging Resources

Interviewees described collaboration as "a really good investment," because its serves to leverage resources across organizations. From the perspective of individual organizations, the equipment needed to undertake cutting-edge work in many fields is too expensive for them to obtain on their own. From the perspective of the scientific community as a whole, it is inefficient for individual organizations to maintain similar expensive equipment or facilities when mechanisms for sharing these resources are available.

In our field, a lot of what drives collaborative research is access to equipment. Any one lab can't afford the whole array of instruments that you would like to analyze a given rock.

The incentive was twofold. First off, we would have access to an $800,000 piece of equipment, but we only had to spend $100,000 up front. But also, because [the collaborating organizations] do this stuff for a living—meaning maintain all these pieces of equipment—they have trained staff. That particular instrument is used by people in the museum, in physics, in engineering and material science, and at the dental school—different needs, but they all basically share the same piece of equipment.

That might be one reason that we go outside to collaborate—to have access to the most up-to-date equipment [in areas] where we have talented people who might be able to add to a program because of their knowledge or skill sets or interpretive skills. … Collaboration can provide access to instrumentation and facilities for us as well.

Even when collaboration does not bring benefits that can easily be quantified in dollars, one agency interviewee suggested it can still "lower your cost of operations, because people work more collegially."

Prestige and Visibility

A number of interviewees noted that much of the most visible, impactful, and prestigious work being done in science today is in interdisciplinary fields:

People who are in collaborative relationships tend to get a lot more attention. They are generally doing something that is cutting across disciplines and is, therefore, by nature

having a so-called "broader impact." It's more visible to more people—more scientists notice that kind of research. It brings more attention to that institution, to that chair, that dean. It brings in more grant money.

Service

Some interviewees saw the basic value of collaboration and IDR in terms of the benefits for stakeholders other than scientists themselves, such as students:

Collaborative interactions will get [my students] a lot further along with their research because they will have other things to look at.

…Or taxpayers:

The fundamental reason why we should push for more collaborative research on a national focus is to add public value to the public's investment in our respective institutions. You can look at some real specific opportunities to add public value by increasing the efficiency of resource use.

…Or industry:

There may be similar constraints to sustainability in agriculture across the United States, for example, so it can help to focus on what those constraints are across a range of climatic zones or range of crops. Stakeholders are another common way to look at things. You can take a common group of stakeholders, like the potato industry, because those people have some of the same issues. So it can really help to bring those people together and use that as a strategy to develop collaborations across different locations.

Personal Relationships

Finally, it should not be forgotten that scientists are often motivated by personal relationships as much as by calculated considerations of costs and benefits. Some collaborations emerge spontaneously from existing relationships or may in turn result in a self-sustaining relationship over time.

That association came about because we were on a field trip in 1978, and we just kind of kept in touch over the years. In about the mid-1980s, we started working together. So we have been working together for a long time and have had several papers coauthored.

You go after things that have been successful in the past. I don't think that it's to the exclusion of people who are in the Smithsonian; it's just the nature of friends and people

that you have worked with for a long time. All things being equal, you continue to work with those people; it's a successful model. I've pursued collaborations in that way.

Certainly a lot of the people I work with now are people I went to graduate school with a long time ago, or people with whom I've collaborated for 10 years.

Barriers to Collaboration

This section provides an overview of the reasons the study team commonly heard about why collaboration within the Institution may fall short of what its proponents envision, as well as the disincentives and barriers to collaboration as described in the literature. Again, some barriers apply to science research in general, while others are more specific to the Smithsonian. Many of the reasons discussed by interviewees for not collaborating, especially within the Institution, are pervasive cultural barriers.

> *There doesn't seem to be a culture of interdisciplinary research or a culture that promotes collaboration—it just happens on an individual basis. Which is the way a lot of the Smithsonian operates—it's your personal relationships.*

Some barriers are practical in nature—the Smithsonian simply may not have staff with the skills or knowledge to round out what is needed to answer a particular research question. Time and/or distance may trump good intentions to collaborate. Difficulties in crossing the disciplinary divide pose other barriers to collaboration and truly synthetic interdisciplinary research. Still other barriers include administrative hurdles embedded in the Smithsonian and Federal bureaucracies (these are discussed at greater length in a later section of the report).

In general, it was clear that interviewees did not want to see the Smithsonian pursue collaboration for its own sake. There was concern about the possibility of top-down, arbitrary mandates for collaboration that would not accord with the interests of individual units and researchers:

> *When you try to make these centers, where you say we're going to study climate or the response of vegetation to climate [changes]—well, these people aren't interested in that per se. They're not going to collaborate with you. … So you start shoehorning people into an administratively defined research collaboration group that none of us really fit in.*

Practical Barriers

Intra-Smithsonian Skills

Some interviewees suggested that one reason for the relative lack of collaboration within the Smithsonian was that the scientists were looking for collaborators with very specific skills and

expertise—and there was generally no reason to think they would be found within the Smithsonian:

> *The chances of having the right collaborator, whether for geographical or topical reasons, here in the Smithsonian staff, are just sort of low. I think that is one of the reasons why the cross-cutting initiatives have failed in the past.*

> *Within the Smithsonian, I don't collaborate with people that much because of the nature of the scholarship I do; those I collaborate with are largely found outside of the Institution.*

> *You want people who have very specific talents when you do collaborative work. Unless you're lucky they don't tend to live in the DC area. There's nothing you can do about that.*

> *The thing we always hear with collaborative research and interdisciplinary research is "Let's all work together within the Institution." Most of the people I want to work with aren't in the Institution. I think it's great if you say that we want to do collaborative research, but let people pick collaborators who are logical collaborators for their research.*

> *Let's say the guys at SERC with their marine invasives program get all these crabs and nobody knows what they are. They can't go to Natural History because there is no crab curator anymore; there is no specialist [in that area]. Trying to answer certain science questions forces you sometimes to go outside.*

Narrow Focus

Some researchers at the Smithsonian have very narrow, specialized research foci that do not require a collaborative or IDR approach.

> *There are people who are very narrow in their focus. They do one thing and do it well, and they go home at the end of the day.*

> *A lot of scientists in our [science agency] group don't want to see the whole picture; they don't care. The truth is, they are focused in their area. For example, they're building equipment for making a measurement. They know that measurement's importance, and that's all they want to know. They don't want to see the rest of it. And, you know, they really don't need to.*

Distance

The geographical dispersion of Smithsonian research units—particularly the distance of SAO and STRI from the Smithsonian headquarters in Washington—was cited as an obstacle to collaboration and development of a common Institutional research strategy.

Time

Many Smithsonian researchers saw time as a major obstacle. A common sentiment was that researchers and units had their hands full looking out for their existing interests, and simply could not spare the time to pursue larger collaborative projects:

> *I have to spend so much time supporting myself and my lab, I don't have the time to write grants to support [IDR network initiatives].*

> *There is a lot of interest from people, but not a lot of time. People have full-time jobs, and even if they are interested in [the research], they don't want to take part in the boring, admin-type fundraising, getting permits, etc., which requires a lot of heavy lifting.*

As discussed in a later section, part of this sense of not having enough time may be due to poor administrative support systems, which leave the scientists to handle many administrative responsibilities that divert them from their primary research activities.

Barriers to Interdisciplinarity

Differences in epistemologies and methodologies of the different scientific disciplines present a challenge when attempting to do IDR. Many interviewees likened the process of engaging colleagues across disciplinary lines to learning a new language. For example, in referring to a project design, one scientist said, "anthropologists think about these kinds of things—biologists usually don't." One interviewee suggested that the different disciplines in fact have different cultures and "personalities."

> *Each of the scientific disciplines has its own personality. The astronomers will fall right in line and salute and say that is how it is going to be. The biologists will fight with each other. The geologists will be completely suspicious (what are you really up to?). The anthropologists will probably forget about it in a month or two.*

Some interviewees complained that leaders and managers who push for more collaboration for its own sake do not fully appreciate the differences between disciplinary perspectives:

We will find ways to collaborate when it's useful. We don't need somebody telling us, "you must become interdisciplinary" or "the only way you are going to get money is by being interdisciplinary or being collaborative." The fact is, [scientists in different fields] work entirely differently—the way we collect, what we work on … everything is completely different. There is almost no situation in which we would work together in the field. We might both be interested in biodiversity and doing inventory work and that kind of stuff, but the way we do it is entirely different.

Other interviewees noted the sometimes strained relationships among researchers from different disciplines:

Everyday I've had lunch with the people working in the plot, but only the botanists can go in there because I might step on a seedling, or whatever. That's a very bad mentality. Those are the kinds of barriers that we have to overcome. … They understand how we do our science. I certainly would not step on a seedling that is part of somebody's research, and they have to appreciate that.

One interviewee also discussed how many scientists continue to see IDR as diluting research or as a kind of compromise or sacrifice of their disciplinary identity: "[It is] harder than it needs to be to collaborate in bureaus. I'm sure you see it at universities, in collaboration across departments: if you are doing some sort of psychological biology you are not a 'true biologist' or a 'true psychologist.'"

While acknowledging that there are indicators of change, many interviewees felt that specialists were still more esteemed by their scientific peers than generalists, even though interdisciplinary work has been going on for decades and has been lauded by funding agencies. They see a disconnect between what is being preached and what is actually happening on the ground. Many believe it is still easier to get tenure if you are an expert in a traditional discipline, and generalists have a tougher time succeeding early in their careers. One science administrator said that on paper, internal evaluation is designed to be flexible and emphasize a team project's impact on science, but in practice, "the folks who do IDR feel they're somewhat underrated relative to the guys that specialize." A number of scientists engaged in interdisciplinary work told stories about butting up against the traditional disciplinary structures and culture when writing dissertations, seeking employment, or applying for grants. They also talked about the vindication they have felt as they have watched their interdisciplinary interest become more mainstream—"Many of my cohorts were advised to hide that [interdisciplinary] aspect and to do something else for their dissertation, [so they had] that specialty in their back pocket … Now some people are actively out recruiting for this."

Institutional Administrative and Bureaucratic Barriers

Interviewees pointed to the need for support elements—including appropriate facilities, management, incentives, communications, information technology (IT) infrastructure, administrative and logistical support, and so on—that make up a work environment conducive to collaboration. Almost unanimously, Smithsonian interviewees stated that the Institution did not provide such an environment, and that existing collaborative projects were taking place in spite of the Institutional framework, not because of it. For example, scientists described having to use outside organizations or collaborators to handle routine logistical and administrative tasks because of the stifling Smithsonian bureaucracy and a reward system that offers few, if any, incentives to engage in collaborative research. The study team gathered that many scientists at the Smithsonian were open to collaboration, but the Institution made it very difficult for them to do so in an efficient and productive manner.

The administrative obstacles often dealt with funding, budgets, and who gets credit:

> *The Smithsonian has embedded incentives not to collaborate—for example, the need for money and credit to go to one entity, the ability to have only one PI, the difficulty of allowing someone to move to different units.*

> *The way the Smithsonian budget works is a disincentive. For example, if staff from the Zoo and NMNH apply for a research endowment award together, one wins and one loses.*

Cultural Barriers—Science

> *Scientists are the hardest people in the world. They don't trust anything. But that's a good scientist!*

Interviewees spoke about aspects of scientific research and science organizational cultures that were antithetical to collaboration and teamwork. For example, interviewees characterized scientists as independent and stubborn, loners by nature, driven by stature and territorial, and engaged in a competitive, entrepreneurial business. "Like pushing a rope up a hill" was how one science administrator described the process of managing scientists and attempting to change their behavior. He added, "You have all these years of history, and people say 'we just don't do it like that here.'" Another external scientist observed that "Managing scientists is a difficult thing to do—you are basically dealing with very independent minds who think that the world revolves around their group. It takes a very charismatic leader to talk people into working on these issues together."

Yet another science manager spoke of the challenge of getting scientists to function in teams: "Scientists are very collaborative by nature, but the team functioning was a challenge. You have to make decisions together and not have turf [battles]. You're sharing resources and trying to figure out the best way to use them." One external interviewee emphasized a recurring theme about managing scientists in a hierarchical organization: "There really is a scientist culture, and it's very clear that top-down [management] is the kiss of death. You cannot do that; you have to get them to buy in by a bottom-up process."

Another prevalent aspect of the science culture—the scientist working alone at his bench—may be stereotypical, but according to one scientist is "kind of true," at least for scientists in museum settings. An external interviewee explained,

> *Getting scientists to communicate—I'm a scientist so I can say this—is difficult. There's a reticence. Usually if you go into science, you aren't good at communicating and not necessarily good at collaborating. There has to be an exciting idea, something exciting to coalesce around that will drive them.*

Interviewees talked about how the competition and territoriality intrinsic to the "publish or perish" ethos of science research can impede IDR efforts. However, some scientists also described a breakdown in that territoriality as researchers have begun to realize that it is actually a good thing to share data. This is, however, a fairly recent development:

> *Ten, fifteen, twenty years back, [there is] no way you [would] let anyone look at your data because you're going to publish it—and if someone else gets it, you're not going to get that publication. Whereas now it's more like, "If someone else works on it, I may get another publication." So people are starting to do that, and there are models out there in ecology and conservation biology.*

One scientist also saw professional pride as a big source of resistance to interdisciplinary research: "People don't want to acknowledge that they don't know very much about other areas. You want to act like you know everything—and in your little area, you do. But working across disciplines, people don't like to acknowledge that they don't know that much."

Cultural Barriers—Smithsonian Science

In addition to the barriers to IDR inherent in science culture in general, interviewees pointed to aspects of the Smithsonian's culture that further impede collaboration and IDR. The Smithsonian's status as a historical, even iconic organization adds another dimension to its culture—interviewees from other long-established institutions commiserated on the special intractability of cultural barriers that may be decades or even centuries in the making.

Internal Smithsonian interviewees described a culture of rivalry and mistrust across and within units, and uncooperative attitudes built up over years of being forced to compete for resources and being measured against one another. There is a pervasive "silo mentality" and only weak allegiance to the Smithsonian as a whole.

The culture is also driven in part by dominant personalities:

> *I think there are a lot of [individual] personalities—often really strong personalities—that put other personalities off. You have clashes, competitions, resentment, histories of resentment. Coupled with that, many of these personalities have a prima donna approach to life—"I'm going to do my own thing; I don't care what anybody else does."*

Along these same lines, another researcher said,

> *[Another research unit] is very focused on what it wants to do, and it will not deviate from that. [They do not provide] incentives for any of us here to become involved in their projects. We are at that point being relegated to a service role. When you build collaborative projects in general, both collaborators need to participate in formulating the project. … [Otherwise,] it's not a win-win situation.*

Turfism

Both interviewees for this study and respondents to the December 2008 online strategic planning survey said there is no unified Smithsonian institutional culture. Typically, Smithsonian scientists' allegiance is to their own self, professional society, department, or unit, rather than to the Smithsonian as a whole, which dissipates the potential energy and impact of the Institution. From the scientists' perspective this appears eminently reasonable; as one person said, "The Smithsonian leadership isn't supporting science, the directors are out for their units and aren't willing to share money with other units, and department chairs can be somewhat the same way."

From the central administration's standpoint, since there is little identification with the Institution as a whole at the lower levels, science units have to be pushed to work together. But such initiatives are typically met with resistance as units and scientists jockey for advantage.

The lack of identification with the Institution was seen as a problem from a development standpoint, because foundations and other funders are increasingly interested in projects that promise a big impact, and because proposals are more persuasive when an organization brings more people and resources to the table. Cross-unit collaboration and resource leveraging are simply not part of the Smithsonian science mindset. (SIGEO was cited as one of the few instances where units had successfully banded together.) Interviewees indicated that development presentations cobbled together out of contributions from multiple units have been

fragmented rather than cohesive, and suggested that the integrative work needs to happen at the scientist and unit level before such things are ready to go up to central development.

One interviewee observed that the silo mentality pertains not just to science units but pervades the whole Institution. Key central offices dealing with development, budgets, Congressional relations, international relations, and public affairs also have their own unit and functional silos, leading one interviewee to say, "Institutionally, it is hard [for units] to get out of their silos if the fundraisers and public relations people and budget people are in silos also."

Competition for Resources

The culture of turfism is exacerbated by the competition for funding, post-docs, new equipment, and other resources across units and, within units, across departments. While some competition is healthy, many interviewees agreed that it has become counterproductive at the Smithsonian. One Smithsonian scientist shared an example of his attempt to use equipment owned by a different science unit:

> *The casual questions I asked to the person running it implied that there was not a hope in hell that they would let me use it. It wasn't important enough for me to raise a stink about it. [But w]e actually have a number of people in the department who would use the [equipment]—we would do important research if we had access to it. Those are the kinds of things I've given up on, because I recognize some of these things are real turf battles.*

Units often engage in keen competition for funding for post-doctoral fellows, and there is no mechanism for sharing interns, students, or post-docs. One interviewee said, "It wouldn't take much. … It's amazing to me that in the 20 years I've been here, everybody screams [that] there's no interbureau [coordination in this area]. Well, you never put any funds there!" Another interviewee recalled at least two times when the Smithsonian tried to pursue fellowship money from an Institutional standpoint and came close to developing opportunities for an unrestricted fellowship. However, "because there's always this tension between central development versus individual units' development, those efforts have fallen apart." In another case, a molecular genetics fellowship that was initially supposed to be for cross-unit research instead ended up being alternated among the units.

Interviewees gave examples of funding streams that have been designated specifically for inter-bureau collaboration. However, by and large, these initiatives were unsuccessful, in part because unit directors had discretion to redirect the money and could siphon it off to other areas. One interviewee said that plans to use part of the Johnson Fund endowment for synthesizing marine projects across the units did not come to fruition because "everybody fought for their little piece of the pie—STRI, SERC, and NMNH," and the fund was whittled down to monies used for

awards and basic operational support. A further example was the molecular genetics lab, which had positions that were supposed to be earmarked. But "it [the funding for those positions] wasn't protected in any way, and the bureau directors have the power, apparently, to divert that money, so we never got that position."

One person thought the culture of protecting your turf and mistrust had a lot to do with the Smithsonian's tendency to bring in administrators from outside who lacked cultural understanding of either the units or the Smithsonian as a whole:

> *The operating units have always had tension, as long as I've been here, with the Castle, and that tension is exacerbated by a feeling that the people in the Castle don't understand what we're doing. The same tension exists between the departments and the central administration—at least at this unit.*

Cynicism

Some interviewees noted that collaboration within Smithsonian science has been discussed *ad nauseam* in the past, without much follow-through or major results. This has reinforced attitudes that leadership is not really serious about the issue:

> *I haven't seen a lot of things that are obviously resulting from [former IDR efforts] … [I have not seen] a big, successful program that is now recognized to be a terrific thing [in the sense that] it is funded research or has brought in lots of students or post-docs. I just haven't seen that.*

> *Part of it is a credibility issue. [The IDR issue] keeps coming up, and nothing happens. If conditions were right, there are a number of people who would rise up and embrace IDR projects.*

> *You've got a lot of jaded personalities here. Folks are going to roll their eyes and say, "Well, here we go again—yet another attempt to get something done at a pan-Institutional level." There is such a history of "let's do something," and nothing ever really comes from it.*

Consensus Decision Making

The Smithsonian's culture of autonomy and consensus, which regards buy-in from all affected parties (all of whom are considering the matter from the standpoint of their own interests) as necessary for any substantive decisions, in combination with a lack of consistent leadership and a general unwillingness to prioritize, has undermined past strategic planning efforts. As one scientist related,

Every time one of those [efforts] happens, it seems like it's the same drill. Everybody is busy trying to figure out how to make sure their piece doesn't get left out of the plan, whatever the plan is. We always end up having pretty much the same ideas, because there are not that many ways of including everybody.

Insularity, Conservatism, and Entitlement

Many interviewees characterized the Smithsonian as insular, conservative, and risk-averse. One relatively youthful scientist said part of the problem stems from a tendency of the older generation of scientists to be set in their ways—"Until my generation and younger, people have tended to want to sit in their offices and do what they do." The problem is exacerbated by the Smithsonian's aging staff and lack of young replacements. One older scientist who has spent his entire career at the Smithsonian explained that he and his peers never wrote proposals when he first started to work here—if you wanted to do something, you went and told your supervisor and the money was there. Unsurprisingly, it has often been difficult for scientists who came of age in that environment to make the transition to a situation where researchers are expected to be more entrepreneurial. A scientist commented,

For a long time, the model here was that it was easy to get money, and you could just do your own thing, and that was fine. Now as it's getting harder to get money. You look at people and say, "How are you going to go get a grant?" They are not going to give you a grant if you are just working by yourself probably; you have to have a team of collaborators.

Others elaborated on what they saw as a legacy of entitlement: "There is this sense when you get a job at the Smithsonian, it's a MacArthur grant for life."

In all fairness, this mindset is not unique to the Smithsonian. An external museum interviewee described his experience with university-based natural history museums, which he thought had, in effect, walled themselves off: "They become too insular by failing to embrace a broader definition of natural history and its scope. They have made their lives more difficult."

Several interviewees both inside and outside the Institution observed that the Smithsonian needs to come out of its shell and be more of a player on interagency working groups involving biodiversity and other areas of interest. One interviewee said, "Those are the kinds of questions that I think Smithsonian scientists should be engaged in because we have these facilities, we have these terrestrial systems. And we're not." Another Smithsonian scientist who was on a NRC committee that reviewed a multi-agency effort called the Ocean Research Priorities Plan commented, "The Smithsonian was on paper a participant in that, but I never saw any evidence of its being a really active participant."

At the same time that interviewees spoke of a general culture of risk-aversion and stasis at the Smithsonian, some interviewees did acknowledge that certain science units—such as SERC, STRI, and SAO—were models of entrepreneurship. The explanation in the case of SAO can be found in its history. Shortly after SAO moved to Cambridge, its first director, Fred Whipple, started aggressively working with the National Aeronautics and Space Administration (NASA) to bring in new Trust income to support programs that could not be supported out of the Federal appropriation, and that entrepreneurial mentality has continued to this day: whereas in 2008 SAO got approximately $23 million from the Smithsonian's Federal appropriation, it brought in just under $100 million in contracts and grants. In the words of an interviewee, "That's very entrepreneurial activity. It influences the culture, and it feeds back into the Federally supported scientists—the culture that if you want results, you go out and find the resources."

Elitism

Ingrained in Smithsonian science culture is what amounts to a kind of scientific pecking order—interviewees working in more applied areas thought that their curiosity-driven, basic-science peers considered them inferior. There was a perception that newer, more applied research was seen as "blue collar":

> *It's kind of funny; some of the old-timer biologists … bristle at the term "conservation biology." They see it as a bastardization of pure science. They see it as activism and policy and not research. [They think] research solving problems is not true science. There is an elitist sort of view—even to the point where if we were to say, "Let's establish a center for conservation biology," you'd have a lot of scientists saying "I'm not a conservation biologist."*

Another interviewee brought up the need for more mutual respect: "I respect the need of people with those deep specializations. [But] very often, those people don't really respect the kind of people who are not chugging out those *Science* and *Nature* papers but trying to change the world. So there is a discord there."

According to some interviewees, a generational factor was at work here. Older scientists were much more likely to have a self-enclosed mindset toward their research: "[It seems] to be sort of a generational issue…There does tend to be an 'ivory tower scientist' type of approach to research. I've encountered this quite a lot in the Smithsonian where they'll say, 'I do research; I don't do conservation.'"

Organizational Structure

> *Since departments are almost always organized by discipline (e.g., physics, chemistry, biology) rather than by problems (e.g., earthquakes, semiconductor packaging, tissue engineering), they sometimes provide, often unintentionally, disincentives for interdisciplinary and inter-institutional work (Bozeman and Boardman, 2003).*

> *The real question that you always have in government management and also large organization management that recurs is a common theme. How do you coordinate? How do you make sure you have the synergies? ... I think the best of both worlds is when you have both decentralization which allows innovation, autonomy, creativity, but at the same time synergy in what I call the common areas (Zerhouni, 2005).*

Until fairly recently, scientific research organizations, particularly universities, typically were organized along departmental lines corresponding to specific disciplines (with notable exceptions such as Bell Laboratories), often combined with some form of tenure to insulate researchers from shifting political, intellectual, or peer-group pressures. The primary strengths of this arrangement were having researchers who "speak the same language" in close proximity to one another, thereby facilitating constructive interchange and ensuring that students acquired deep specializations. The structure also facilitated departments' advocating for resources.

In environments where there is little need for horizontal coordination, a discipline-based departmental structure works tolerably well. It does not, however, work well in an environment that requires flexibility, open boundaries, and contributions from more than one discipline. In this regard, the classical departmental system has fatal flaws:

- A focus on the minutiae of narrow specializations rather than the complexity of the big picture;
- Pursuit of lines of research of personal interest with little regard to the host organization as a whole and what would have most value to science or society more generally;
- A culture characterized by operational autonomy and insularity, intellectual compartmentalization, resistance to change, and inter-departmental competitiveness, exacerbated by the perpetual search for funds and staff;

- Loyalty to departments and personal research interests, rather than to the overall organization and its goals and priorities;
- Low turnover that can lead to stagnation;
- A tendency to downplay the need for management and to promote individuals to management positions based on scholarly accomplishment rather than managerial competence, and without proper preparation or training.

Many Smithsonian interviewees mentioned similar weaknesses with regard to the current organizational structure of science at the Smithsonian.

As research organizations have embraced IDR and focused on finding solutions to complex contemporary issues, they have had to look for programmatic frameworks other than disciplines to organize around and for more supportive organizational structures.

> *To provide fertile ground for this type of research, interdisciplinary centers need not only to be well-funded but to have an independent physical location and intellectual direction apart from traditional university departments. They should have clear and well-articulated organizing principles—be they problems, products, or projects—around which researchers can be chosen on the basis of their specific technical, methodological, or topical contributions, and to which the researchers are deeply committed. While a center should be established as a long-standing organizational body with continuity in management and leadership, its researchers should be appointed for flexible, intermittent but intensive short-term stays that are dictated by the scientific needs of projects rather than administrative mandates. Not only will such rotating appointments allow researchers to satisfy their intellectual curiosities without jeopardizing their professional responsibilities, they will also better serve the epistemological priorities of interdisciplinary research (Rhoten, 2004).*

Organizational structure has also been seen as a way to help change inappropriate organizational cultures and promote efficient use of resources.

The organizations reviewed in this study that had shifted to an IDR emphasis typically began the transition by adopting a research agenda, or programmatic framework, that focused on overarching scientific questions, challenges, themes, societal needs, or topics requiring an interdisciplinary approach, such as biomedicine, ecology, sustainability, emerging technologies (e.g., nanotechnology), and climate change or loss of biodiversity. Some centers focused on the synthesis of existing data to address problems, rather than the creation of new data. This type of framework was a marked departure from the traditional emphasis on curiosity-driven research

that reflected scientists' personal interests and that often followed disciplinary lines, perhaps branching out to other subdisciplines within a broader field such as biology.

This new type of research agenda necessitated an organizational structure that:

- Facilitated accomplishment of overall purpose, goals, program foci, needs of staff and stakeholders, and realities of physical space;
- Supported research by teams of people from different backgrounds and often working at different locations around the world;
- Provided the flexibility to adapt to scientific breakthroughs and new technologies and to respond to new issues.
- Offered informal support for researchers to share ideas, approaches, problem solving, technologies, etc.
- Facilitated the needed transition to a team-based, adaptive, organic, and open-minded culture.

Despite the resulting variety of organizational structures, all involved the creation of a separate IDR unit or office (referred to here as a center) that at a minimum provided administrative support and visibility. Some centers went further, emphasizing boundary spanning, providing office and lab space where researchers could work and get together outside their departments or home organizations, and, in a few instances, offer competitive grants for IDR research. Other variables that emerged as key considerations in the structure of IDR centers were:

- Staffing—whether the center had its own staff, supported researchers from other units within the umbrella organization and from outside, or combined the two;
- The location of the center within the overall structure of the home organization and to whom it reported (some centers were, however, self-standing);
- Whether the center belonged to a single organization or a partnership of organizations that worked under a single management and administrative structure and core office;
- Whether the work was done at the center, within other departments/schools of the home organization, at outside organizations, or some combination of those locations;
- In the case of universities, whether degrees were offered by the center, by other departments, or a combination of the two.

This section describes some of the research frameworks and organizational restructuring that private and public research entities have taken to support interdisciplinary work.

"Campus"-based Model

In this model, common to universities, the locus of research is the campus, but with new interdisciplinary units set up that pull researchers from across the university and/or hire their own interdisciplinary staff. The predominant model seems to be a non-departmental center with shared faculty from multiple departments/schools (Bozeman and Boardman, 2003). Some universities have established a multiplicity of IDR centers, elevating IDR studies to the college, school, or department level, or otherwise changing basic structures. Theil (2008) described this as the outgrowth of a process, begun over two decades ago, to enable schools to play a more direct role in solving societal problems and pushing economic growth. Academic reformers such as Michael Crow, president of ASU, have been engaging in a "fundamental rethinking of how universities should function in the 21st century."

Bozeman and Boardman (2003) document the proliferation of multipurpose, multidiscipline, university research centers with a range of ways of organizing to support research aimed at particular topics rather than disciplines. In the case of the MMURCs, the structure often encompassed not just different parts of the host university, but other universities and the private sector, including industry. Participation by the latter resulted from an important goal of universities to produce graduates who have the skills and knowledge needed by the private sector.

The study team encountered a variety of organizational structures with respect to where universities and museums located their IDR programs, including IDR units associated with disciplinary departments, non-departmental centers and institutes that sat outside of traditional departments and where faculty associated voluntarily with the centers, and interdisciplinary units that operated as distinct departments in their own right. The centers variously reported to provosts and vice provosts for research, deans, and department chairs, and students' advisors might be part of the center, the home department, or both.

One interviewee commented that such flexible, interdisciplinary arrangements, geared toward the resolution of complex problems, served as the new "water coolers" of the research world, enabling scientists to informally exchange information and ideas. This person added:

> *These new forms of organizations are viable alternatives to tired old departments. Simply merging departments will not work. [That] inhibits the organic morphing of creative organizations … In a sense, [these arrangements] become flexible overlays because [the faculty] reside in "mobile homes," without tenure. [Such] temporary*

structures are able to draw upon widely distributed talent and promise to become a source of creativity—a place where ideas are conceived and evolve into solutions. … As such, the research is a progression from the basic to the applied.

Following are a few examples of university IDR centers that the study team spoke to for this study. Note that research projects at most of these entities involved researchers from other organizations; where, however, participation by external researchers was a particular feature of the organizational structure, it is noted. (See also the profiles of 35 IDR organizations contained in Appendix C.)

- MIT created the Operations Research Center 50 years ago to bring together diverse departments and to bridge their cultures. It also offers its own degrees. Today, according to an interviewee, the center "does more than work—it thrives." MIT provides the Center with a small budget and space for its two co-directors (one each from the Schools of Management and Engineering) and visiting researchers. The center has 47 affiliated faculty, with roughly half active at any one time, and 50 graduate students. The center was described as dynamic and flexible—when opportunities arose in a particular field of research, it could form a team of internal and external researchers to write a proposal. For example, under the auspices of the center, five different faculties across MIT and the University of Texas recently won a NSF grant for aviation-related research.

- Harvard University's Center for the Environment encourages participation by students and faculty across Harvard's campus in research and education about the environment and its many interactions with human society. The center has a director, managing director, a small number of its own staff, and more than 100 affiliated faculty from different academic departments and university museums. The center provides seed money for IDR, holds seminars, maintains a post-doctoral fellowship program, and hosts events that facilitate informal interaction among people from different disciplines. Students work with the center but are enrolled in a home department that grants their degree. The center reports to the Assistant Provost for Science.

- Stanford University has created dozens of multidisciplinary centers and programs to promote teamwork and cross-fertilization. Bio-X is one example. Neither a department nor degree-granting entity, it is described as "a truly interdisciplinary and cross-university initiative" that has worked partly because it is "not stuck within a discipline such as a medical school." The purpose-built James H. Clark Center serves as home base to faculty from all departments and as the locus for 40 open labs. Bio-X funds "seed"-type projects of investigators from across the university, offers fellowships to early and mid-career scientists outside Stanford, and promotes relationships between industry and Stanford researchers.

- The interdisciplinary, university-wide Nicholas School for the Environment at Duke University, created through the merger of several older units and functions, has 3 research divisions and 11 research centers and programs. Some of its 105 participating faculty are part of the Nicholas School, while others remain part of their departments but are also affiliated with the school. Since the Nicholas School is largely self-supporting, the university treats it as a quasi-autonomous entity.

- The Behavior, Ecology, Evolution, and Systematics Program (BEES) at the University of Maryland, College Park, is a degree-granting, interdepartmental graduate program administered from the College of Life Sciences. Affiliated faculty come from departments across the university, as well as from collaborating partners, including the Smithsonian, USDA, and others. Staff from the partners teach at BEES and host graduate students to conduct research on their premises.

- Based on work ASU's Crow did when developing Columbia University's Earth Institute in the 1990s, he has begun abolishing traditional departments at ASU and regrouping the pieces into "transdisciplinary" institutes. For example, the new College of Nursing has architects, policy experts, and business professors working together on health care innovation. The School of Sustainability has professors from 35 disciplines bringing expertise ranging from desert-water ecology to energy-saving building design to bear on urban development. The Biodesign Institute was formed to address global challenges in biomedical research and development.

- Globally, the new King Abdullah University of Science and Technology opening in 2010 in Saudi Arabia will have no academic departments—instead it will have four interdisciplinary research institutes for biosciences, materials science, energy and the environment, and computer science and math.

Distributed Research Models

The distributed research model involves a small core "center" that manages and facilitates approved research projects mostly carried out by teams of external scientists who have a common research project that typically relates to a complex and time-sensitive problem or challenge. The teams, which can consist of researchers from a single or multiple organizations, work at their home locations, convening periodically to plan their project and share and synthesize results. That is, most of the researchers are not staff of the center. However, at least two of the organizations discussed below are hybrid models that support both dispersed and campus-based research. And there are a handful of virtual research models, in which the

researchers work as a virtual team, supported by an administrative office that may be under the funding agency or one of the researchers' home organizations.

Precursors to Today's Distributed Research Models

Several external interviewees spoke of the Manhattan Project as a precursor of distributed research and development. In the early 1940s, in a wartime setting where time was a crucial consideration, the project harnessed the efforts of a dispersed network of scientists and engineers from laboratories, universities, and the private sector to meet the pressing challenge of developing nuclear weapons before the enemies of the United States did so. The project had three principal work sites—Richmond, Washington; Los Alamos, New Mexico; and Oak Ridge, Tennessee—as well as numerous smaller sites throughout the country. The operating philosophy and approach of the Manhattan Project have had enormous influence on subsequent interdisciplinary research, technology development, and project management.

The Apollo project, which culminated in the moon landing in 1969, was partly modeled after the Manhattan Project. It, too, involved the rapid mobilization of a dispersed network of universities, contractors, and government agencies to move forward cooperatively to meet an extremely complex technical challenge. It operates under the direction of one agency, NASA, which aligned its priorities to focus on the project.

A more current example that interviewees cited is the Gates Foundation's Global Malaria Initiative, which is comprised of 20-30 dispersed research centers working on the overall goal of reducing malaria deaths by the year 2015. Rather than acting as self-enclosed, autonomous units, these centers share information and coordinate in other ways to meet the considerable challenges of preventing, treating, raising awareness of, and ultimately developing a vaccine against this disease. With support from the White House, a large number of corporations, individuals, non-governmental organizations (NGOs), and 68 nations are participating in the initiative.

Research under SFI, whose research focus is understanding complex, adaptive systems, was founded in 1984. SFI has a small full- and part-time resident faculty of around 20 people and an external faculty of close to 100 people from various institutions. Although it has dedicated physical research space to house professors, post-docs, graduate students, visiting researchers, etc. doing work onsite and to hold meetings and workshops, it considers itself to be essentially dispersed—"without walls"—with the bulk of the work of scholars from universities, government agencies, research institutes, and private industry occurring at their home bases and other places.

Today, a requirement of much NSF funding is the creation of partnerships among public and private organizations to carry out interdisciplinary research and freely share the results among

the partners. An external interviewee discussed NSF's investment in nanotechnology as another example of the dispersed network model. NSF also requires that a single entity manage and coordinate the network of partners. The open flow of information among researchers challenges conventional thinking about how to tap brilliant minds and attain leadership in competitive arenas where the cost and speed of achieving tangible results are critical.[6]

Following are descriptions of three types of distributed research models.

Consortia

Consortia are in many ways similar to distributed research networks, except that the member organizations often come together not to carry out research, but to gain access to a range of expert talent in different disciplines and to physical facilities, laboratories, and other resources not necessarily available at their own organization. They may form to address complex problems that are too large for one organization to tackle alone and that require novel interdisciplinary approaches. Organizations also set up consortia to facilitate sharing of information and problem solving on organizational issues, including best practices and experiences dealing with such issues as overcoming resistance to interdisciplinarity. Knowledge transfer among consortium members generally occurs through research publications, program reports, newsletters that are circulated via the Web, and face-to-face meetings.

Consortia usually jointly retain a small central staff to provide administrative support; sometimes the partners are required to pay a yearly fee. University researchers engaged in consortium work often receive compensation beyond their usual annual salaries. Generally researchers at different universities are integrated into research teams with multiple PIs.

Following are some examples of consortia set up for different purposes.

- ***Smithsonian Institution Global Earth Observatories (SIGEO)***. The 30 year-old STRI-originated research consortium began as the Center for Tropical Forest Science, a network of forest dynamics plots administered by STRI but led and managed by partner institutions in tropical countries around the world. Today it encompasses 20 sites in 15 countries in Latin America, Africa, and Asia, and involves hundreds of scientists from more than two dozen institutions. The CTFS-SIGEO network has produced the first actuarial table for tropical trees around the world, which provides a baseline for

[6] NSF has also supported nanotechnology education projects through the Museum of Science in Boston, Exploratorium in San Francisco, and Science Museum of Minnesota as part of an effort to explain nanotechnology to the public. Purdue University and several other institutional partners are involved in this educational aspect.

determining quantitatively how trees and forest systems are responding to the Earth's climate change (Group on Earth Observations, 2007).

- ***Encyclopedia of Life (EOL).*** This consortium, which includes NMNH, was established to create an online reference and database for the world's 1.8 million known species. The "cornerstone" partners are the Biodiversity Heritage Library, Field Museum, Harvard University, Marine Biological Laboratory, and Missouri Botanical Garden. Scientists from all over the world provide data, images, and feedback to EOL. Audiences include not just scientists and researchers, but also natural resource managers, conservationists, teachers, students, and the general public. The MacArthur Foundation and Alfred P. Sloan Foundation provided start-up funds for EOL; funding to sustain the project is a concern.

- ***Consortium for the Barcode of Life (CBoL).*** Hosted at NMNH, the consortium includes 160 member organizations from 50 countries. Its purpose is to explore and develop the potential of DNA barcoding as a practical tool for species identification in taxonomic research, biodiversity studies, and conservation, and for diverse applications that use taxonomic information in service to science and society.

- ***Consortium on Fostering Interdisciplinary Inquiry.*** Led by the University of Minnesota, the consortium involves nine other research universities: Brown, Duke, California–Berkeley, Illinois–Urbana-Champaign, Michigan, Minnesota, North Carolina, Chapel Hill, Pennsylvania, Washington, and Wisconsin. The consortium explicitly seeks to break down the traditional departmental and disciplinary barriers that have obstructed interdisciplinary teams, projects, programs, and initiatives. A multi-institution study and identification of best practices will be used to advance change at consortium members and other organizations.

As described elsewhere, many NSF funding programs encourage or require the development of consortia. Similarly, through its Roadmap for Medical Research, NIH made funding available in 2007 to nine interdisciplinary research consortia with the intent of jump starting the integration of different disciplines to address health challenges that have been resistant to traditional research approaches. In announcing the initiative, NIH called it a fundamental change in both the culture of biomedical and behavioral research and the traditional approach at NIH of managing research within individual institutes (NIH, 2007). An interviewee explained:

When you look at academic research … you have all these individual activities being funded through individual grants—a training grant, a center grant, clinical infrastructure, a particular disease center, maybe some core curriculum for teaching grants. These may be funded by 10 different institutes. What happens now is you come through a consortium, and we provide an administrative core that links these various activities together. They are still funded by individual units, but they are linked by the umbrella.

The Virtual Research Model

In 1998 NASA established the National Astrobiology Institute (NAI) as an innovative way to develop the field of astrobiology and provide a scientific framework for flight missions. It envisioned NAI as a virtual, distributed organization of competitively-selected teams that would promote, conduct, and lead integrated astrobiology research guided by an Astrobiology Roadmap. NAI has a resident director and small staff at NASA Ames who support 14 dispersed research teams with a total of 600 investigators from 150 institutions. Based on the success of NAI, NASA recently established the Lunar Science Institute as an interdisciplinary virtual institute to support research, in the words of one interviewee, "of the moon, on the moon, and from the moon."

The Campus-Based/Distributed Research Hybrid Model

Research at the National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California, Santa Barbara, whose focus is ecology and allied disciplines, is carried out by a combination of campus-based and dispersed teams of affiliated researchers. NCEAS, most of whose funding comes from NSF, supports projects that make use of and synthesize existing data or lead to the development of new databases that draw existing information together, rather than the generation of new data. NCEAS is administratively under UC-Santa Barbara, but its operations are largely independent of the university, and it has separate physical space in downtown Santa Barbara. NCEAS offers four research programs, three of which are on campus and one of which is both onsite and offsite (the information below comes from the NCEAS website and from interviews):

- ***Post-doctoral associates.*** NCEAS makes competitive 12-18 awards per year for these research fellowships. The work must involve synthetic projects in ecology and allied fields, focusing on the use of existing data. The term of the appointment is one year with the possibility of a second year; sometimes the appointment may be extended for a third year. The award involves a a salary of "approximately $41,000, plus benefits, a discretionary fund, mentoring funds, and access to all NCEAS and UC Santa Barbara facilities."

- ***Working groups.*** The working groups consist of 10-15 researchers who work intensively together at NCEAS for one to two weeks. The center "supports researchers' travel and provides the infrastructure necessary for deep analysis and collaboration in a hospitable environment."

- ***Sabbatical fellows.*** These fellows take up residence at NCEAS for three to twelve months, with the center providing up to one half of the fellow's salary, a housing allowance, and travel costs to NCEAS.

- ***Distributed graduate seminars.*** This program involves integrated, multi-campus teams of graduate students who conduct research on different aspects of a common, large project. A faculty member at each participating university teaches a seminar related to the research being conducted and supervises the team's work. At the end of the seminar, the faculty leaders and two students from each university gather at NCEAS to synthesize the results. NCEAS covers "travel, lodging and per diem expenses for the organizational meeting and the final synthetic meeting … [and] up to $1,000 per institution in discretionary funds to support course activities such as telephone use, photocopying or additional travel (e.g., for student travel to collect information)."

NCEAS has staff of 14, including five managers—General Director, Deputy Director, Director of Conservation and Research Management, Director of Informatics, and Director of Computing—supported by an administrative staff of nine.

Matrix Management Model

Echoing earlier discussions in this report, Hollingsworth, Muller, and Hollingsworth (2008) described the problems with the buildup of "huge departments constructed like silos" in the traditional academic structure with an increase in bureaucracy, fragmentation, and difficulty communicating across fields.

> *In some respects, the research segments of many US universities have become like holding companies. As long as researchers can bring in large research grants and pay substantial institutional overhead costs, universities are happy to have the income. Granting agencies and universities, realizing that this kind of structure has become dysfunctional, have made serious efforts to reduce the number of managerial levels and to develop matrix-type teams to minimize organizational rigidities. However, organizational inertia hampers these efforts.*

Although matrix structures have many forms, most employ joint planning processes and dual assignments for managers. For example, the director of a department may also be given

responsibility for managing a project that draws on his/her own training but may not be placed in his/her department. As the head of a project, he/she may also gain knowledge that can increase his/her own department's capabilities and efficiency.

A major strength of the matrix model is that it formalizes the sharing of specialized skills and talents across disciplines and departments. It is well-suited to balancing large project goals (the domain and area of research) with specific technical goals (the implementation and quality of work). Other strengths include enhanced coordination of a multiplicity of activities and an ability to respond rapidly to changes in the environment—in mature matrix systems, resources may be diverted from one area of operation to another through negotiations, much like buyer/seller relationships.

On the downside, a matrix structure may create confusion because of unclear expectations and reporting requirements, along with role conflicts and complicated overview and appeal processes. At times, organizations structured along matrix lines tend toward disorder. In their formative stages, they generally require additional personnel, which means higher overhead and increased expenditures. Another problem may be whether a staff member has the right to choose not to participate in a given project. At times, people are reluctant to gravitate toward interesting projects because they may be overlooked for interesting assignments in their own departments.

Increasingly, universities are using matrix management to respond to interdisciplinary initiatives that cannot be handled in existing departments. Bozeman and Boardman (2003) noted that many of the new multi-institutional IDR centers involve a "latticework of reporting relationships and authority lines." Often, the center director has cross-disciplinary, interdepartmental, and inter-university relationships to manage in addition to the traditional hierarchical ones. Some universities make use of quasi-market mechanisms such as re-imbursements to professors' permanent departments.

The study team spoke with a number of Federal mission-mandated agencies that have changed their programmatic frameworks, necessitating changes in their organizational structures. A number have opted for a matrix management structure, along with many of the same approaches and techniques found with distributed research networks and consortia. Two agencies are highlighted below.

- ***National Oceanographic and Atmospheric Administration (NOAA).*** NOAA, which is known primarily for its weather service, ocean mapping, and protection of fisheries, has realigned its resources away from a discipline-based structure to an issue-oriented one, one issue being climate change. Its strategic vision is "an informed society that uses a comprehensive understanding of the role of oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions." A NOAA staff member

noted "A tendency and a trend that will continue is to migrate away from classic disciplines and meld those disciplines into a collective pool of intellect to solve societal problems. NOAA is now moving forward to [become] a more integrated agency."

NOAA uses a matrix management approach to align staff in its five line organizations (weather service, fisheries service, ocean service, research, and satellite and information service) with its problem-oriented strategic objectives—"so a biologist coming out of the fisheries world is paid for through an appropriation, but that person's work assignment is also to the ocean service for work in a coastal erosion application." Besides cross-organization matrices, NOAA is building greater awareness regionally so that "[staff] in New England know what the fisheries issues are, but also what are the weather-based issues [and] coastal community and ocean service needs and interests—we are trying to make people more aware of what their colleagues do." One desired outcome of the matrix approach and regionalization is to have staff identify with NOAA as an organization, rather than with an individual lab or investigation within the lab. The administration reinforces this perspective through its strategic goals, which to a great extent determine the allocation of funds. A central Office of Program Planning and Integration, established to facilitate the new corporate management culture, is responsible for developing the capacity and integrity of programs within the matrix system, including the integration of social science research and analysis capabilities.

- ***Agricultural Research Service.*** ARS has over 100 research locations in the United States and four overseas labs. Originally its programs were based on commodities or disciplines, but 11 years ago it instituted a National Program system to better leverage resources to address national problems and to facilitate the required interdisciplinary, cross-locational research —"our labs' strength lies in the work they do locally, but why couldn't we bring to bear some of those same results on problems of national priority?" Management anticipated resistance and a need for culture change, as the agency moved from commodity to problem-focused National Programs, numbering 22 in 2008. One interviewee explained, "The incentives we used were good old common sense. It just was time to do this; it made sense. It was going to strengthen ARS, it was going to increase the impact of our research, increase our profile, [and] leverage our resources." Another selling point for the National Program structure was an enhanced ability to respond to high-profile emergencies—"ARS has all these resources that we can bring to bear on problems immediately as they arise. This became very attractive to scientists to become part of a national team that was addressing a high-profile problem."

  The National Programs are grouped under four overarching program areas: natural resources, crops, animals, and food safety and nutrition. ARS uses a matrix structure to integrate the National Program office—which sets up interdisciplinary teams for the

National Programs that exemplify the kind of collaboration expected from the field—with a dispersed system of research centers grouped in eight geographic areas, each with area and center directors, laboratory directors, and research leaders who oversee projects. Each National Program holds a customer/stakeholder workshop at which half the audience is ARS scientists from all over the country who do research in that area, and the other half is customers. Subsequently, ARS scientists devise their research strategy on a national, cross-disciplinary basis to address the problems they heard about from the customers. The goal is to write objectives that support the National Program but that are loose enough to allow the research centers to "get there however they want—the scientist writes his or her own approach and project plan around these objectives." Line managers are responsible for scientific quality and performance; the National Program office holds the program leaders responsible for program performance, impact, and relevance—"that's the matrix in a nutshell ... if it works well, it's great. In reality, if those people don't talk to each other, you're in big trouble. We're constantly working to keep the lines of communication open; it just boils down to human nature."

Structural Challenges

Center-Department Tensions

A science administrator explained that two risks with non-departmental centers is that they become "junior citizens in the university," and that tenure and career tracks of affiliated researchers may be jeopardized by the at-best three-year appointments at the centers. A university interviewee said the same thing—"We're rushing to catch up in our organizational structure because those places mostly aren't tenure homes; most have limited input into the review of faculty. The faculty are spending their time there without getting the rewards managed there."

One interviewee related his experience with the School of Computational Science and Information Technology (SCS) at Florida State University, a non-departmental IDR unit that was formed to bring people doing computational research together from all over campus. The school had a core group of computer scientists and applied mathematicians, but also physicists, structural and evolutionary biologists, chemists, atmospheric scientists, geologists, and engineers—"the idea was to put us all into one building where we would work together, eat together, have coffee together, and things like that." Tensions arose because SCS scientists were still members of other departments. While some departments saw the situation as an opportunity for a SCS-affiliated researcher to contribute to the department without it coming out of their budget, others viewed the school as a threat and competitor for resources. Other problems included how departments would evaluate staff for tenure when they had little contact with them

and, for SCS-affiliated researchers, the extra layer of committees, annual reporting, and other responsibilities that squeezed the limited time they already had. Eventually, "it became too big of a headache to deal with the special challenges of having this unit that was outside of the normal departmental hierarchy," and SCS became a new Department of Scientific Computing. While still multidisciplinary, it was, according to the interviewee, a step back, and stifled the synergies that can happen with the intersection of departments under a single umbrella.

Similarly, another interviewee described the fractionation and split loyalties that developed at grant-funded centers such as the NSF-funded STCs. There was concern on the part of the organization, university department, or museum that the center would hollow out the organization. One interviewee told of a center focusing on conservation that was set up within the Field Museum—

> *because the center was looking at these issues and was better able to translate how the basic research was relevant to conservation, [it] started growing and getting big grants. Instead of putting the money [back into] the departments, they started hiring their own scientists outside of the departments. They built a mini-empire. It turned the rest of the museum against them.*

Bozeman and Boardman (2003) described the difficulties inherent in centers that involve multiple universities. In many instances, the director had to manage the cross-disciplinary and interdepartmental relationships of the center, the traditional hierarchical relations of the home university, and, on top of that, the inter-university relations.

> *"Report" has very different meanings … The center director seeks to bring some order and cohesion to the center's work activity but has very little authority to use in negotiations with faculty members of the center inasmuch as the faculty research likely receives pay from a different source, tenure and promotion from a different source, and generally has the option of unilaterally disembarking from the center … Whereas the department chair must juggle the interests of faculty, staff, and students, and accommodate a dean, the center director often must relate to multiple departments, a web of university administrators, and, often, faculty and administrators from partner or affiliated universities, government sponsors, industry, and various accountability overseers.*

Administrative Support

IDR poses unique needs in terms of administrative support, such as research and performance review committees and sharing staff. Interviewees gave examples of how their organizations set up central administrative and logistical support.

- NIH's Office of Portfolio Analysis and Strategic Initiatives (OPASI) was established in conjunction with the Roadmap for Medical Research to improve management of large and complex scientific portfolios; identify, in concert with multiple stakeholders, emerging scientific opportunities and public health challenges; focus investments in those areas, especially where the research involved multiple NIH institutes and centers; and coordinate use of NIH-wide evaluation processes. Former Director Zerhouni, to whom OPASI reported, said that it was set up in an effort to share a common set of standards that all institutes would use to report on research activities and to create a toolset for truly understanding NIH's portfolio (Zerhouni, 2005).

- NSF interviewees said that rather than reporting to any one directorate or division, which tends to promote silos, NSF-wide programs like STC and CDI report to the Office of Integrative Activities under the NSF director.

- At the University of Minnesota, the Graduate School's Office of Interdisciplinary Initiatives was established to seed, support, and sustain IDR initiatives and programs. It engages members of the university community in identifying institutional policies, programs, and best practices that encourage collaboration and interdisciplinary inquiry. Recognizing that its IDR entities exist outside of the traditional academic hierarchical structure and thus do not have the same voice and advocacy as departments, the Network of Interdisciplinary Initiatives was organized to bring together leaders of IDR centers and other enterprises that work on interdisciplinary grants that support labs, post-docs, etc. At first these leaders did not think they had anything in common—

  > *The conservation biologists thought of themselves in terms of a subject area just like any department or discipline would, and the folks in the museum studies interdisciplinary program had a different preoccupation. And once they started talking ... they started to see that indirect cost returns got in both of their ways, the absence of being able to assign course designators prohibited them from getting tuition revenue, or the lack of leadership at the level of the provost meant that when they argued for certain changes, instead they got workarounds.*

- The University of Washington also has a Network of Interdisciplinary Initiatives to bring faculty, staff, and students from the three campuses together to identify challenges to IDR and initiate institutional change to resolve them. An interviewee related how the university created a seed fund called the University Initiatives Fund that allowed faculty-driven proposals for new interdisciplinary initiatives. Once an initiative had passed the first few years, it could get reviewed for permanent funding.

- The Office of Interdisciplinary Program Management at Duke University was set up to ensure efficient and effective administrative staffing and processes in support of the

seven university institutes and centers and for interdisciplinary activities within, across and beyond them.

The Smithsonian Workforce

> *Again and again, it seems to me that it comes down to the human capital. If you don't have people around who know new things, or who have different ideas about how you might answer a question, then it's difficult.*
>
> *Having people come into your orbit who have new skills is really an extremely important thing in fostering collaborations, because suddenly, 'Oh, have you ever thought about doing … if you want to know that, why don't you try this?… I didn't know it was really possible for us to do that.' That's actually a really important part of this, that people sink gradually into their familiar world … and it's really hard to keep yourself focused on … how to do you might be able to answer a problem in a different way than you could go about it before. Having students and post-docs around is a really important part of that, and new staff members.*

A great many interviewees noted that the human element is the underpinning of high quality collaborative and interdisciplinary scientific research in general, and at the Smithsonian in particular. One theme stood out in interviewees' comments—the Institution has a profound need for generational change given its aging science workforce. Younger scientists were routinely described as inherently collaborative, hard-wired to cross disciplines and think outside traditional boundaries, entrepreneurial, and energetic—the qualities required in an increasingly interdisciplinary and dynamic global research environment. One long-time researcher at the Smithsonian commented,

> *By going through all these applications [for a research position], boy, did we learn what people are doing today. What an education! And they were exciting people. The idea that we have to bring in new technology—that's not an issue. The people you recruit have those new ideas and technologies because that's what the universities and post-doc positions are producing these days. You don't have to actively seek someone different from yourself. There is no one left like me.*

Four other human capital-related themes were prominent:

1) To augment the limited numbers of permanent research staff and keep up-to-date, the Smithsonian science community needs a constant inflow of people with new ideas, perspectives, approaches, knowledge, skills, and technologies.

2) The system for awarding Smithsonian Fellowships is not set up to handle IDR proposals.

3) The performance evaluation system does not reflect the unique characteristics and results of collaborative and interdisciplinary research.

4) The human resources system does not adequately accommodate the needs of scientific research, particularly in terms of flexibility in the hiring and deployment of the Smithsonian's workforce.

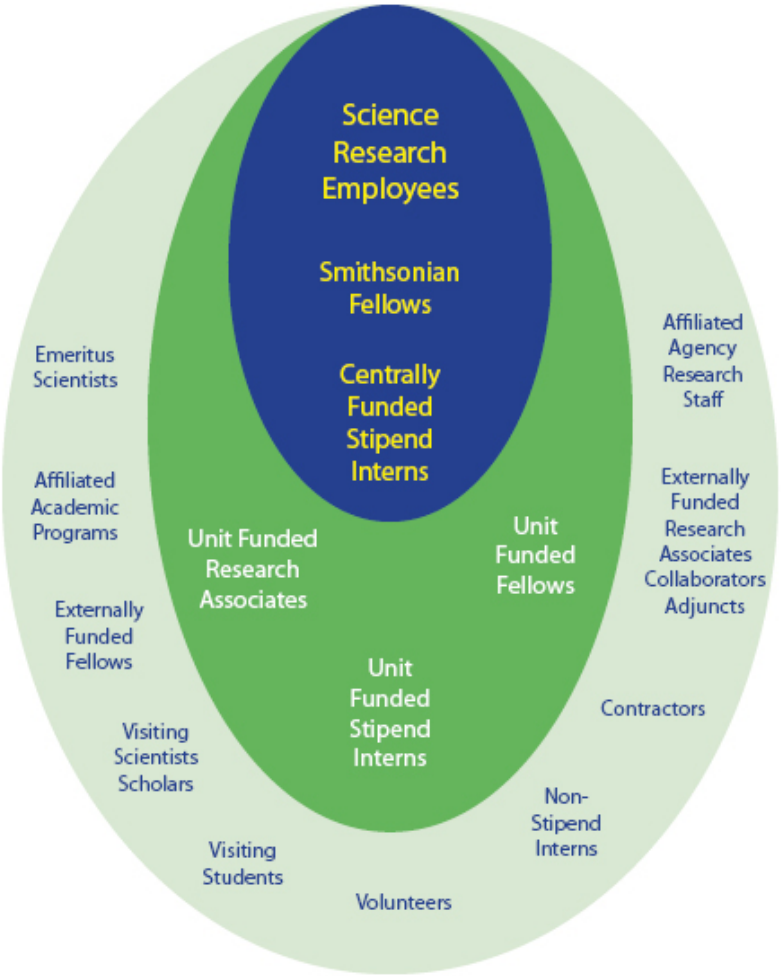
These themes are explored below, following an overview of the workforce at the Smithsonian currently and in comparison with 1993.

In this report, the Smithsonian's workforce/human resources are defined broadly to encompass not just full-time permanent Federal and Trust employees, but other categories of researchers. For example, the work of the full-time permanent staff is augmented by a very large number of other researchers, some of them employees and many who are not. These other workforce categories include temporary, term, and part-time employees, academic appointees (e.g., fellows [graduate students, pre-docs, and post-docs], visiting researchers [visiting students, scientists, and scholars], and interns[7]), staff of other Federal agencies working at the Smithsonian, and volunteers (Figure 1). Virtually all interviewees strongly emphasized that Smithsonian science would be much reduced were it not for these other categories of personnel, who carry out valuable research on the collections on their own, contribute to the research of Smithsonian scientists directly and indirectly, and bring with them a steady flow of new ideas, perspectives, knowledge, skills, approaches, and technologies.

Beyond the contributions of these other workforce categories, there is a clear link between fellowships and permanent hires. For example, as of the time of this writing, 21 NMNH research scientists and 9 NMNH technical staff and affiliated agency research staff were former Smithsonian Fellows, and seven SERC research associates were former fellows. Aside from their capabilities as researchers, these former fellows come with strong connections to Smithsonian scientists and familiarity with the operations of the Institution.

[7] These terms come from Smithsonian Directive 701, Smithsonian Institution Academic Appointments with Stipend. Some units offer additional academic appointments.

Figure 1. The Workforce Supporting Science Research at the Smithsonian Institution: Centrally Funded, Unit Funded, and Externally Funded



Because there is no single database that accurately tracks these other categories of the science workforce, the OP&A study team did not attempt to quantify the numbers of people involved (except for fellows) or the hours of work they represent.

An Overview of the Smithsonian Scientific Research Workforce

Smithsonian Employees in Scientific Research

A recurring theme heard at the Smithsonian is that the number of full-time permanent Federal science staff, both researchers and technicians, has fallen significantly over the last 10-15 years, while the age distribution has become increasingly skewed toward older personnel. One Smithsonian interviewee noted that the average age of scientists in many parts of his unit was over 60, in part because nobody wanted to retire. Even when they do retire, said one interviewee, "you don't know that they've retired because they're still there the next day" in emeritus status.

The importance of this age profile is that these longer term employees tend to come from "the old system." They are less likely than younger scientists to engage in interdisciplinary science because it is not personally of interest and they resist change. In contrast, said one interviewee, "it's often the early career scientists who are more energetic and excited about taking on bigger projects and will step forward." However, many interviewees also noted that the system makes it difficult to undertake collaborative and interdisciplinary work. If a person's current work is absorbing and easy to carry out, why make the effort to change?

In that context, the OP&A study team looked at National Finance Center (NFC) data for Smithsonian and Trust, permanent, temporary, and term, scientific researchers and technicians for the period 1993 to 2008 at seven research units/departments—SAO, SERC, STRI, MCI, NMNH, NZP, and CEPS (NASM).[8]

Numbers. According to NFC data, in January 2008 the Smithsonian employed 659 full-time permanent and temporary Federal and Trust science researchers and technicians in the seven

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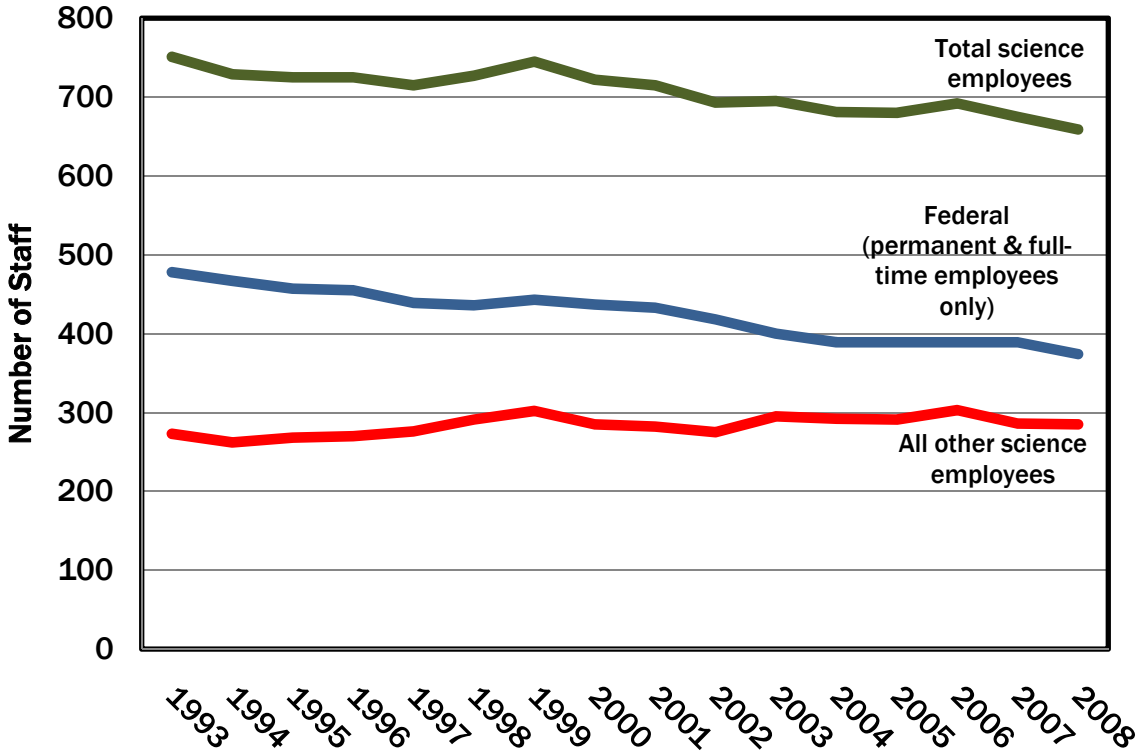
[8] The NFC handles the payroll for the Smithsonian. The data cover several categories of employees: (a) Federal and Trust (central and unit donor funds, grants, and contracts); (b) permanent (no limit on the duration of the appointment), temporary with reappointment possible, and term (specified duration of up to four years with no renewal); and (c) full-time (40 hours per week) and part-time. The data were gathered for employees whose job classifications fell into specific scientific series corresponding to the scientific disciplines covered by each unit, such as 410 (Zoologist), 440 (Geneticist), 1015 (Museum Curator), and 1016 (Museum Technician). Some of the employees classified as Museum Technician, such as some collections managers, may spend a considerable percentage of their time on research.

science units (Figures 2 and 3).[9] This number is 12% lower than the 751 employees in January 1993.[10] When only full-time permanent Federal employees are taken into account, the decline is more severe—22% overall, and 26% for science technicians specifically. This decrease in full-time permanent Federal research staff was partly compensated by a 4% increase in Trust, term, and part-time employees.

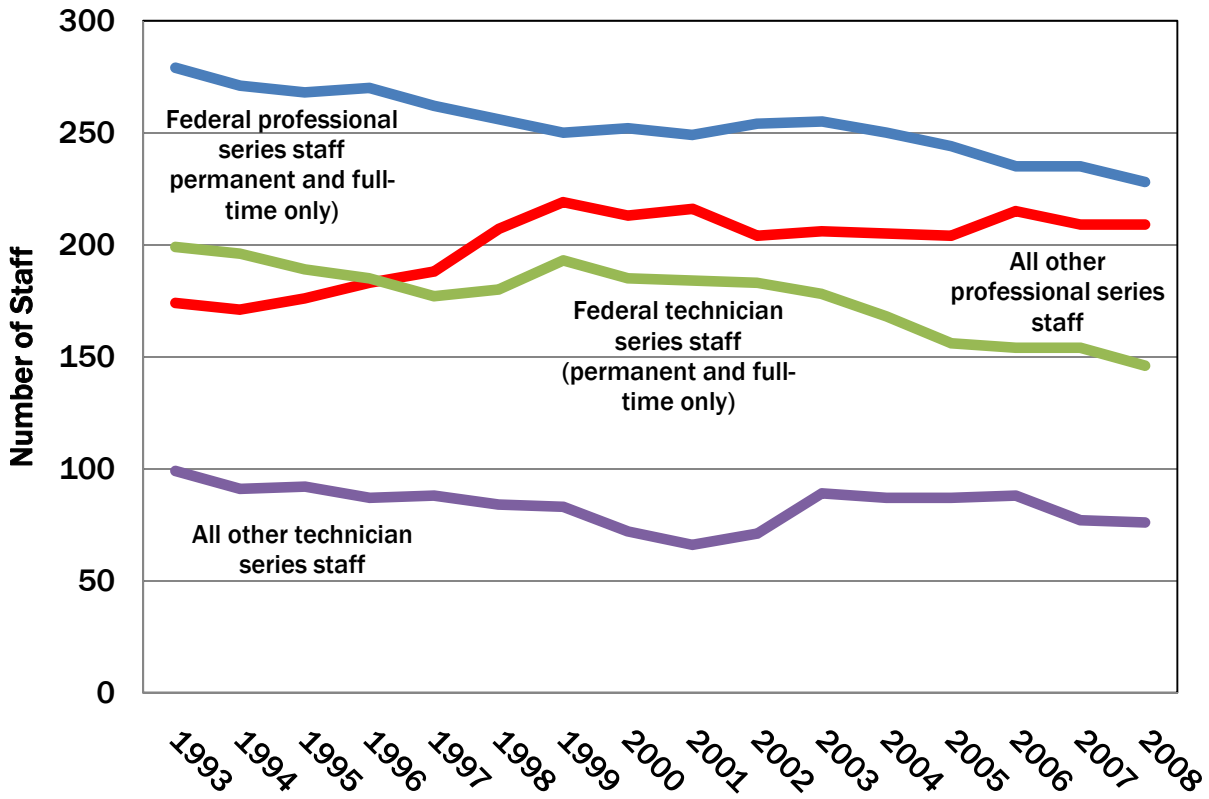
Figure 2. Smithsonian Science Unit Staff, January 1993-January 2008
(*Note: other science employees include Trust and Federal term, temporary, and part-time)*



[9] The number of staff doing scientific research may have been higher if people classified under different job codes were in practice assigned to perform science research tasks, such as caring for scientific collections. The study team could not identify such people.

[10] These figures take into account two anomalous situations. First, in 2000, the Panama Canal Zone reverted back to Panama. After that time, a number of employees, mostly science technicians, were transferred off the Smithsonian employee workforce paid through the NFC, and STRI now pays them locally, in accordance with Panamanian rather than US labor laws. Twenty-nine researchers continued to be paid through the NFC. Second, in 2005, when MCI's mission was modified, it lost several positions.

Figure 3. Smithsonian Science Research Staff by Type, January 1993-January 2008
(*Note: other science employees include Trust and Federal term, temporary, and part-time)*

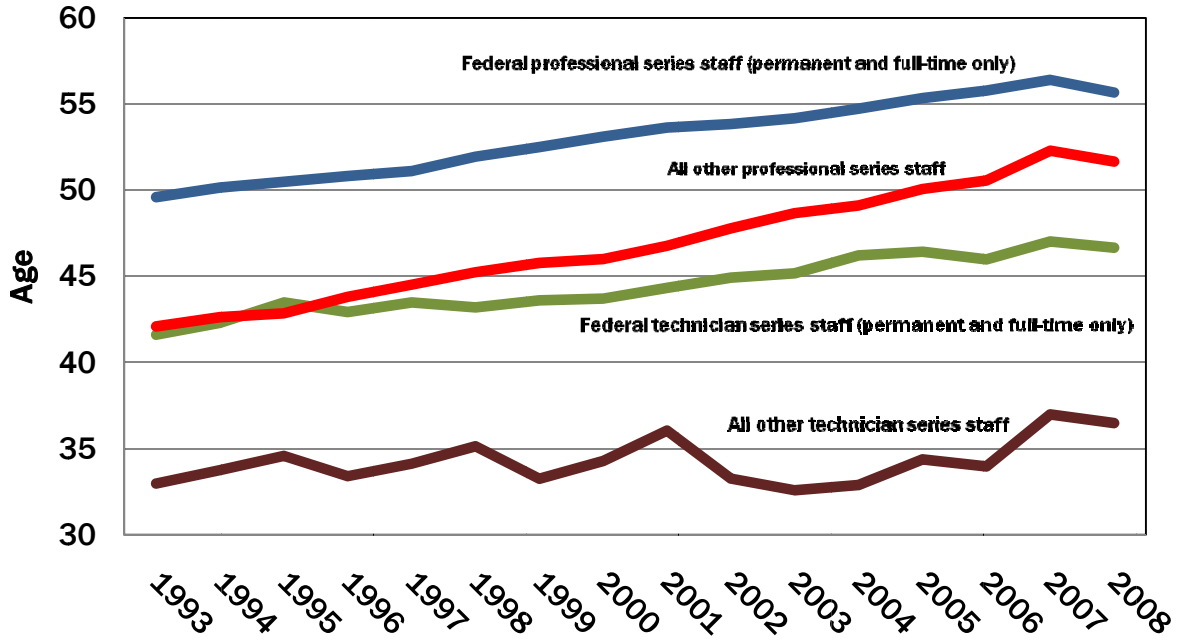


Different Smithsonian units experienced different reductions in the numbers of science staff overall between 1993 and 2008 (Appendix E).[11] NMNH, for example, saw a 32% drop in full-time permanent Federal researchers and 26% in technicians, the most pronounced declines. At SAO, which secures much of its funding from grants and contracts and the number of whose researchers are not full-time and permanent rises and falls, the drop was 8% over the period. SERC experienced minimal changes in the number of full-time permanent researchers, but the number of research and technical staff who were not full-time permanent grew substantially.

Age distribution. The data show that the average age of full-time permanent Federal science research employees did rise over the period 1993 through 2008, the same conclusion the Science Commission reached in its 2002 report (Figure 4). Whereas in 1993 the average age of these

[11] STRI was not charted because of the change in NFC statistics following the reversion. The number of CEPS (NASM), MCI, and OUSS employees was too small to chart.

Figure 4. Mean Age of Smithsonian Science Employees by Type, January 1993-January 2008



researchers was 49.6 years and that of technicians 42.1 years, by 2007 it had increased to 56.4 and 52.3 years, respectively. However, in 2008 there was a small drop to 55.7 and 51.7 years, respectively.

The relative proportions of full-time permanent Federal and Trust employees over 62 also showed a definite shift over time toward an older workforce. For example, for the period 1993 through 2008, the percentage of full-time permanent Federal and Trust science employees 62 years and over increased from 11% to 20%; for technicians, the percentage went from 2% to 9%.[12]

There was also a very slight grade creep over the same period. The increasing age of Smithsonian science staff reflects the decreasing number of full-time permanent researchers and a low rate of turnover among full-time permanent Federal researchers. On average, the science staff exiting the Smithsonian workforce between 1993 and 2007 (including the science series technicians but excluding museum technicians) were 39 years old, had a grade of 9.5, held

[12] In this case, Federal and Trust employees were combined because the number of employees in each category was small, and the resulting percentages might not have been reliable.

permanent appointments (44%), and were Federal (35%). In comparison, employees entering the Smithsonian workforce between 1994 and 2008 averaged 33.7 years, were grade 9.0, held permanent appointments (33%), and were Federal (29%). Typically, half of exiting employees had worked at the Institution more than 15 years. Conversely, normally, half of the employees who were not full-time permanent, Federal and Trust, exited the Smithsonian workforce within two or three years.

Non-Employee Workforce

At any time, a large number of people who are not Smithsonian employees are carrying out research on their own projects or on projects of Smithsonian staff. These researchers come to the Smithsonian through a variety of programs, including paid academic appointments such as centrally- and unit-funded fellowships, unfunded academic appointments, including emeritus Smithsonian scholars and volunteers, and research associate appointments. Their reasons for choosing the Smithsonian include access to the collections and specific research facilities, interest in working with a particular Smithsonian researcher, and educational and professional development opportunities.

The magnitude of these categories of researchers can be seen from figures provided by NMNH, which has hosted the largest number and variety of non-employee researchers. Based on information from its website (updated as of November 15, 2008), in fiscal year (FY) 2008 the museum had 48 Smithsonian Fellows, 113 unit-funded fellows, 21 externally-funded fellows, 87 visiting scientists and students, 272 undergraduate interns, 162 research collaborators, and 251 research associates, for a total of 954 non-employees. Emeritus NMNH researchers, interns, and volunteers would increase this number if included. During FY 2008 alone, NMNH hosted a total of 118 fellowship appointees, regardless of funding source, and 551 academic appointees[13], while SAO had about 100 fellows.

Smithsonian Fellowships.[14] Each year the Smithsonian awards on average 60 Smithsonian Fellowships (senior post-doctoral, post-doctoral, pre-doctoral, and graduate student), which carry a full-year stipend for post-doctoral Fellows of $40,000 and for pre-doctoral ones of $25,000. Between 1998 and 2008, 659 Smithsonian Fellowships were awarded at the seven science units—31 senior post-doctoral, 354 post-doctoral, 191 pre-doctoral, and 83 graduate student (Figure 5).

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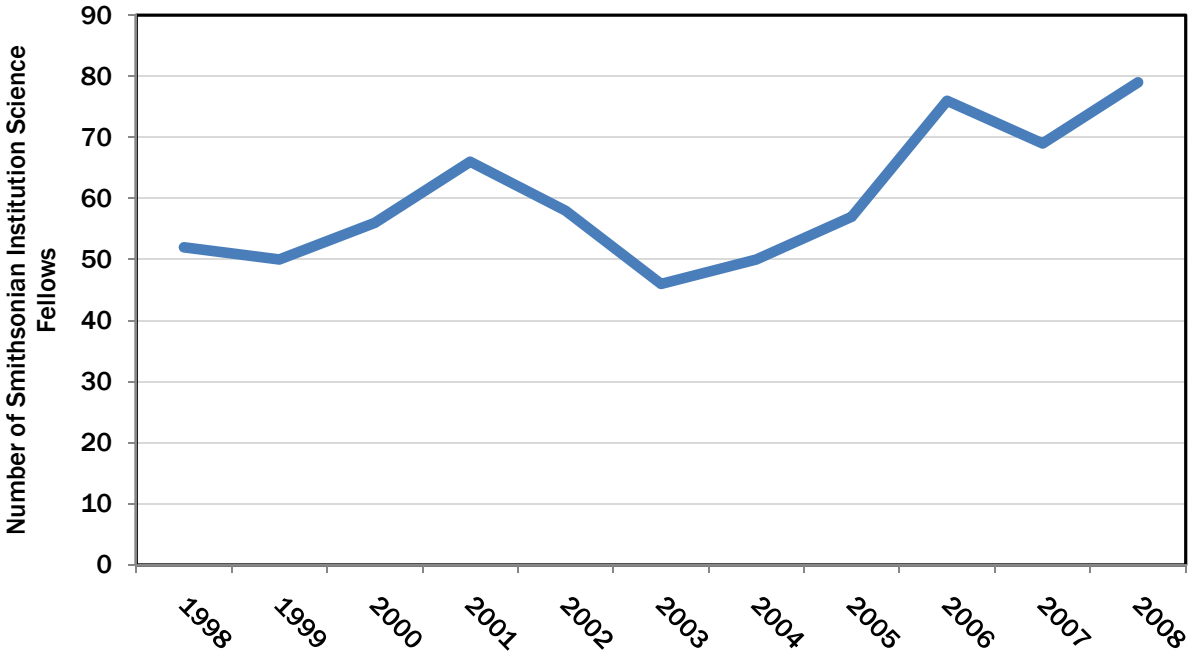
[13] The total number of fellows being hosted at NMNH in a given fiscal year may exceed the number of appointments made in that year because some of the fellows had been appointed in a prior fiscal year.

[14] "Smithsonian Fellowship" applies only to the set of centrally funded competitive fellowships administered and awarded through OF. It does not refer to any fellowships funded or awarded by a Smithsonian unit (referred to as unit fellowships) or external organizations (external fellowships).

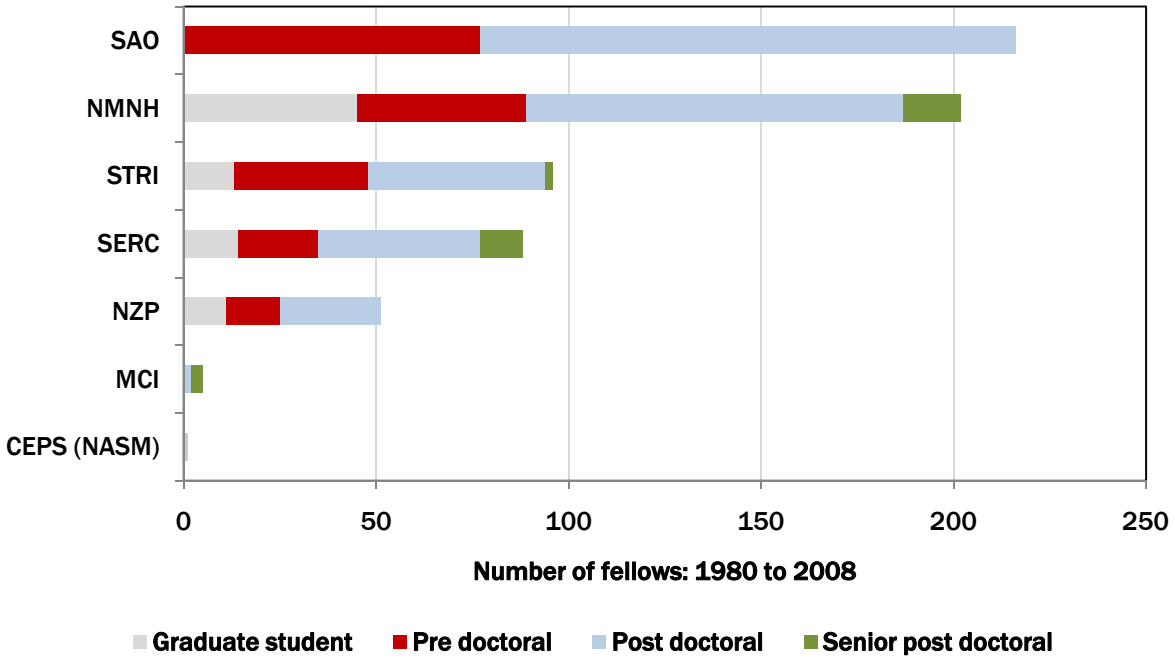
Figure 5. Total Number of Smithsonian Fellowships Awarded for Fellows in the Science Units, 1998 to 2008



Smithsonian Fellows interviewed for this study said that working with unique collections related to their research and with renowned scientists conducting research in similar areas were the main reasons they applied. Between 1998 and 2008, SAO hosted the largest number of Smithsonian Fellows, primarily post-doctoral, between 1998 and 2008, followed by NMNH, STRI, and SERC (Figure 6). MCI and CEPS (NASM) had very few. (A CEPS interviewee explained that the numbers can be misleading—since Smithsonian Fellowships do not provide enough funds for CEPS to be competitive in attracting applicants, it hosts post-doctoral fellows through external research grants).

Because Smithsonian Fellowships, like other fellowships at the Institution, specify that recipients pursue their own independent research, there may or may not be a close connection with the work of the Smithsonian's own researchers. Nevertheless, to judge from the comments of Smithsonian researchers, the opportunities for interaction and discussion about different

Figure 6. Smithsonian Fellowships Awarded by Science Unit, 1998-2008



methodologies, technologies, scientific advances, perspectives, etc. make the presence of these fellows very beneficial.

As with the non-employee workforce generally, there is still no single database for all Smithsonian academic appointments (i.e., fellowships, internships, research associate appointments, visiting scholars, etc.). All academic appointments, whether involving stipends or not, pass through OF except for non-stipend internships, which are handled by the Smithsonian Center for Education and Museum Studies (SCEMS). OF pays the stipends for stipend internships and Smithsonian Fellowships (and a small number of other fellowships), and it obligates the funds for fellowships paid directly by Smithsonian units. Although SD 205 states that the units are to notify OF of research associate appointments they make, that does not happen in all cases.

Beginning a few years ago, the Smithsonian Office of the Chief Information Officer (OCIO), in cooperation with OF and SCEMS, investigated web-based applications that could facilitate the application process for fellowships and internships. It went active with SOLAA (Smithsonian On-Line Academic Appointments System) in November 2008. SOLAA is currently being used to post information about, and receive applications for, fellowships and internships offered by fewer than 25 Smithsonian programs, which are run by a smaller number of units. No unit currently uses the system to process appointments for designated fellowships (defined by SOLAA as unit-paid and non-competitive) or other academic appointments. When SOLAA is

fully operational, and assuming all Smithsonian units participate, OCIO will be able to generate Microsoft SQL reports with the number of academic appointments at any time. As presently configured and planned, however, SOLAA combines designated fellowships and other academic appointments (such as research associates with or without stipends, and visiting scholars), so that it will not be able to provide disaggregated figures.

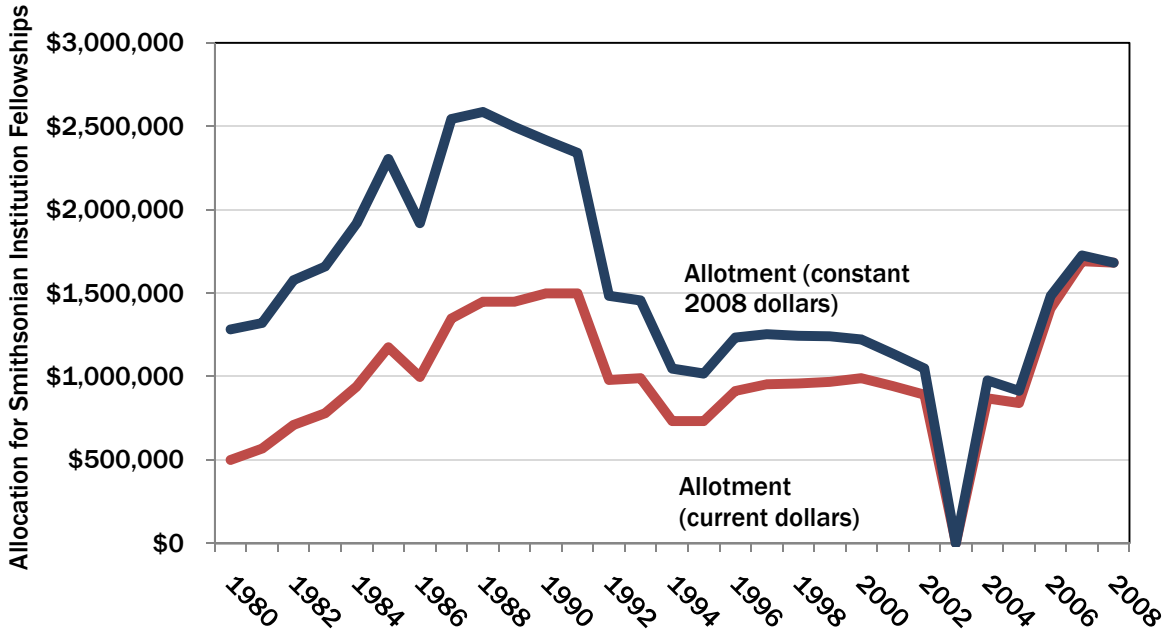
What data the study team did receive from different sources were not consistent. For example, the website for the Behavior, Ecology, Evolution and Systematics (BEES) program of the University of Maryland identifies two BEES students as Smithsonian Fellows in 2008—a one-year post-doctoral Smithsonian Fellow at NMNH, and a two-year post-doctoral Smithsonian Fellow at SERC. The list of Smithsonian Fellows from OF does not, however, mention the BEES affiliation.

In FY 2008, $1,682,000 was allocated for all Smithsonian Fellowships, in science and non-science units; the total for the period FY 1980 to FY 2008 was $29,453,000 (Figure 7). Through FY 2005, funds for Smithsonian Fellowships came from a centrally managed pool. (In FY 2003 no allocation was made to the central pool, and OF cobbled together money from various sources, including the units, to fund a smaller number of Smithsonian Fellowships; for this reason, Figure 7 shows $0 in that year). Beginning in FY 2007, Smithsonian Fellowships were included as a line item in the Institutional budget, using a Trust fund supplement granted by the Acting Secretary. The highest level of allocations for Smithsonian Fellowships (in constant 2008 dollars) occurred between FY 1987 and FY 1991; since FY 2006 the allocations have been higher than those made in the previous decade and a half. The FY 2008 allocation was approximately three fifths of the peak allocation in FY 1988 (in constant 2008 dollars).

Most Smithsonian Fellowships run from several months to one year, with a few awards running two or three years, especially in the science units. Interviewees thought the one-year term was a major problem with science fellowships. Not only does it take time to start up the research project, but the intern quickly had to begin thinking about the end of that year and applying for jobs. An interviewee said, “You spend most of your waking hours applying for jobs or thinking of some other post-doc.” Another stated that post-docs “would be a lot more productive with at least 24 months … There is definitely an efficiency gain from a longer post-doc period. Even if there are fewer awards given, I think 24 months should become the minimum.”

The awards for Smithsonian Fellowships are made as follows. Applications are submitted through OF, which distributes them to 12 review committees, each of which is discipline or unit-based and composed of Smithsonian scholars in the relevant disciplines. As of January 2009, eight of the committees dealt with scientific research: Anthropology; Earth Science; Evolutionary and Systematic Biology; NZP; SERC; STRI; Molecular Evolution; and

Figure 7. Allocations for Smithsonian Fellowships, 1980 to 2008
(current and constant 2008 dollars)



Conservation. The total Smithsonian Fellowships allocation for each year is divided across all 12 committees proportionate to the amount of money each requested based on the applications assigned to each committee. That is, Smithsonian Fellowship funds are allocated based on an equity principle, rather than Institutional priorities. The committees are free to allocate the funds across their applications as they wish.

One problem with the award process noted by interviewees is that it is not set up to handle IDR proposals—there is no interdisciplinary review committee to look at proposals that involve more than one discipline or more than one Smithsonian unit—and therefore they almost never get funded. For their part, the discipline-specific review committees resist accepting interdisciplinary proposals in part because they do not have the relevant membership. But, according to interviewees, it is also because they are loath to relinquish a discipline-based position to someone who might not spend full-time in one department or unit.

Unit fellowships and other categories of non-employees. In addition to Smithsonian Fellowships, units offer three categories of academic appointments: fellowships; visiting researchers; and internships.

- ***Unit fellows.*** Unit fellows may or may not receive a stipend. Generally, the appointments are made competitively, with review of the applications conducted by staff

in the unit where the research is to be carried out. Post-doctoral fellowships run up to three years; pre-doctoral fellowships usually cannot exceed five years.

- ***Visiting researchers.*** Appointments of visiting researchers are made non-competitively.

- ***Visiting students, scientists, and scholars.*** *Visiting students* must conduct research involving the collections and Smithsonian staff. *Visiting scientists and scholars* are expected to facilitate exchanges of ideas and new research with Smithsonian research staff. All of these appointees must have an invitation from the host unit. Their appointments run up to three years.

- ***Internships.*** Internships come with and without stipends. The terms for those with stipends cannot exceed 16 weeks.

Here, too, there is no comprehensive database from which to determine how many fellows and visiting researchers, with and without stipend, are at Smithsonian facilities. These categories of researchers are supposed to receive brown badges through the Office of Protection Services, but some get badges of another color, while some units use brown badges for other categories of non-Smithsonian workers. Some units may not request badges for all visiting researchers, especially short-term ones. Finally, there is no source of numbers for very short-term students and other researchers for whom a badge is not required.

Importance of Staying Up-to-date

Many interviewees, as noted, very strongly emphasized the importance of a continual influx of new people with different perspectives, ideas, knowledge, skills, etc. Said one Smithsonian scientist,

> *Post-docs and pre-docs are a great vehicle for both getting people juiced up and going in new directions, and we need much more of that … [they serve] as a center that draws people to both the resources and the expertise we have here. It's formed a really great, interdisciplinary collaborative group … I'd love to see that model taken out more broadly, to see the rest of the Institution realizing that as well.*

From another, "For me the challenge is continually looking at what the cutting edges are. I bring in people to learn about new things … It's also a matter of trying to see where we're going." Interviewees singled out post-docs as being particularly vital to the Smithsonian's scientific research function, whether they come to work on their own projects or Smithsonian scientists' projects. But a range of non-permanent researchers were also referenced, such as fellows, research associates, undergraduates, pre-docs, professors on sabbatical, temporary and term

employees, joint/shared employees, and Trust appointees (Trust positions offer greater flexibility in deploying human resources than do Federal ones). Also noted was the value of rotating positions, whereby external researchers can come to the Smithsonian and vice-versa, and Smithsonian staff can move around internally.

Janelia Farm, the new Howard Hughes Medical Institute research facility in Virginia that emphasizes high-risk, cutting-edge interdisciplinary research, hires resident scientists for those very attributes for renewable terms of five years pending review. Recognizing the value of maximum exposure to diverse perspectives, knowledge, and approaches, it complements this staff with a "visiting scientist program. Scientists come for three weeks, a full sabbatical year, or a series of short visits spread over multiple years—we're open to any arrangement that makes sense" (Rubin 2008).

Beyond greater access to younger scientists, interviewees suggested a number of workforce options for keeping permanent staff abreast of new developments and challenged by new ways of thinking, as discussed below.

Younger Scientists: Agents of Change

> *There are a few young people around [here] who do have that fire in their belly. We just hired a new [young] researcher … he would participate in any of these things going on, even if it wasn't his forte … He is collaborating with everybody in the world. He is just so good at doing all this stuff. I'll guarantee it—any request for proposals that comes along, I'll get an email (he was my post-doc for the last couple of years) … saying, 'I was thinking maybe we could put in a proposal for this,' and it will be something totally not related to what we want to do, but he'll figure out a way to make it seem like it's natural, and we're on this. He's a grant-writing fool.*

Many interviewees made the point that change will come naturally to Smithsonian science as older staff retire and younger ones replace them. According to one person, younger researchers "are thinking way outside. The way of thinking is completely different … all the new hires are people who are starting out their careers and they are by discipline, [but] the way they view the world is much more open. They are thinking across disciplines."

This experience was shared by interviewees from non-Smithsonian organizations. Said one,

> *I was fortunate enough to have two of the best students anyone could have in their entire lives, and they were here at the same time … and oh my God, it was awful. They beat me up all the time. But they made me think every day … I see it as an important part to promoting the health of a research organization.*

Post-docs

In an article in *Nature*, Vastag describes one finding of a study of six NSF-funded interdisciplinary centers—"graduate students were the 'bridges' between disciplines. This bridging was particularly stark at one centre: remove the graduate students from the network map and only single-discipline islands remained" (Vastag, 2008). Likewise, interviewees in this study touted a range of benefits they derived from post-docs.

- ***Support for research.*** "If you have a robust program, a fellowship program would be a great way to do that. You bring in a targeted post-doc for several—two or three—years, in a targeted research design." And "Having those students and post-docs is really great because the time in traveling between sites consumes a lot of time. A lot of PIs don't have the time for that. They provide a bridge between programs."

- ***Catalyst for collaborations.*** "They all shared this post-doc. They said that because they had this post-doc, they spent more time talking to these other people and exploring their disciplines, and they wrote papers together … It's not just to have it all together and say, 'Yeah, we work on this,' but also have this glue of the post-doc that keeps us working collaboratively."

- ***Professional development of permanent staff.*** "They [post-docs] start to take you in some new direction. That is that component of new blood that we don't always have."

- ***Access to technical expertise.*** "We spend $1.5 million buying a time-of-flight mass spectrometer, which has a lot of potential for a lot of different things, but we haven't really realized that potential because we haven't been able to get consistent funding for post-doctoral help."

Despite the obvious and oft-cited benefits of post-docs, the Smithsonian offers "a pathetic level of support for fellowships," in the opinion of one person. Beyond the limited funding available, another interviewee said, "We don't sell our fellowship program. There are other science fellowship programs [at other research organizations] that are much less in terms of who they've produced and what they've produced, [but] they package it nicely, put it on the web, show their successes, the profiles of their successful people. We don't do any of that!" This interviewee went on to say, "Ask any of the science bureau chiefs what the crown jewel of the science program is, and I would be surprised if they didn't put the fellowship program as being very high. But here the fellowship program—the oxygen is out of the air in this place, and every year we get fewer." Two other problems were mentioned earlier: the difficulty the Smithsonian has handling interdisciplinary post-docs; and the one-year term for fellowships.

Not everyone agreed that support for post-docs was lacking, to wit, "We've invested one way or another to triple these fellowships. In 2007 we had the equivalent of $1.25 million in fellowships. Given that our direct S&E budget was $3.1 million, that's an indication of a pretty good commitment."

Sabbaticals/Rotating Positions

One interviewee proposed the following as a way to address the rigidity inherent in a permanent workforce and the need for fresh people from outside the Smithsonian:

> *[offer highly attractive] two-year rotating places … The Smithsonian via its budget pays the university from which the person is coming on sabbatical and the differential to live here … and provides them the support staff they need—the collections managers, research assistants, and stuff like that—and they just crank away on the research. It would be a beautiful little sabbatical.*

The responses to the 2002 survey of Smithsonian biologists contained the following suggestion:

> *Joint projects [with universities] should be encouraged. Provide space and facilities for university staff to do research on a competitive basis, for short or extended periods of time. There should be some type of scholarship to support qualified faculty members … to take a sabbatical or leave of absence at the Smithsonian. The [position] of Associate Researcher should be implemented [for] qualified professionals.*

Other interviewees called for internal sabbaticals, both to acquire new knowledge and skills and help bridge the divide across units:

> *[B]uild an exchange program. The best thing we can do is have the people go on sabbaticals across the units … It's beyond just knowing, getting the information. It's … getting people together, over a cup of coffee or parties or expeditions. It's personal relations that build strong projects and strong collaborations.*

A respondent to the 2002 survey of Smithsonian biologists commented that the isolation and insulation of many staff "could be a problem for the overall health of the Institution. I would encourage rotating invitations to employees from different divisions to meet on an annual basis to learn about SI overall."

One of Duke University's interdisciplinary institutes offers

> *a series of semester-long internal sabbaticals, in which … [faculty members] move out of their departments, and they come live with the genome people. We pay their salary for*

that six-month period of time, and they get engaged in some of the scholarship within the institute … they learn a new way of thinking about some problem, and then they go back home and continue to work with us from there.

Shared Positions

To further collaboration and IDR at the Smithsonian, an outside interviewee commented that "if several of the units would come together and jointly offer a fellowship, then it would facilitate the Institutional response right there." This same point emerged in the 2002 survey of Smithsonian biologists: the units need "shared appointments or post-docs, say between SI [units] and STRI." Specific opportunities for sharing staff mentioned in the interviews were SIGEO, NEON, and lab technicians. The latter would be particularly advantageous because technicians today require far more education to work with today's sophisticated equipment and therefore are increasingly expensive. Further, a lot of equipment and technicians are funded through grants; when they run out, "you still have the equipment but the technician is gone, and what do you do then?"

The reality, however, according to many Smithsonian interviewees, is that sharing of academic appointees—and hires—happens very infrequently because of major administrative and cultural obstacles. In the case of full-time employees, Office of Personnel Management (OPM) rules require that an employee must be assigned to a single unit and provide it 8 hours of work per day; it does not allow an employee to have two part-time positions. Thus, to share an existing employee, the receiving unit must reimburse the home unit for the time the employee is with it. Smithsonian Trust positions are not constrained by OPM regulations, but rather by an internal administrative hurdle: "Payroll can't cope with two part-time jobs." Although within units different offices or departments can share an employee, the units resist doing so for fear that they would somehow lose one of their jealously guarded positions. Administering joint appointments, said one interviewee based on personal experience, is a "nightmare." There are difficulties from the employee's perspective—"expectations on both sides must be clear; there should be a written agreement on the time spent at each unit; [and] … different units may offer different benefits." Performance evaluation can be complicated because the units use different measures. One of the few examples of a shared position is the director of SAO, whose salary is paid jointly by the Smithsonian and Harvard University. Arranging for this "unique legislative beast" proved very difficult.

At bottom, however, the main issue was seen to be the intense competitiveness across units. According to one person, "We had joint appointments with other SI bureaus, and it didn't work out well because of … who gets credit for what is done … [and] something as trivial as the big to-do about who is going to do a press release on a researcher's discovery." Another interviewee

reiterated this point—"it's always about which of these groups are going to corner most of the money and which institutions are going to control the money."

Some universities have begun to address the above issues. For example, at the November 2008 meeting of the Consortium on Fostering Interdisciplinary Inquiry, there was discussion of the approaches the member universities had taken to promote interdisciplinary teaching and research. One was the University of Wisconsin-Madison's Cluster Hiring Initiative, launched in 1998 with a mix of public and private funds. It creates

> *nearly 150 new faculty lines allocated to developing interdisciplinary "clusters" of faculty to facilitate cross-disciplinary work. The initiative provides an alternative to departmentally based hiring practices by providing central salary support for faculty positions devoted to an area of knowledge that would not be addressed through existing departmental structures. Part of the initiative is a campus-wide Interdisciplinary Advisory Committee appointed by the Provost (Clark, n.d.).*

Another practice that generated strong interest was to put in place specific guidelines for interdisciplinary faculty appointments in the form of memoranda of understanding (MOUs) between hiring units (Marty, 2008). At Harvard University's Faculty of Arts and Sciences, the departments "are beginning to loosen up. They are doing more joint appointments. In some tenure cases, letters of recommendation from people outside of the candidates' home department are given equal consideration" (Lok, 2008).

Interns

One interviewee thought the Smithsonian did not make adequate use of interns, although the interest was there—"I've always asked our new hires, 'What's your level of interest in being involved in any kind of collaboration with local universities?' People say they'd love to do that." Another interviewee who used interns talked about the personal satisfaction he got when, "years later, you have someone calling you up and saying, 'Oh, I just got this job. Remember I was an intern with you?' It's like you change [people's lives]. What can be better?"

Here, too, some interviewees spoke of obstacles. One was a lack of formal credit for mentoring interns. Another was laws intended to protect interns from being exploited for cheap labor. Paid interns cannot work more than 16 months, and graduates six months out of college who are not enrolling in graduate school within six months of their Smithsonian appointment do not qualify. But, according to an interviewee, "this is where we get our future people. Often those are the most qualified people, they're more mature, they're more motivated, they're more successful, they're here to learn, and they really benefit from the program." The interviewee wondered if

"we're putting [enough] effort into figuring out what is it that we need and then going to the Department of Labor [to solve the problems]." According to an internal NZP study,

> *The Science Council estimates that the great majority of our short-term associates are effectively '"interns" from a learning/training standpoint because most (>80%) enroll in graduate school within a few years of working with us. If SI internships could be made more flexible, we could serve the needs of this growing group of "betweeners" (between academic or professional programs), giving us more flexibility in recruiting people to our research programs.*

The study recommended that OF create a new category of traineeships, such as an apprenticeship program, to address some of the administrative requirements that restrict internships—"Ideally, such an associate could work with SI scientists for up to 12 months, which would allow for needed flexibility in designing a meaningful trainee experience" (NZP Science Council, 2008).

Pre-docs

At universities, according to one interviewee,

> *the main way … that principal investigators branch out and start new projects is through their graduate students. It happens by finding a student being charged to investigate some new thing that is on the fringe of their field, and they need to get help from someone who is in a slightly different thing, and it grows that way.*

One university interviewee spoke of a win-win relationship with NMNH. NMNH used the University of Maryland's BEES program to attract pre-docs interested in paleobiology. BEES benefited because "the Smithsonian is our major co-advising hub right now ... we don't do taxonomy here. Most institutions don't have it. That's why the museums are so important." BEES suggested that the Smithsonian might want to partner with the University of Maryland to take more advantage of the NSF Research Experience for Undergraduates (REU) program—

> *you might want to piggy-back with the university … If you had the REU program based at the Smithsonian and Zoo, and if you needed us in terms of bringing it all together, that would be a wonderful opportunity. It doesn't cost a huge amount to run it. They're in a lab for 10 weeks, they give a research presentation, they collect data through the summer, they give a final presentation, and we publish this stuff eventually with a lot of them. You attract very good students.*

An interviewee at a Federal agency commented that its student programs are "a nice way to keep temporary employees and have a little bit more flexibility in managing the workforce." The agency also uses the student programs to recruit future employees, such as the "STEP program—

a student career enhancement program—and a student temporary employment program … We have extensive summer employment programs … another way to get students interested."

Despite the benefits of student programs, they have not gotten a lot of support at the Smithsonian—"From my point of view, that's the thing the Institution could do that would provide the most intellectual ferment, which is what I think is part of what you need to get these collaborations going ... it does take money, but probably it can be done in partnership with universities that would see that it's in their own interest to support some proportion of this."

Temporary and Term Employees

As noted, some interviewees suggested greater use of temporary employees as a way to ensure a regular infusion of "new blood." At least one unit is exploring the possibility of converting permanent positions into term ones, which can run up to four years and aren't renewable. But there is some strong opposition to this idea because of a fear that the department/office could lose the position.

Trust Employees

Trust funds appointments offer greater flexibility. According to an interviewee, "The only reason we're able to bring in a constant stream of young people at our unit is because of our Trust account." Trust hires are one way around the "glacial" rate of hiring on the Federal side, in part because they do not need to be competed. Termination is also easier. A Smithsonian interviewee said, "We [now] hire somebody on a four-year Trust appointment, and in year three, they go PAEC [Professional Accomplishment Evaluation Committee], and it's basically like a tenure review. If they are not good, we just let some of them go."

There is a downside to Trust appointments. One person noted that "[Because some of] my grants are one year … it's hard to get somebody good whenever it's just a Trust fund for one year." Moreover, Trust employees are more vulnerable when central and unit Trust funds decline or are wanted by management for something else; there is no job security. Also, using Trust funds for salaries ties up the most flexible pool of money. "[If I could shift my Trust employee to] Federal funds," said one person, "the money that I'm spending on her now could be put into programs for her to travel, hire grad students to grow the program … and that sort of thing." There are equity issues from the perspective of the Trust employee, as one interviewee noted—"I have people who have been with me seven years who are still Trust employees … A lot of them are young entry-level type positions, so it would help them in their career if they had time, and it might help us to get better quality people if we had a little better job security that we could offer through our grants."

Partners

Interviewees described how important partnerships with external organizations have been as sources of fresh ideas, perspectives, etc. But an equally vital role of partnerships is that they often provide a vehicle for applying for grants for which the Smithsonian is ineligible on its own and for handling logistics in the face of the Smithsonian's cumbersome bureaucracy. An interviewee at one unit "enters into partnerships in part because of a lack of capacity at the Smithsonian to handle projects of the scale" of his unit's. An interviewee with a Federal agency commented on the benefits of university partnerships. They provide "a means of bringing in outstanding individuals who could not be hired under civil service procedures and salary limitations. International people are difficult to bring in as Federal employees, not so at a university." This person continued, "there are just certain flexibilities … establishing a larger concentration of talent in synergistic disciplines than either institution can do on its own … It's like a breeding ground, a training ground of employees for our agency. I can see the same thing for Smithsonian employees." There were also comments that the Smithsonian does not take advantage of possible partnerships with other Federal agencies.

Support Staff

Although most interviewees focused on researchers when it came to human resources, a few emphasized the importance of also investing in support staff, particularly technicians. One interviewee commented that his technician had "doubled my productivity," while another who lacked a technician described how "it took forever to use this new system, and nobody knew how to use it … this has dragged on for a year; it's really frustrating." Yet another interviewee thought technicians could also be a good vehicle for furthering collaboration by "encouraging them [scientists] to collaborate and helping them get the equipment that they need. That builds the network instead of building an edifice or something like that." A point that emerged from the 2002 survey of Smithsonian biologists was the need for research assistants and administrative staff "to relieve scientists from the mundane and allow them to focus on science."

Filling the gap may be difficult, in the opinion of some—"In the science realm, we don't need low-grade technicians, we need high-grade technicians. It's the mindset of how you go about it. If you get somebody coming off a university degree now, it could easily be a $200,000 education [which commands a higher salary] … There are so many disparities and disjunctures between [where we are] and the reality of modern science on a big scale to address real problems."

Contractors

An internal NZP study identified several issues related to contractors that negatively affect productivity, such as requirements that limit use of Smithsonian vehicles, restrictions on the

content of advertisements for contractors, a misalignment between a contract's statement of work and the specific tasks required by research projects/programs, and the protracted and seemingly arbitrary contracting process that is at odds with scientific grant and research requirements.

Re-configuring the Smithsonian Workforce

> *It's who you hire and their priorities and the nature of their work that can make a difference in the extent to which your institution collaborates and how easy it is to foster that collaboration.*

> *Push the interdisciplinary thing ... [go] after people who are broad-based and really think quite broadly in terms of their science … not all museums take this strategy. Some are really stuck in the past, or the mode of hiring people who are straight down the middle in their particular discipline.*

In an interview, Elias Zerhouni, former director of the National Institutes of Health (NIH), commented on his time at NIH. "I consider it [hiring] the number one job of a manager-leader in any one of our government organizations … recruiting as a NIH director is almost like fighting with one hand behind your back, because of the constraints that government service brings" (Zerhouni, 2005). To combat those constraints, Zerhouni said he competed very aggressively to recruit new people.

> *[I] would go personally and visit the candidates in their own laboratory, at their own universities. And you would be amazed how effective that is to find out if there is a cultural match and a managerial spirit that will fit within the government agency. That's important, too; you don't want to mismatch an individual to a position.*

Many interviewees reiterated the need for a different profile for the Smithsonian's scientific research workforce, and what is required for that undertaking. Key themes related to what the Smithsonian should be looking for in new hires, what new hires are looking for in an organization, and how to make the transition to a new type of workforce.

Transitioning to the Right Workforce

The transition to a different workforce will, according to one interviewee, be "very difficult, unless you are going to … go out and hire a bunch of new people, to think of an initiative that you want to do and say, 'well, this is what we want to do,' unless you are going to have an iron fist and just totally do it." He suggested that "a way that it can work is finding entrepreneurial scientists who are already here … who want to develop something, and then try and find ways of facilitating that." Another interviewee cautioned that the quality of hires "depends on the quality

of the people making the decisions," and sometimes the hiring process was set up in such a way as to allow people "to hire people who will not rock the boat. You get departments hiring people within their departments, and there's no oversight to see what goes on." Organizations have to guard against movement toward "more complacent kinds of hiring practices." To safeguard against this tendency, one external organization uses

> *a general committee of researchers who are elected in-house that basically can throw back the entire search committee report…About one out of four or five of our searches is actually repudiated by this general committee of curators, who say, 'Look, you are obviously just trying to hire someone who will not rock the boat or is going to be just like whoever is retiring.' It makes for searches for people who may be more controversial, who may be more interactive, more collaborative.*

A Federal agency engages in agency-wide vs. departmental human resource planning:

> *We've put together a human succession plan, and we've identified disciplines we need more of in order to meet some of the demand our national priorities have. We have backed that up with special hiring protocols for certain disciplines … we have a program [in disciplines where it is hard to find people] where we can pay for part of school if people will come work for us. We also have a special hiring authority where if someone happens to meet [a person in an area we need] at a local university, they can hire that person; they don't have to go through the normal process.*

A number of the interviewees talked about the importance of having clear hiring criteria that encourage collaboration and IDR. Said one person, "You better know what you want in advance, and you'd better put all those criteria into a search, or you might not end up with exactly what you wanted." He went on,

> *We [the Smithsonian] don't necessarily always do a good job of being able to get out the intangibles [such as someone's belief in collaboration]… Everybody on the shortlist is going to have the same general skill set, experience doing X, Y and Z. What you want to get at are the flavors. Who has an interest in what? Further, sometimes it's better to go with someone less well-established—"here's a junior person who we really want because he has been doing these open source types of things. He doesn't have as much experience as these three people, who are the old dogs, but can we teach them a new trick?" You might not even get the opportunity to interview that fourth person, because they wouldn't rate high enough numerically on your stupid scoring system.*

Along the same lines, an interviewee at a Federal agency noted that "I take into account not just that they are the best in the field, but that the second person down the line may be a better fit to our mission, our goals, to being able to talk to [stakeholders]."

Rhoten (2004) also spoke to this point:

> *[IDR centers] should have clear and well-articulated organizing principles—be they problems, products, or projects—around which researchers can be chosen on the basis of their specific technical, methodological, or topical contributions, and to which the researchers are deeply committed. While a center should be established as a long-standing organizational body with continuity in management and leadership, its researchers should be appointed for flexible, intermittent but intensive short-term stays that are dictated by the scientific needs of projects rather than administrative mandates.*

Criteria that interviewees mentioned included:

- ***A broad outlook.*** "People who are broad-based and really think quite broadly in terms of their science … we give high priority to the quality of the science and to doing more synthetic research and things that are more interdisciplinary or cross-cutting."

- ***Creativity.*** "Hire people who are kind of free thinkers about what they are doing instead of viewing themselves … very narrowly as increasing a particular kind of knowledge about a particular group of animals or plants."

- ***A strong belief in collaboration and interaction.*** "People who would look around [our open labs] and ask who else is here and what are they doing; they wanted to know how it was going to enrich their research. They were right for us."

- ***New knowledge, skills, etc.*** "Folks who are better than we are—they have to do stuff that we don't know how to do because it's so brand new and requires years of training … We look at people who are going to have a major impact on Science with a capital S … put it out in a way that has a big impact."

- ***Entrepreneurism.*** "Another issue when hiring is getting someone who has potential to get grants, to bring in revenue."

- ***A good fit.*** "Hiring people who will take advantage of the resources that are here and use those resources to bring attention and importance to this place."

One Smithsonian employee also said the Institution needs to stop getting "someone at a GS 14 level to do X, Y and Z, like the other person, rather than hiring a person at GS 9 to do X, and another at GS 9 to do Y, and grow them."

Offering a Compelling Workplace

Interviewees pointed out that you have to offer a compelling workplace if you are to attract the best people. One person talked about what graduate students are looking for at his university—

> *they could care less what labels exist on people—they just like ideas … [programs that] are cross-cutting, broad areas that have, for the most part, a science arm and a policy arm … They are looking for applications; they are looking for places where the consequences and implications of what they learn can sort of hit the road.*

Another external interviewee thought the Smithsonian could attract top people by offering "very good opportunities to do interesting things." A Smithsonian interviewee believed his department had accomplished that, based on results: "[We've] got a very high reputation nationally. We can hire the best [people] in the country, and when we have positions, we get the best people applying." Several people pointed out that the Smithsonian offers the incentive that it has no teaching requirement, although there is a strong tradition of mentoring younger staff.

But other interviewees questioned whether the Smithsonian was a competitive workplace. One person feared, for example, that the "intrusive bureaucracy of the Smithsonian is making life so difficult that people are going to start leaving or these young people will stop coming here." Others worried that the Smithsonian can't compete when it comes to salaries. Zerhouni (2005) described how he addressed the obstacles to competitiveness sometimes faced by the Federal government.

> *You need to compete with universities and so on. And I do—I compete very aggressively. The one thing that we [NIH] can offer is a research environment that is just unparalleled in the world and the ability to influence a discipline that is just unparalleled around the world. And those are the two things you have to combine.*

Rhoten (2004), quoted above on the importance of flexible, rotating appointments to support an organization's research agenda, commented further that "such rotating appointments allow researchers to satisfy their intellectual curiosities without jeopardizing their professional responsibilities."

One Smithsonian interviewee added another aspect of what makes for a good workplace—"There has to be in the end a career path, not so much monetary reward as grade increases, scientific recognition."

A Biased Performance Evaluation System

> *On the one hand, our administration has been imploring us to undergo joint scientific projects with co-authors within and outside of the Smithsonian, but when one does this—and I have done it a lot with other scientists in related fields and with some in the same discipline, both foreign and domestic—the members of PAEC seem to worry more about who contributed how much (something that usually cannot be logically measured) than the fact that the quality of the research may have been much improved by co-authorship of individuals with somewhat different disciplines and backgrounds.*

> *It's not so much that you don't want to know the new things; it's just that there is an overhead to learning how to do those new things. You have to decide to not publish a paper for a year while you learn how to do X. That's a hard decision to make, especially if someone is kneeling on you, as everybody feels pressure to continue to be productive, as they should. But there is sort of a trade-off between sometimes long-term keeping your horizons open and becoming capable in new areas and actually producing the next thing that your current training allows you to produce. I don't know how you get the right balance between those things.*

The Smithsonian's performance evaluation system came up frequently, with a number of interviewees describing it as an obstacle to collaboration and interdisciplinary research, although not everyone held this opinion.[15] The most common complaint is that the performance evaluation system is biased against collaboration and IDR in terms of the performance criteria being used or the inconsistent way in which they are applied.[16]

Inappropriate performance evaluation criteria. Interviewees pointed out that there are "transaction costs" involved in collaboration and IDR. Both, for example, take more time—for team meetings, learning how to talk with people from different disciplines, re-learning how to do and frame things—all of which mean a greater likelihood, for some years, of a reduction in the number of grants coming in and papers published. Bozeman and Lee (2003) pointed out that "a collaboration that is quite productive for an experienced junior researcher may prove 'inefficient' for the mentor." Rhoten and Pfirman (2007) noted that various reports, including the NAS's

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[15] When interviewees at the Smithsonian talked about performance evaluation, they often did not distinguish between the annual reviews and PAECs, and many of their comments are therefore included here under a general performance evaluation heading.

[16] Because the focus in this study was collaboration and IDR, the study team has not included comments that addressed the lack of credit for time spent on exhibitions, education, and other activities that are direct parts of research per se.

Facilitating Interdisciplinary Research, identify promotion criteria as the greatest obstacle to the future of interdisciplinary research—

> *pointing first and foremost to the problem that the potentially unique contributions of a researcher's interdisciplinary work may not be sufficient enough to compensate for what is likely to be his/her lower output of disciplinary research. Good interdisciplinary work requires not only depth but also breadth of knowledge across different disciplines, the pursuit of which inevitably takes time away from the (re)production of the type of narrowly focused research in sub disciplines favored by the contemporary tenure system.*

Interviewees shared numerous examples of how current performance evaluation criteria and metrics actually impeded collaboration and IDR, and stymied innovation and risk-taking:

> *This business of saying that you have to publish five papers every year is ridiculous…the start-up time for any given group [of collaborators] is going to preclude that … The annual reviews have become a real burden … They take so much time for people, it's just ridiculous really.*

> *I spend 50% of my time answering questions, soliciting relationships. Very little of it actually generates anything. Probably 50% of the time I spend is constructive time dealing with people, whether they are former students, current students, people I mentor long-distance, just answering questions, providing information, scanning [my] literature and sending it off. None of that ever shows up anywhere. I've accepted that as a cost of doing business.*

> *Preparing grant proposals, particularly when it involves collaborators, is just as intense as writing a paper of research. When you submit that grant and get that grant, I think it's equal to publishing a paper. But not everybody sees it that way.*

> *That goes back to this team thing, and how the reward system works for performance evaluation … If we all work together, even 12 of us, and we end up getting a grant … everybody should get some credit for doing their part … because it's unfair for us lower in the ranks in that I wasn't the one to make the ask.*

> *As individuals in the middle of the food chain, those above us don't value risk-taking approaches. They're happy for all successes, and not understanding of failures. There will be failures. If I were taking tons of risks and failed, they would boot me out of here.*

> *Unfortunately, the way the PAEC reviews and a lot of things were done penalized that, because if you are one of 35, it wasn't counted as if you had a single-authored paper. We have to overcome that. I'd say half the publications done by our new curators are multi-authored, 10-plus authors, whereas for the older researchers it is 1 out of every 20.*

As noted, performance evaluations at the Smithsonian often do not take the transaction costs of collaboration and IDR into account. Unfortunately, those whom the discipline-specific, single/lead author bias in performance evaluations is most likely to affect are the younger scientists at the beginning of their careers, the very people the Smithsonian needs to attract, facilitate, and retain. Many younger scientists start at the Smithsonian in temporary appointments. They will be reviewed in year three for a permanent job. But those younger scientists who have been engaging in collaborative or interdisciplinary research may be at a disadvantage, as their publications take longer to come out and most likely will be multi-authored. So, as one person commented, if your goal is to remain at the Smithsonian, you have an incentive to produce quick and easy-to-write papers. An article published in *Nature* (Vastag, 2008) contains the following:

> *The risks of crossing departmental boundaries can be greatest for fledgling scientists. Tenure review committees can be a big obstacle, says Bozeman, as promotion criteria often fail to register interdisciplinary achievements. "If a young researcher joins an interdisciplinary research centre, the fruits of such labour—as measured by publications, for instance—may not be readily apparent."*

In contrast, as a long-term Smithsonian researcher observed, the more senior scientists have "got enough publications, their name is known, and so it's not going to hurt their career." The solution, the scientist went on, is an "evaluation process [that] is flexible enough to substitute those activities for others. Then there really isn't any downside. And in the long term, if you [the young researcher] are successful, there's a plus side to having done it. Clearly your name becomes more known for doing that kind of thing as well as individual research."

One interviewee described a two-track performance evaluation set up at his university to address these biases, with one track addressing teaching and the other research. In the case of the latter,

> *we look mainly at their research progress, funding, that they've taken advantage of the collaborative open environment, some record that other people can attest that they've contributed to the institute in a major way. We are going to reward people who are valuable to their colleagues.*

The interviewee also noted that at his university, "Even if you have a negative [research] result, it's an advance."

Another university is explicit that it

> *will actually reward it [collaboration] in performance review—we're looking for multiple-authored papers across three or more units that produce new insights or that*

disseminate the knowledge beyond its original field. There are reward systems that you can put in place that just say it [collaboration] is an institutional value.

Still another university "modified the promotion and tenure process … so that any of the faculty who have one leg in an interdisciplinary institute will have representation from the institute on their promotion and tenure committee."

Other quantitative approaches aligned with collaboration and IDR are to look for new word combinations "in titles of papers … They have been charting the growth in the number of faculty collaborations over the last five years, and it's quite astounding what has happened. And then, you can make a direct measurement … if you invest $6 million in three rounds of $2 million seed grants and you ask the faculty if they have gotten any external or Federal support, and if they tell you that they've gotten $60 million worth of support, that gives you another assessment. Then … you ask how the faculty and students are doing. Where are they going? Have they gotten awards … prestigious honors?"

A university interviewee suggested a social network approach

to define who have been in collaboration for how long, internal to the Smithsonian and with external partners or academics. You just do it by virtue of collaborative authorships, joint authorship … And you provide seed money to those who have had ongoing collaborations across two or more units for X period of time, because you are going to reward successful relationship-building that produces knowledge. You can actually start to seed collaboration based on those who made the moves already and have demonstrated success in it.

Russell (1983) discussed various aspects of performance review:

Critical factors are the need to distinguish successful from unsuccessful innovations, to develop sponsor agreement on program goals and priorities against which to measure performance; differentiation between scientific merit (quality of research) and scientific contribution (applicability to the discipline), and also economic quality of research (multiple spillover effects and impact of change). In addition to these criteria, IDR needs criteria that acknowledge the unique qualities of IDR—orientation to group output, as opposed to the traditionally used orientation to individual output.

He also noted that

IDR is harder to assess and evaluate because it is frequently undertaken to probe new issues, expected outcomes are sometimes ill-defined, the benefits are occasionally found primarily in the process itself (the influence that collaboration and communication

among scientists have on research productivity), and successfully completed IDR may result in recommendations for several disciplinary approaches to subsequent analysis, or a reformulation of the definition of the problem. Contributions such as these would be absent from traditional measures of research productivity. Five questions that [are] both ex ante and ex post evaluation of IDR are suggested:

1. Does the project formulated in ID terms show recognition of the existing contribution made by the separate disciplines?

2. Is the interdisciplinarity genuine in the sense that the problems are formulated in terms that enable the different disciplines to get together rather than compete with one another?

3. Is the method of data acquisition likely to be helpful to all the relevant disciplines or is it biased in a particular direction?

4. Does the interdisciplinarity enhance the possibility of hypothesis testing or does it obscure it?

5. What difference will the results of the research make to the policy decisions that will eventually be taken?

Inconsistent application of performance evaluation criteria. Some units at the Smithsonian have made their performance evaluation criteria more consistent with the nature of collaboration and IDR, but interviewees indicated that practice too often contradicts principle. One person said, "When we go to review, I know that they are sitting there going, 'How many first-authored papers, how many sole-authored papers?'" Another interviewee commented that performance reviews have a lot to do with who is conducting them, with some department chairs more supportive of IDR than others. There was also the following comment about the composition and capabilities of PAEC review committees when it came to IDR: "Suddenly you have got a botanist and an invertebrate zoologist [on the review committee]. They work under some different model where they think, 'These should be sole-authored papers.'"

The OP&A study team looked at the Smithsonian Directive on PAECs and the guidelines for PAEC reviews at five science units. There were significant differences, not all of them seemingly explainable by the units' different missions, areas of work, etc. The Smithsonian Directive gives as criteria "level of supervision received, impact, extent to which the employee has developed the program on which he or she works, and innovation of the employee's contributions." Two units' guidelines described a review process but gave no performance criteria. A third unit listed originality, creativity, research performed, dissemination of ideas, and science administration, while a fourth specified honors/awards, grants/contracts, membership on

advisory committees (internal and external), refereeing activities, educational activities such as undergraduate or graduate courses taught and lectures, and other efforts to serve the public. The fifth unit's criteria were scope, complexity, originality, impact, and productivity of the research, effectiveness of the use of collections as a primary research tool, role in training more junior researchers, scholarly products of research (i.e., publications), and dissemination of research products through scholarly publication.

Other Issues. Interviewees and the literature pointed to still other ways in which the performance evaluation system seemed inequitable.

- ***No credit for "service."*** Several scientists raised the matter of "service" vs. "research," particularly when the former was part of the person's job. Said one person,

  > *The question comes up with their performance evaluations—does editing these things or writing these accounts count? They [performance evaluators] said no, that is not research. If you get promoted on research, and you are told that [this work is considered service] not research, who is going to do it? ... You don't get promoted on service credits.*

  Another scientist talked about his efforts to set up and run an interdisciplinary group on a work-related topic. The researcher believed the initiative was important to the unit's mission, but "I don't get any recognition or incentive for it. I feel I'm not getting to my own research for which I'm being evaluated, and I'm doing this service to the Institution, but the Institution doesn't really care. But if I say this, [the answer will be that] all of this is not true."

- ***Bean counting.*** The annual reviews "have been focusing far too much on bean counting." One result is that researchers may only formulate goals they know they can achieve. Instead, suggested an interviewee, the Smithsonian should be asking,

  > *Are these people doing the things they should be doing? ... more important than the number of papers, have you set yourself up for success? Is it clear that you can come up with good ideas? Is it clear that you can get money? Is it clear that you can run a lab? Is it clear that you can work with students? Those are the things that measure success.*

- ***Problems with the composition of review panels.*** Interviewees made numerous comments about problems with the composition of review panels when it came to IDR. Mainly the issue was that too often the membership of the panel represented only a single discipline and did not have expertise or interest in reviewing research that encompassed other disciplines. The performance review was further complicated when the researcher was working at different units.

The literature also noted to the issue of poorly configured review committees. According to the 2004 NAS report, even when an organization is committed to interdisciplinary research, "it can be difficult to find reviewers who understand the overall quality of the work, which usually lies outside of the expertise of people on the tenure evaluation committee—that is, members of the department." People understandably approach the work through the lens of their discipline, which may not align well with the nature of another discipline. The report goes on to suggest that "Reliable methods for prospective and retrospective evaluation of interdisciplinary research and education programs will require modification of the peer-review process to include researchers with interdisciplinary expertise in addition to researchers with expertise in the relevant disciplines" (National Academy of Sciences, 2004). Russell (1983) concluded that "The potential for IDR evaluation to expand and refine scientific disciplines lies in the responsiveness of reviewers and scientists to this process." But Russell also noted an inherent conflict in the IDR peer review process:

> *The continued coupling and recoupling of new and existing specializations require flexibility in the composition of such peer review teams. Yet the maintenance of direction and standards requires stability in the process and criteria. Modification of university reward structures, making rewards for ID more visible, and facilitating the use of a common language among reviewers have all been suggested as ways to improve the review process and accommodate the needs for peer review in IDR.*

An interviewee said that NSF came to the same conclusion, based on its experience with interdisciplinary research reviews. Finding the right people was not enough. Even when a review committee included multiple disciplines, the members still tended to view the research through their own disciplinary lens because they didn't know how to work as an interdisciplinary team. Thus, NSF decided that the committees must also receive some orientation on the thinking and approaches of different disciplines so as to be able to work as a team.

Performance Evaluation Isn't a Problem

Not all Smithsonian interviewees thought the performance evaluation system was a problem. Some stated that the PAEC review process at their unit offered researchers considerable latitude to put in whatever they thought was relevant and important about their work. One interviewee described a process that asked the scientists to "describe what their contribution to a multi-authored paper was." That interviewee went on,

> *[As to] collaboration, everyone understands that there are really boom years and fallow years in terms of publication, because you can't really control much of it … The other thing that we have become very mindful of is the relative impact of the journals. [We are] being careful with the citation biases and other issues, because there are certain disciplines that are underrepresented.*

Another interviewee noted that "when there is a big NSF grant [through an external collaborator], we credit our researchers for being a success on the whole project and give them full credit regardless of how much money comes to the unit." A Smithsonian researcher said the PAEC reviewers at his unit "were very interested to know about the students, how many PhDs and MA students, and what kinds of collaborations I was involved in."

Some researchers, most often senior ones, were dismissive of the whole issue. The outcomes of reviews, whether good or bad, had little meaning in practice, so that people tended to pursue whatever brought them personal satisfaction. "I don't care about the PAEC … I just want to do exciting things, train people … Bringing in cutting-edge people helps the Smithsonian a lot, and it helps me personally because I end up getting new ideas."

Finally, an interviewee emphasized that the proof was in the pudding: the PAEC system worked and therefore should not be considered an obstacle. PAECs

> *are done basically with a sort of structured curriculum vitae and blind letters. Those letters are telling … there's rarely much doubt about how a candidate has done, what their potential is, what their standing is. People know around the country, the world, when someone is surfing as opposed to getting something serious done.*

An interviewee from a university acknowledged that the faculty, especially younger members, felt a lot of stress over evaluations of collaboration and IDR, but he still took a hard-nosed approach.

> *My philosophy is to acknowledge that there are stresses and strains but be unwilling to give in … If the scientists are going to be successful in the world of interdisciplinary thought, they are going to have to figure out how to keep multiple groups happy, and they might as well start at a young age and get with it.*

Funding

> *The biggest problem we have is a more generic one, not just single individual lost opportunities, but lost opportunities for large collaborative projects because we don't have a research pool of funds available for that.*

> *Unless there is money to plan and conduct the research...there is little hope that staff will work together in any true sense. A lack of funding creates competition for scarce resources and heightens any petty differences between units, thus hampering any true collaborative efforts (2002 Smithsonian science strategic planning survey of SI biologists).*

The general perception among interviewees was that the Smithsonian's scientific research in general has not been an Institutional priority on a par with facilities and exhibitions, and that this has led to a smaller pool of central funds for research. As one researcher noted, "[We have had] almost a decade in which SI has failed to identify new funds for science in its budget. Lack of new funds for programs has led to serious erosion in the SI science mission … aggravated by a lack of access to National Science Foundation funding." There was a sense that central fundraising for science had been de-emphasized. Moreover, some funds once reserved for science—notably the Scholarly Studies Program—at one point were reallocated to cover funding deficiencies elsewhere. In addition, interviewees spoke of a belief throughout the Institution that if a department temporarily allocates funds that "support" a project in another department, it will lose the money forever.

Interviewees cited a number of consequences of the shortage of funds. It has discouraged cross-unit collaboration and IDR, despite apparent interest in interdisciplinary projects. Said one scientist in his response to the 2002 survey of Smithsonian biologists,

> *Holistic conservation of a species might need five scientists working on different aspects [of that species], but only one or two may get funding for their piece. Two of the others might get funding to do parts of a second species, and the fifth gets no funding. The result is a haphazard treatment of species, with few complete stories to tell. We need a mechanism to fill in the holes.*

At a number of science research units, researchers are engaged in fields that are inherently interdisciplinary, such as ecology and conservation biology, and would expand their efforts were more funds available. Interest is also evidenced by the number of proposals that have been put forward in response to internal opportunities. Absent funding, however, units and departments have focused on funding their own projects—"On an economic basis, when there's a shortage of funds, the academics always retreat to their departments," while Smithsonian scientists have

turned to thinking "smaller and smaller, which is, of course, the very opposite that you want when you want to seek interdisciplinary funding." Scarce funds also proscribe travel to other Smithsonian units that would enable regular contact with colleagues. One scientist suggested having a "fund that would easily allow travel to other SI units. Presumably this is what the Research Opportunities Fund was earmarked for, but this program has been defunct for several years." The NAPA study concluded that "the Secretary has an opportunity to demonstrate support for the 'increase of knowledge' by tying specific Institution-level fundraising initiatives to scientific endeavors as part of the strategic planning process" (National Academy of Public Administration, 2002).

Money emerged as the most powerful motivator for buy-in for new collaborative and interdisciplinary research, as one scientist commented in response to the 2002 survey of Smithsonian biologists—

> *There are many ways that integration could benefit science, but such integration across bureaus will only be achieved when financial incentives are provided from the central administration, or through major interdisciplinary grant applications to outside funding agencies. Money has a way of making people see the power of collaboration.*

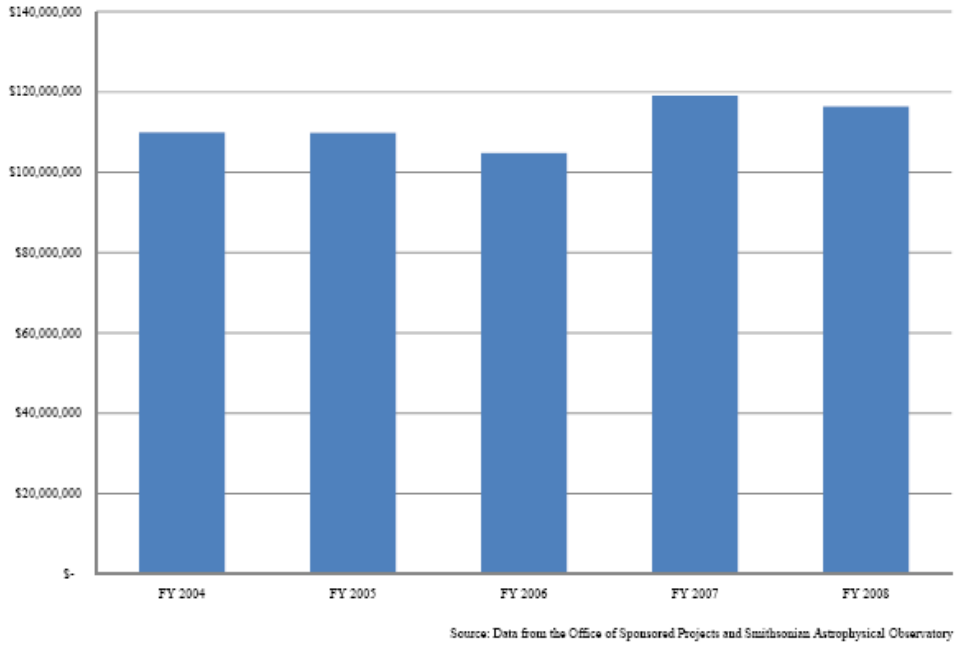
This section looks at sources of funding, actual and potential, and approaches to developing a more stable flow of funds.

Grants, Contracts, and Philanthropic Funds

The NAPA study concluded that "During interviews with Smithsonian staff and their colleagues, it became apparent that the Smithsonian does not aggressively publicize the acquisition of research funds through competitive processes. Nevertheless, funding received from external sources is substantial" (National Academy of Public Administration, 2002). The study found that while there were only modest increases in the funding from grants for the most part in FYs 1996 to 2001, the number of grants received rose over 70 percent. "This suggests that Smithsonian researchers have worked substantially harder to obtain these funding increases" (ibid.). The report noted the varied ways in which Smithsonian researchers competed for external funds, such as partnering with university researchers, serving as adjunct professors to get research funds through the university, and submitting their own grant proposals. One Smithsonian researcher pointed to the importance of outside funds, but also noted a drawback: "Our current [research] successes are thanks in large part to external funding and not Smithsonian support, but [the research] therefore has to conform to external grant priorities rather than scholarly hunches."

According to Smithsonian data, from FY 2004 through FY 2008 the Smithsonian science units brought in approximately $560 million in grants and contracts for research projects (Figures 8 and 9). Of this amount, $456 million supported SAO. From FY 2003 through FY 2007 philanthropic gifts designated for research (all types) amounted to $46 million, or roughly 7% of gifts raised for all purposes Institution-wide (Figure 10). In FY 2007, gifts for research accounted for 12% of total philanthropic support, an increase over previous years.

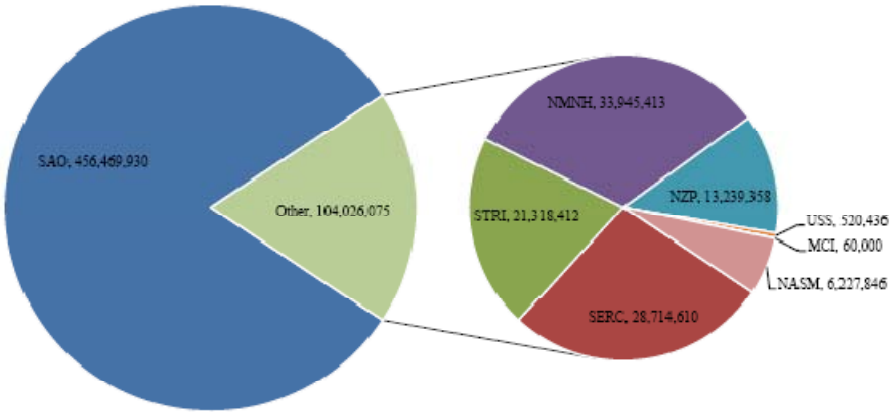
Figure 8. Grants and Contracts for Research at Smithsonian Science Units



According to interviewees, increasing the level of funding from grants, contracts, and philanthropic gifts will require strengthening in three areas, and likely an investment in funds and staff to accomplish it:

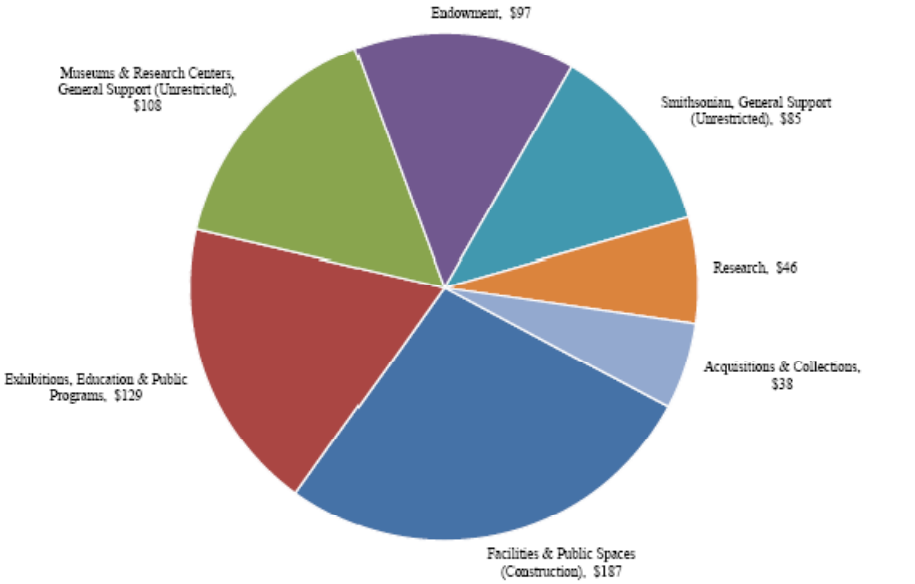
- *Communication functions* aimed at building awareness of, and support for, Smithsonian science among the public and potential donors. Interviewees often noted that the Smithsonian is better known for its exhibitions and educational activities, while there is less knowledge of or appreciation for its scientific endeavors by stakeholders and the

Figure 9. Grant and Contract Revenue by Unit, FY 2004-2008



Source: Data from the Office of Sponsored Projects and Smithsonian Astrophysical Observatory

Figure 10. Philanthropic Gifts by Purpose of Funds Raised, FY 2003-2007
(in millions)



Source: SI Annual Reports, 2003-2007

general public. Many interviewees suggested that raising public awareness of Smithsonian science was a critical first step toward more effective fundraising, and that communications efforts to raise awareness should center on the scope of Smithsonian

science as a whole and its value to the nation and world. This message needs to be crafted in a way, interviewees indicated, that resonates with a mass audience, which may require collaboration between marketing personnel and scientists, and possibly the hiring of science writers who are adept at translating technical research results into laymen's terms.

- *Assistance to researchers* in finding grant opportunities and writing proposals. Several interviewees suggested that systematic identification of opportunities for funding should be undertaken at each of the research units, or centrally in the OUSS. One scientist noted that OSP already does this by routinely sending Smithsonian-wide emails about funding opportunities. Interviewees noted the importance of such a central service for younger researchers who may not yet be aware of all the sources of funding in their fields, and in uncovering interdisciplinary sources that could otherwise fall through the cracks of the current organizational structure, in which no one has responsibility for shepherding cross-unit initiatives.

- *Fundraising personnel dedicated to science*. Several interviewees pointed to the absence of science-specific fundraising personnel at most units as an indication that science is not a priority. Many Smithsonian scientists rely on their own fundraising efforts, but there is a trade-off in terms of research productivity, as writing proposals is very labor-intensive.

Fundraising Incentives for Scientists

Interviewees noted a lack of incentives for Smithsonian scientists—especially those who have been with the Institution for some time—to seek outside funding. One reason was that their Federal salary gave them a sense of entitlement, particularly in light of the amount of time soliciting grants took away from research. Grants generally came with a lot of administrative requirements and specified research that did not fully overlap with the researchers own goals or those of the Institution. For many older scientists, grant-writing was not something that was expected or seen as necessary, although that mindset may be changing. The general tightening of science and Institutional funds in recent years has led some researchers to accept that grant writing is an integral element of their work. Younger hires, in contrast, are very entrepreneurial.

Overhead emerged as an issue in several regards. The Smithsonian's overhead rate on grants, which is set by the Office of Naval Research, is modest in comparison with that at most university and independent research organizations, making the Institution attractive to potential funders. However, some interviewees expressed resentment that in some units what little overhead the Smithsonian received went primarily to the central administration and not back to the scientist, department, or unit that procured the grant. In contrast, universities channel significant funds from overhead to the departments, which allows them more operational

flexibility. Some scientists would like to see the Smithsonian's overhead rate increased and more of those funds accrue to the units. The additional funds, they said, would help stabilize research monies, cover grant-writing costs, and more generally contribute to maintaining the infrastructure needed to keep them competitive with other organizations. Some interviewees mentioned past attempts to circumvent the current low overhead rate by classifying funds as a gift.

Need for Stable Funding

A further deterrent to collaboration, according to some interviewees, is doubt about the stability of funding streams within the Institution. Funding has, for example, been redirected from one project to another, or to infrastructure and operations. Some people noted a lack of consistent commitment of resources for cross-unit initiatives. Most grants typically run only a few years, so that researchers must cobble several together for long-term funding.

Many interviewees spoke of the need to diversify funding sources ("just like in any financial portfolio") as a means of ensuring more stable funding for IDR projects. Interviewees cited several sources that might contribute to such a funding portfolio, including Federal appropriations, central endowments, leveraging of resources, NSF grants, and contracts.

Appropriations

The Smithsonian's appropriation is a vital funding mechanism for Smithsonian research, particularly for salaries. According to one source, the allocation of research dollars to the seven science units collectively has been approximately $70-80 million a year in recent years.[17] Many interviewees thought that the Institution could do a better job in securing more funding for science from Congress but that it "needs to package its science better." One person lamented the general lack of recognition that the Smithsonian "does serious science." Interviewees said it would help if the Smithsonian could communicate an overarching vision that reflects the breadth of research across the units and makes a case that "translates into tangible arguments for funding." The Institution also needs to better engage Congress in activities that communicate its scientific accomplishments.

Interviewees also brought up the detrimental effects of operating under continuing resolutions, which compress the timeframes in which to spend appropriated funds. Another challenge is mandated pay increases that are not fully funded by appropriations and that cut into funding for research, programs, and investments in infrastructure.

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[17] This figure does not include central services, in particular OFEO support for building operations.

Central Endowment

Some interviewees saw endowments as the best long-term funding mechanism. However, much of the Trust money from the central endowment, valued at approximately $1 billion before the current economic downturn, is used to support current administrative functions.

Interviewees also mentioned the OUSS endowment payout as a source for seed money (discussed at length below). Some thought this fund was consumed by spending on equipment and current projects. Another interviewee explained that in the past, over 90% of the payout was earmarked for infrastructure support, but that situation was ameliorated by amending the Research Equipment budget account to cover maintenance costs on new and existing equipment. Today the endowment payout is used as seed money for new projects, and the OUSS has set up a competitive, peer-reviewed process for allocating these funds.

Interviewees at other organizations remarked on the small size of the pool of endowment funds at the Smithsonian. Organizations with more endowment funds at their disposal are able to direct the proceeds toward ambitious new ventures, while the Smithsonian can only provide small internal grants. Many interviewees called for a larger central endowment, with a portion earmarked for science research or interdisciplinary initiatives.

Leveraging Resources

Most interviewees acknowledged that even with an increase in Federal appropriations or endowment funds, other science research funds would still be necessary. Given that reality, one suggestion was that "central funds be used to augment and extend research grants which best align with the Institution's strategic directions."

Partnerships with other organizations were often mentioned as a way to leverage resources, as they offer access to expertise, facilities, instrumentation, and other resources not found at the Institution and obviate the need to build similar capabilities in-house. In particular, partnerships were seen as key to pursuing grants or engaging in projects that required disciplines such as economics, political science, and engineering not found at the Smithsonian.

National Science Foundation Funding

NSF is a major source of funding for the US science enterprise. Smithsonian scientists described their access to NSF funding as uneven and dependent on how specific NSF directorates interpreted the policy on when Federal dollars could be awarded to Federal agencies. Some disciplines such as mineral sciences received direct funding while others, such as the biological sciences, did not have direct access to NSF funds. Smithsonian interviewees argued that the Institution should be eligible for NSF money on two fronts. First, as a Trust Instrumentality and

not a Federal agency, the Institution should have direct access to NSF money. Second, in many cases Smithsonian research is unique and has no private sector competition, and therefore should be eligible for NSF funds. One scientist commented, "We need to break the block on NSF funding of [scientific] research [and education] at the Smithsonian. This should be a major priority for the Congressional Liaison Office."

Both the 2002 NAPA and 2003 NRC studies noted considerable inconsistency in how NSF program managers treated Smithsonian proposals. The 2002 NAPA study found that "Overall, [Smithsonian] proposals to NSF are funded at about the same rate as all other researchers. However, there are substantial differences between the centers in the percentage of total awards received from NSF. Interviewees indicated that some Smithsonian researchers may have been reluctant to develop proposals for NSF due to the actual or perceived bias. The study noted that "some [NSF] program managers will not consider Smithsonian proposals under any circumstances, while others will" (National Academy of Public Administration, 2002).

The 2003 NRC study similarly found that "Because SI receives a direct appropriation, its employees are not eligible for NSF support as a general policy, except in special circumstances when their contributions are deemed unique. Even with the latter exceptions, opportunities for Smithsonian curators are more constrained than those investigators in other eligible institutions." The study noted "considerable variation among [NMNH's] departments in terms of success in winning research funds from NSF, "with the Department of Anthropology barred from applying for NSF grants and the Department of Paleobiology reporting considerable success" (National Research Council, 2003).

When Smithsonian scientists could not apply directly for NSF funds, they sometimes worked with non-Federal partners such as universities to do so, but disadvantages were noted, for example, with respect to the overhead allocation, fundraising, and authorship credit.

> *For NSF proposals, you have to go with the universities. The trouble is the university gets all the overhead—we get squat. We get our hours reimbursed and the headache of keeping track of that. The reason people don't like to do that, and only do it as a last resort, is you get all of the accounting and all of the nightmare, and very little money.*
>
> *Some of our scientists, depending on the program within NSF, are co-PIs. That means the money, the overhead, everything runs through a university somewhere to their colleagues; in that regard they don't get credit for it because they didn't bring money into the Smithsonian.*
>
> *If you are sort of a ghost PI, that's a little hard. It would really help scientific staff if we could get NSF staff to see things differently.*

Contracts

Some scientists have gotten contracts to do work for other agencies such as the Department of Defense and Federal Aviation Administration. Interviewees also noted that corporations are increasingly interested in cost-reimbursable research and suggested the Smithsonian might explore opportunities in this area—but cautiously. Mapel (2008) saw a chance for the Smithsonian to capitalize on the "corporate social responsibility" movement (also referred to as the sustainability movement) and pursue a role in working with corporations to conduct research and understand the science behind their business decisions. A properly constructed agreement that provides benefits both to the Smithsonian and the outside organization within the framework of the Institution's mission can be a win-win situation. However, interviewees stressed that the Smithsonian must guard against entering into agreements that run contrary to the Institution's mission to "increase and diffuse knowledge" or that might compromise its scientific integrity. Contract work also must be undertaken with a realistic look to balancing the short-term goals of a specific project with the long-term goals of the Institution. Some external interviewees cautioned against letting a business model drive scientific relationships and allowing crisis-oriented searches for short-term funds to overshadow the Smithsonian's commitment to its mission.

Other Sources

Some interviewees saw STRI's lease agreements with other organizations that use STRI facilities as a potential funding stream. Perhaps other units could explore similar arrangements. Some external interviewees also spoke about revenue generation from licensing products and selling carbon offsets. One proposal for increased support for the Pacific Science Network identified membership dues as a possible source of revenue, noting that the Planetary Society, National Space Society, and Mars Society use that approach (Smithsonian Institution, Executive Committee of Scientists Throughout the Smithsonian, 2006).

Competitive Smithsonian Grants

> *[Researchers] think within their own units, so you need to push inter-unit collaboration.*

Seed Money

> *Seed money, seed money, seed money. That first $5,000 or the first $10,000 for that little piece of equipment or the travel or whatever to get the preliminary data so that you can go for the big $200,000 or $300,000, $1 million NSF grant. … I think seed money is*

really important for collaborations in particular, because it's usually when you initiate collaboration that you don't already have funding. It's an idea. It's something that happens at lunch at a conference, or you review a paper and write back to the person, "I really like your paper, and I actually think we could do this together." But then, how do you fund that collaboration in its nascent stage?

A common suggestion was for a central pool of seed money, specifically earmarked for interdisciplinary and cross-unit projects, to propel planned projects into life and motivate the growth of IDR. Said one scientist, "[Interdisciplinary research with which I was involved had] no seed money to get people actually working together on pilot projects, and hence the budding initiatives failed to materialize." Another suggested that if funding is made available, "Aggressive, entrepreneurial, mostly younger, but not exclusively younger, scientists will go after it because that's where they can make the most progress." Seed money was seen as particularly important for junior researchers who may not have the preliminary data, or access to funding for preliminary research, needed to apply for grants. Seed money allows researchers to produce the preliminary data or test a potential research approach that then permits applying for larger grants.

Two university interviewees described how the importance of such granting programs as springboards to larger projects and/or external funding:

[The seed money program is] an amazing success; what has really been incredible about it is that when we fund people, they go on to become very competitive for external support because we've given them the background research and preliminary results that they need to show proof of principle.

[The grant program is] a catalyst or seed fund where we promote the initial contact between research communities that are potentially able to launch larger scale efforts beyond our capacity to fund.

Relatedly, some researchers thought a seed fund should cover "high-risk" proposals, awarding larger grants to meritorious scientists who "are likely to come up with a good idea to solve something." They noted such programs at the MacArthur and Sloan Foundations and HHMI, and plans underway at NIH. Along this line, one university interviewee described its approach of "trying to fund things that wouldn't get funding from NIH or NSF to start with because of the current funding climate … it is really, truly seed grants for glimmer-in-the-eye ideas that are interdisciplinary, require an approach that no one person could do alone in their own lab, and are on important topics."

Seed money was widely seen as an important tool for guiding the research activities of a large institution toward priority areas. A Smithsonian director hoped to use seed money as an

incubator for a large project and outlined the process, beginning with "a call for idea statements; identifying 15-20; selecting five to six that look really promising; putting some money in efforts to bring the people together, including the outside collaborators; having a couple of workshops; developing a pre-proposal with five to six of them; narrowing it down to the two to three where the best opportunities would be; and turning them into full-fledged proposals, where anyone of them could mobilize tens of millions of dollars."

Seed money can be essential for travel for research and to get to meetings or conferences, both of which are fundamental steps in developing interdisciplinary research projects. Some scientists wanted seed money to bring in graduate students or post-docs who were working on interdisciplinary thesis projects and could serve as links between departments. Post-docs can "jump start" projects that have come to a halt due to larger funding or scheduling concerns, and they provide momentum without which a project could be derailed.

An external interviewee talked about the diversity of opportunities at her organization through a "program portfolio of funding workshops, travel grants, short-term research exchanges, speakers to international conferences, and virtual joint centers" (which are first efforts at longer term interactions with ongoing research groups).

Interviewees mentioned various sources of seed money to get projects started—the central administration could create a new pool from existing funds or Congress should provide it. Some noted that other organizations use indirect cost funds as a source of "bid and proposal money" to develop large-scale project proposals.

The amount of seed money that interviewees said would make a difference ranged from small amounts of a few thousand dollars for small initiatives to six-figure amounts for larger projects. An outside interviewee said that if his organization had extra money, "we would probably have a really interesting debate about whether we should give more grants or bigger grants." Some suggested increasing the funding proportionate to the number of units involved in the project as an incentive for collaboration. Others suggested a multi-tiered approach to encourage both small projects with a couple of researchers doing preliminary analyses as well as larger initiatives that might require post-docs or dedicated staff.

Smithsonian researchers surmised that current funding concerns at the Institution would make any incentive very popular—"my guess is given how starved we are throughout the museums, even small amounts of money will get people to jump." A few researchers thought the best approach would be "to start out small and hope that if it succeeded, it would be sufficiently interesting that others would buy in." Others wanted calls for proposals to include disciplines beyond the sciences. Finally, some internal interviewees wanted to be sure that the projects supported by an interdisciplinary seed fund would supplement, not supplant, current research—"of course, we should play to our strengths and what we do well here, and continue to do that."

A number of scientists insisted that proposals to a seed fund be peer reviewed to insure accountability and access by women, minorities, and young researchers, but others were reluctant to burden small sums of money with too many hurdles. A significant hurdle, as noted, was assembling a panel capable of reviewing interdisciplinary proposals involving wide-ranging fields—"It's much easier to judge a series of more focused proposals." One scientist who advocated for peer review wanted a "system in place where there are multiple calls and quick turnarounds—multiple opportunities per year such that people can have a research opportunity or collaboration opportunity, seize that opportunity, and get the funds to pursue it before it passes." An external interviewee said that at his organization there was a pool of "totally discretionary funds at the level of the provost. If you need a few thousand dollars, he'll just let you have it, but you have to make the case for it." Another suggested approach was to provide seed money based upon a social network map drawn from co-authorship data, essentially rewarding individuals who have a proven record of collaboration and IDR.

There were some cautionary comments. For example, one person emphasized that "you need to follow up; if you don't have funds for that, people get very quickly frustrated." Another Smithsonian researcher worried, "If we want to encourage interdisciplinary research of a particular kind or in one direction, I think we have to be very selective about how we decide which direction to go in." Still others cautioned management to be careful to ensure that funds in fact go to interdisciplinary research that is "actually generating good science, rather than people collaborating because there's a source of money they are trying to acquire."

Full Project Grants

HHMI set up a four-year, $40 million pilot program, the Collaborative Innovation Awards, to award large grants to eight teams of scientists "to devote substantial time and energy to pursuing collaborative, potentially transformative research." The intent is "to encourage both HHMI investigators and outside scientists to undertake projects that are new and so large in scope that they require a team of collaborators with a range of expertise" (Howard Hughes Medical Institute, 2008). Former NIH Director Zerhouni emphasized the importance of dedicated pools of funds for innovative, potentially transformative research. In 2004 NIH created the NIH Common Fund, which Congress enacted into law in 2006, to support "programs that address fundamental knowledge gaps, develop transformative tools and technologies, and/or foster innovative approaches to complex problems." Zerhouni also set up the NIH Director's Pioneer Awards to support highly creative and pioneering people who propose exceptionally innovative approaches with the potential for high impact, "but that may be too novel, span too diverse a range of disciplines, or be at a stage too early to fare well in the traditional peer review process." The NIH Director's New Innovator Award similarly "is designed specifically to support only a small group of unusually creative new investigators with highly innovative research ideas at an early stage of their career."

The Smithsonian has three internal programs for science grants: Scholarly Studies, Restricted Research Endowments, and Marine Science Network (MSN). OF administers the first two in collaboration with OUSS, and OUSS administers MSN. While researchers appreciated having the Scholarly Studies Program (which had been eliminated under the former Secretary Lawrence Small), they commented that the size of the grants was too small, barely covering a post-doc's salary. Interviewees said the absence of a mechanism to make research funding available to those Smithsonian scientists precluded from submitting NSF grant proposals, and the underfunded Scholarly Studies program with its $50,000 annual limit, puts the Institution at a competitive disadvantage—"Many of the best applicants for Smithsonian science positions never apply because the Smithsonian has no mechanism to fund their research at a remotely competitive level."

Administrative Support

Bureaucracy within the Smithsonian has become worse and is sometimes an obstacle to efficiency ... The last time I gave a talk to a nearby teaching college, [the reimbursement of $100 in expenses] involved an unusual amount of forms and letters, which caused significant complications in obtaining the reimbursement and administrative costs well above the amount to be reimbursed … I have been told by NSF officials that they try not to call [one unit's] scientists for their panels because they don't know how to deal with our reimbursement procedures … Is it really necessary to have such complicated and rigid procedures even when the sum to be reimbursed is small? (Responder to 2008 the Smithsonian strategic planning online survey of staff)

A widely held view among Smithsonian researchers was that the administrative support systems currently in place are not conducive to world-class research, indeed actually undermine it. Attempts to engage in interdisciplinary research, which is by nature collaborative, are stifled by ineffective, bureaucratic support systems and services. Several scientists described their administrative burden as another example of how the Smithsonian does not value or understand researchers and their needs.

Systems and Processes

Smithsonian researchers said that bureaucratic red tape increasingly consumed their time and energy—"I spend more than half of my time on bureaucracy that has nothing to do with my research," said one scientist. Several cited the excessive time needed to navigate approvals and amount of paperwork required for purchases, even micro-purchases. One person, talking about large purchases, sighed, "If something goes down to the contracting office … kiss it goodbye." Sometimes administrative rules and processes are ambiguous, so that "you think you're doing it right, and it comes back." While never easy, the process is significantly more onerous when one is in a remote field location.

OHR was criticized for its lengthy hiring process, in particular when it comes to time-sensitive projects. Short-term hiring issues such as the time it takes for short-term assistants to get their badges, etc., were said to seriously detract from the ability to run effective research programs. Some interviewees thought that the multi-day equal employment opportunity training courses

that supervisors were required to retake every few years could be offered more efficiently through a self-administered online questionnaire, as OCIO does for computer security. Still others mentioned that time and attendance forms for salaried staff must be submitted before the end of the pay period, necessitating guesswork and corrections.

One researcher pointed out that the net effect of these frustrations was much more than mere inconvenience—"This is really cutting into our time and reducing our ability to do [research work]. At some point, it is bleeding down our creativity because every time you think of a new idea, you think what a hassle it's going to be to implement it." Another interviewee proclaimed, "It's death by a thousand cuts."

Interviewees noted that governance reforms instituted in the wake of recent scandals have thrown up additional impediments, even though the questionable practices were committed by senior managers, not scientists. Some understood the need for reforms but expressed concern about their implementation:

> *We realize past events at higher levels of SI have forced greater scrutiny of many transactions. However, the significant cost of too much regulation should also be seriously considered, to strike a reasonable balance between due diligence and efficiency (NZP Science Council, 2008).*

Some interviewees questioned whether those who set procedures and approval processes had considered how they would impact the ability of the Smithsonian to serve its mission, while others doubted whether their impact on efficiency was ever considered. One person commented, "The Regents got very much involved and made a number of decisions on our behalf, and I don't think they really knew the consequences of some of them because there's no feedback loop that includes them." Another opined, "What we frequently feel on the frontlines is that the infrastructure isn't there to help us. It's the tail wagging the dog."

A few Smithsonian interviewees expressed the sentiment that such hurdles are "nothing you wouldn't find anywhere else," but others pointed to greater flexibility at some organizations. Interviewees shared examples of how they utilize partnerships or adjunct faculty status to circumvent burdensome Smithsonian rules, which carries costs to the Smithsonian, such as lost overhead and credit for funds raised. Others simply pointed to universities or other organizations as models for the Smithsonian.

A culture where administrative matters consume too much research time, some interviewees indicated, can reduce the Smithsonian's ability to attract and retain quality scientists. Interviewees cited examples of former Smithsonian staff whose decisions to leave were influenced at least in part by frustrations over administrative support issues.

Interviewees singled out travel as a major problem and noted that, to be a leader in science, the Smithsonian needed both to send its own scientists to professional gatherings, and to host such gatherings. Obstacles to travel and difficulties in securing meeting space, however, made these types of face-to-face exchanges difficult. One interviewee commented,

> *There has been a general desire by senior managers as long as I've been here [since 2000] to use the Smithsonian as a venue for discussions of the scientific topics of the day, and to be a player in that sense. Simultaneously, we are now making the invited travel rules so bad that we can't possibly do it logistically anymore.*

One scientist spoke of moving a conference to another venue because of travel issues for participants. Many interviewees found it illogical to require the purchase of more expensive government tickets, when discount tickets would allow travel budgets to be stretched much further. A particular concern was the time spent securing travel orders through the GovTrip system, seen as the major impediment to research travel. A unit director noted, "GovTrip and the related travel rules have done more to reduce productivity [at my unit] than anything else in its history." Another interviewee wondered if management realized how its decisions about seemingly small matters such as travel had truly profound effects on the front-line staff.[18]

Similar complaints were lodged against inadequate support systems for hosting meetings at the Institution. According to one scientist who had attempted to coordinate one, "We have nothing, as far as I can tell, inside that helps us coordinate scientific meetings. We have no system at all to do that. We have no people to do that."

While interviewees acknowledged that many of these administrative hurdles were simply the result of the Smithsonian following government mandates, some questioned top management's acquiescence to policies designed for other types of organizations and activities, rather than seeking exemptions or otherwise advocating for systems that would better serve scientists' needs. Administrative areas where scientists indicated they would appreciate greater advocacy on their behalf by senior unit and central management included circumventing the irradiation of mail[19] and navigating the increasing difficulty in getting collecting permits and permission to transport specimens. Interviewees indicated that even if such efforts were not successful, the research community would at least get the message that senior leadership was on its side. As it stands, senior management tends to be seen as an impediment rather than an ally:

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[18] Subsequent to the data collection phase of this study, Secretary Clough announced an initiative to review GovTrip and institute changes to address some of the issues.

[19] Although a post office box was acquired for this purpose, some items cannot be sent to such an address; as a result, some scientific items sent through the mail have been irreparably damaged.

When you are trying to create some novel interdisciplinary working group or whatnot and you need help from the director's office, chances are that the response will be that they are busy and don't have time to deal with it. "Do what you can. We don't have time to help you." Basically, everything stops as you try to go up the chain.

Support Personnel

In contrast to what researchers had to say about administrative systems, many praised the administrative personnel in their departments. At the same time they recognized that these staff, like the scientists themselves, often were too few in number and equally overwhelmed with bureaucratic red tape. There was a clear sense that more administrative support staff would address some of the administrative problems: "In the Smithsonian, you need many more people in support roles than you do actually doing the research. It's just as important to the mission and just as critical to the Smithsonian."

One unit director noted that over the past ten years, some units have "tried to keep the number of science-related positions fixed, [because] if the [research] salaries grow, the amount of the budget left over for everything else gets smaller constantly." The result is "wafer thin" administrative support in some areas. Some interviewees actually advocated shrinking the permanent science staff "to make sure that the people who are here get better support."

Several external scientific research managers described building their support staff with an eye toward customer service, which ensures that the researchers get the support they need without hassles and can devote their time to science. Many internal interviewees raised that as a goal for the Smithsonian. The benefits of taking administrative frustrations out of scientists' hands—making sure that all the signatures are acquired, the budgets of collaborating departments agree, funds are spent appropriately, travel arrangements are made, no-cost extensions are secured, and so on—should not be underestimated. One researcher said, "Those sound like little things, but they would really help."

Some tension was evident between central administrative staff and science units when it came to the division of responsibilities. One scientist thought it sometimes was "not clear whose responsibility it is to do things," while another admitted that "administration doesn't really understand what our job is, and we don't really understand what their job is."

Senior managers across the Institution also commented that low levels of administrative staff limited responsiveness. They expressed concern over the level of support in OHR and other offices, such as the Office of the Chief Financial Officer (including the Office of Contracting and the Office of the Comptroller) and OCIO.

Infrastructure

The problem of salaries consuming an ever-increasing share of the budget has squeezed investment in infrastructure as well as numbers of support personnel. Some interviewees indicated that it has begun to interfere with their research efforts. For example, at some units such as CEPS, the infrastructure is unable to support the large investments needed for instruments or desirable programs. A limited network environment and insufficient space were seen as very real obstacles to increased research productivity. One interviewee noted, "You can't compete for world-class projects without world-class infrastructure. I think that is where the Institution has been losing ground, because we just have not kept up the investment."

Information Technology Support

> *IT policy … is backward and paranoid. We had to fight tooth and nail just to get an Internet port opened for us so we could collaborate with overseas project members. The policy disables virtually all of the useful features of the Internet, like videoconferencing … Very weak IT support—impractical firewalls for international science collaborations and data-sharing, small mailbox sizes, weak support for science, and lack of back-up systems.*

Many scientists pointed to information technology (IT) support as the key infrastructure problem. They spoke of a general disconnect between OCIO and researchers, describing the Smithsonian's IT support model as designed "for a typical office environment, not a scientific research institution." Scientists warned that a failure to address the radical disconnect between their IT needs and OCIO services could result in the Smithsonian falling ever further behind its scientific peers.

Specific issues were: insufficient bandwidth; lack of support for Macintosh platforms that are required for some research programs; problems with connectivity; and excessive limitation on email attachment size and mailbox capacity, with the latter two cited as significant impediments to collaboration. Here, too, scientists noted that trying to find workarounds for these limitations meant that they squandered precious research time. As one said, "I do a lot of my own setup and my own systems administration, which is a pain in the neck, honestly." Others mentioned returning from travel to find their email accounts locked due to going over the limit. While scientists fully appreciated the need for security measures for staff who work with personnel, financial, or other sensitive data, security measures are a serious obstacle to scientists whose work depends on the free interchange of knowledge and data.

One solution adopted by many researchers is to work more at home, where they don't have to deal with these encumbrances. Some researchers suggested that they be given administrative

rights for their own computers in order to quickly download software updates rather than going through the "already overloaded computer guy." One interviewee quipped, "I don't need to be in some privileged class. I just need to download software." In fairness, scientists at Federal agencies have encountered similar problems. One interviewee mentioned researchers in his agency purchasing private computers "and not hooking them up to the network," so they would have more flexibility to download and run special software.

Some people expressed frustration about how security and funding concerns delayed the adoption of new technologies. For example, the slow introduction of wireless hotspots within the units has been a problem for visiting scientists who wished to connect to the Internet or to their home organizations. The Smithsonian deemed Skype, a new technology that enables cheap communication via the Internet, insufficiently secure, "but instead of finding an alternative, we just shut it all off."

The ability to archive data was also raised. On this issue, many were hopeful that the new OCIO facility in Herndon, Virginia, would provide needed support. It should also be noted that OCIO conducted a scientific research IT needs assessment in 2008 to gain a better understanding of what issues scientists faced and what hardware and software they needed, and have integrated a plan of action to address these issues into the Smithsonian Information Technology Plan.

Space and IDR

> *Cross-unit sharing of resources like labs is such a no-brainer model it must be supported, because not to do so is missing an opportunity. It's a waste.*

Many interviewees, and the literature, spoke about the importance of providing opportunities for scientists from diverse fields to come together in common venues to learn about one another's fields and projects, discover new approaches to their own research, hear about emerging technologies and their applications, identify potential collaborations, and so forth. One Smithsonian scientist noted that without such opportunities he "never would have understood the sorts of synergies we can have." Another added that without interchange, "you get in your own little area and you compartmentalize."

A traditional means of fostering this interaction, beyond formal conferences, workshops, and the like, is to provide common, congenial space, which today often goes beyond work space such as labs and offices to include social areas, fitness centers, and restaurants. According to the literature, "Demand for interdisciplinary space is steady or increasing in disciplines from engineering to humanities. For new and renovated buildings, flexibility and space for social interaction are critical seed-beds for interdisciplinary innovation" (Marty, 2008). Nowadays virtual space is used increasingly, albeit behind it are researchers' offices and often an administrative support office.

Physical Space as a Catalyst to Interdisciplinarity

Dedicated Buildings

A number of the interdisciplinary centers with which the study team spoke had constructed new buildings designed not just to provide superior research workspace, but to maximize contact among researchers. Other centers have renovated or reconfigured space in existing buildings to again maximize contact among researchers from diverse disciplines. Having a common space not only affords opportunities for interaction, but also provides identity to the center.

There is a long tradition of constructing new buildings designed specifically to support interdisciplinary research. A Smithsonian interviewee remarked that the historic Bell Labs flourished, in part, because of Eero Saarinen's ingenious design of its offices. There are many

contemporary examples of this approach, most offering state-of-the-art labs, social spaces, and open areas with glass and metal panels that provide flexibility to adapt to programmatic needs.

- At one extreme of new construction is HHMI's Janelia Farm research facility in Virginia. At the heart of this residential 689-acre campus is a very large building that encompasses not just research space custom-built to meet the specific needs of the researchers, but also auditoriums, seminar rooms, a library, dining room, restaurant and pub, fitness center, and other communal spaces. The goal is to maximize the time available for research and for interaction.

- Stanford University's interdisciplinary Bio-X program is headquartered in the new, ultra modern Clark Center, which features open labs designed to accommodate multiple researchers from different disciplines, as well as ample communal social space. According to interviewees, the building's design contributes to many productive encounters among researchers; the center's aim is to spur connections across the arts, social sciences and physical sciences.

- To facilitate teamwork, Google's Copernicus research facility has no private offices. The space features bright colors and abundant white boards, paper, and crayons. Amenities include micro kitchens with coffee, tea, water, pastries, and fruit; game rooms; enormous television screens; cyber-relax massage chairs, blankets, and bean bags; lactation rooms; and even oil changes and dry cleaning services—all to attract, energize, and stimulate achievement.

- The Life Sciences Institute (LSI) of the University of Michigan consists of an Undergraduate Science Building, Palmer Commons, and Biomedical Science Research Building. Together they offer almost one million square feet of space that includes open laboratories where research collaboration among scientists from a range of disciplines occurs at all levels.

A Mix of Central and Dispersed Space

Some centers have opted not to construct new buildings.

- As described in the chapter on Organizational Structure, NCEAS at UC Santa Barbara occupies physical space in a building in downtown Santa Barbara. The building is home to the post-docs; researchers on sabbatical; representatives of the dispersed working groups; and synthesis meetings of representatives of the distributed graduate seminars. According to an interviewee, NCEAS is "a fundamentally different environment" than the university campus. Providing a neutral territory for interaction, where "nobody is getting distracted by walking down the hall to see their colleague," is a critical feature.

- At Duke University's IGSP, 36 of the 60 faculty members work out of the Institute's central facility, although they also have appointments with other faculties. The other 24, who have chosen to maintain an office within their home departments, have access to the Institute's communal office spaces with four to five desks that they use for periods of a few hours a day to several weeks at a time. According to an interviewee, this mix of spaces contributes to efficiency, avoids duplication, and cuts down on the cost of work space.

- SFI has dedicated physical space to hold meetings and workshops and to house professors, post-docs, graduate students, visiting researchers, etc. doing work onsite. Nonetheless, it considers itself a virtual entity, where work by scholars from universities, government agencies, research institutes, and private industry occurs at their home institutions and other places. One interviewee described the Institute's purpose-built research facility as an open courtyard surrounded by a series of "pods," based on a novel architecture called caves and commons. The intent is that while people share offices, they will come out into the common space for meetings and discussions—"It was a space that when it was built was designed to encourage interaction between people, and it does that relatively effectively."

Virtual Space

As noted, several internal and external researchers talked about virtual labs or cyberspaces where scientists from different locations "meet" to conduct research, discuss data, and draw conclusions. As the example of NAI indicates, technological innovation such as Web 2.0 may be a driving force for interdisciplinary collaboration; however, many scientists still see the need to get together physically. One external interviewee cautioned, "If you want to truly establish a community of researchers who work well together, time and money need to be invested to bring them together at some point. Otherwise, the virtual entity becomes a funding system."

Physical Space at the Smithsonian

Several Smithsonian scientists spoke of the Institution's geographic dispersion as a physical barrier to collaboration. At the National Zoo, research staff is split between two campuses, both off the Mall and 90 miles apart in Washington, DC and Front Royal, Virginia. With some exceptions, the distance has made it difficult to sustain integrated research teams; however, the Zoo has been using videoconferencing successfully to overcome the distance barrier between its Rock Creek and CRC facilities. NMNH staff are divided between the Mall building and space at the Museum Support Center in Suitland, Maryland. Other units are outside Washington, DC (SAO in Cambridge, Massachusetts, SERC in Edgewater, Maryland, and STRI in Panama). Beyond this dispersion, scientists complained about a serious lack of research space and poor

quality of much of the space they do have. A CEPS scientist noted that a shortage of work space inhibits CEPS from appropriately supporting a data center or spacecraft operations center—"It is a major impediment to expanding our involvement in new mission-related opportunities in space." SAO, located at Harvard University, shares this problem.

Smithsonian research space—much of it fairly old and some consisting of trailers—is not configured to foster collaboration and IDR. At NMNH, the convoluted network of departmental office spaces cuts departments off from one another. Renovation of the building is underway, but one scientist was concerned that the building's redesign is not being configured to encourage greater interaction and collaboration—"The building is like an 11th century monastery, with the monk's cells on the outside and the cloister in the middle, and heaven forbid if anyone should interact." Another researcher commented of the Smithsonian in general, "Warm, welcoming, clear, and modern buildings, which create a sense of community, are few and far between."

Not all interviewees agreed about the importance of common space. One observed that more collaborations occur when flying cross-country for meetings and cautioned that meaningful interactions require far more than an engaging building. For example, there needs to be concrete and well-defined follow-up to initial contacts.

Labs and Equipment

> *Having a [technological] capability self-nucleates the people. The people come and use it for a while, bump into a post-doc from another lab. That is another way the Institution can create these accidental meetings.*

In addition to being a locus of research, labs and equipment can spark interdisciplinary research. Smithsonian scientists spoke about the labs bringing researchers from across the Institution together, including from subfields within disciplines—"serving a pretty broad range of biologists: conservation biologists, systematists, other kinds of evolutionary biologists, population geneticists." An external interviewee noted that his interdisciplinary center designed open lab space to be too big for any one disciplinary group, so that there will always be room for a variety of researchers. In recruiting scientists, he sought people who appreciated the opportunities the lab space created for interaction.

Labs

There were few comments about Smithsonian labs, but they covered a range of points.

- ***Outmoded infrastructure.*** The buildings in which some Smithsonian labs are housed impose constraints. For example, one interviewee said, "We're using every ounce of

electricity given to us … We have a list of 80 freezers we have to check everyday, because there's no automated alarm system … Every time we want to buy something new, we have to ask what we have that is old and we can get rid of, because we're out of space." A SERC external review committee noted that "The foundation of important research programs and the demonstration of leadership in a region are very dependent on the infrastructure" and noted a number of deficiencies at the Center:

> *The previous points led the Review Committee to conclude that major upgrades in infrastructure (instrumentation, cyber-infrastructure, information management, lab and residential space) are required for SERC to continue its leadership role and competitive stance in large-scale network science (e.g., NEON, LTER Network programs). Science programs evolve, and the major programs we now see coming from funding agencies will depend on this level of infrastructure to remain a major force in environmental science (Ducklow, et al., 2005).*

Plans are now underway for several upgrades of SERC's facilities, including a new lab.

A 2007 external review of the NMNH's Anthropology Department similarly noted issues relating to labs and related technology, for example, a "lack of laboratory space and work space in a non-toxic environment for research on collections at MSC [Museum Support Center in Suitland, Maryland]." Further,

> *In biological anthropology and archaeology, many aspects of modern research presuppose stable isotope analysis, microstructure work involving electronic microscopic analysis and other modern approaches, and/or advanced 3-dimensional and imaging technologies. These are not currently available in Anthropology and will become necessary if the Smithsonian is to retain its reputation as a leader in anthropological research (Cordell, et al., 2007).*

- ***Budget cuts.*** An interviewee said that labs are easy targets for cuts in times of scarce funds because "you cut what you can't see."

- ***Research vs. service role.*** Scientists at some labs described a "tug and pull" between the labs' desire to be "an intellectual unit that has a strong research presence," and scientists' need for a service unit. An interviewee at one lab said researchers viewed it as a [free] service—"they wouldn't want to pay for it or enter into collaboration." One interviewee drew a distinction between a small, one-time analysis that is "helping someone out" versus a longer project involving design type input and novel thinking that is more of a collaboration meriting acknowledgement.

  This tension did not apply to all labs. An interviewee explained, "Our lab is set up so that we do some of our own research, but a large portion [of the work] is collaboration with

other people here at SI and outside. A lot of it [occurs] because we have a set of methods we can do that other people don't really have. So we provide collaboration and service to departments [across the Institution]."

One researcher wanted labs that both operate the equipment and provide data back to the researcher, as well as labs that "work with you to analyze the data and write the paper."

- ***Centralized vs. onsite.*** A recurring Smithsonian theme—centralization vs. decentralization—emerged with respect to labs. The issue related to having onsite labs for quick access or having shared labs so as to leverage resources and achieve synergies. The concept of shared labs raised issues of who pays for what and how access is decided when the lab is fully utilized. On the one hand, it was noted that you can't set up a molecular lab in ten different places as economically as you could in one place. Moreover, shared facilities "would greatly facilitate interaction with permanent staff and increase contact with the large fraction of students and post-docs who work primarily at molecular facilities."

  There was also recognition that "some labs are so cross-cutting that they should be centralized facilities." For example, in February 2009 the OUSS announced that the Smithsonian now has two pan-Institutional mass spectrometry facilities for analyzing stable isotopes—an existing laboratory at STRI and a new one at MCI in Suitland.[20] In general, Smithsonian researchers acknowledged that the Institution must do a better job of strategic planning and coordination.

  > *We can't have state-of-the-art facilities for everything because it is not possible to maintain that. So maybe that's where some strategic planning is necessary. We have to think about what facilities we really need, work together, have multiple units share facilities … we can't have the same redundant facilities everywhere. So it requires a level of planning that maybe we haven't engaged in that well.*

  At the least, some suggested, there needs to be better communication about what research labs, equipment, and other resources exist throughout the Institution—as well as about current and proposed research projects—"so people can connect and say 'oh, we're doing that kind of research, maybe we could work together… or bond together to find funding.'" As one interviewee observed,

[20] The STRI facility accepts samples from all interested users, with preferential rates for Smithsonian scientists, fellows, and visitors. Use of the MCI lab is reserved for Smithsonian staff, fellows, and research affiliates; samples accepted for analysis through May 2009 are free of charge but eventually there may be a modest fee-per-sample charge to support the lab.

> *There are certainly a few labs that are held within a department that could be used more broadly … but no one to my knowledge has ever issued a guidebook of all the stuff that we own. If you wanted to foster interdisciplinary research, just knowing what is [available] might be a benefit. Someone might realize they could use something.*

On the other hand, some said there will always be a need for decentralized labs across the units. It was noted that with an onsite lab, "you have more control of what you're doing, and you can use it to attract more funding and more people." A number of interviewees raised the problem of travel time to centralized facilities, a point frequently made with respect to the distance between the Mall and Suitland, Maryland—"You can't do everything in one central location. You're not going to draw people to come to Suitland to do everything. It's only 5-20% of their effort, and they'll sacrifice that limb rather than eat up all the time going to the lab."

Yet others saw the need to maintain a balance between centralized labs that make resources and facilities available and decentralized labs that provide individual scientists the opportunity to use and develop skills for themselves—"In some cases it makes sense to centralize instruments and skill sets, but in other cases it doesn't." Researchers pointed out that savings from cost-cutting measures initiated by past central administrations did not accrue to the labs, and that centralization needs to be done very carefully to maintain the long-term scientific viability of a lab. Experience, according to some researchers, suggests that multi-unit efforts wane over time. A final point was that creating "new central facilities" will require additional staff support.

Equipment

> *Equipment is a technician that never makes a mistake, never sleeps, doesn't take vacations, and its kid doesn't get sick.*

> *I would say in general the Smithsonian is not competitive with the better academic research organizations in terms of equipment and instrumentation. People would come to us for our expertise, not for our equipment, that's for sure! We don't even come close to the budgets those institutions put in to equipment and upgrades.*

While acknowledging the costs, many researchers spoke of the need for state-of-the-art equipment that provides faster, richer analyses if the Smithsonian is to remain at the forefront of science. For example, said one person, "It starts off, and it's new and expensive and innovative, but as it spreads and becomes a common tool, then everybody has one. And if you are going to be a successful competitor in a cutting-edge enterprise, you are expected to have that capability. If you don't, your ability to compete is diminished." Advanced equipment can greatly increase

the speed of analysis ("That [machine] just did in 30 minutes, and 10 minutes of prep, double what I could do on my best day"); accuracy ("if I had to do that many, I would make a mistake"); and efficiency ("those glass capillaries use 1/10 the volume of that very expensive chemical that I would as a person"). These advances translate into savings in time and supply costs.

Conversely, absence of the right equipment "diminishes our capacity to do our science … there is a cost and a consequence to that," said one Smithsonian interviewee. For example, when "we want to run one chip on a bird that's infected with malaria, it will cost us $15,000 for one individual if we went to Virginia Tech's facility … it would be nice to have the machinery here. It would reduce the cost a lot." And equipment can provide an income stream—"If we had the capability, we could run other people's things as well."

Not all interviewees found the labs wanting. One said, "I have very good lab facilities … I mean, you could always use new items of equipment, but it seems to me that the annual equipment fund has more often than not given me what I need."

Interviewees attributed the slow pace of acquisition of new equipment to a lack of mandate and resources. For one thing, equipment is expensive, with some instruments costing hundreds of thousands to millions of dollars. It was noted that resentment can arise within museums when previously collections-oriented funds are redirected to labs. Some interviewees thought that too often funds were directed to "big gobblers who need huge chunks for technology," to the detriment of other units.

The same arguments for centralized labs applied for sharing equipment. The expense of highly skilled people to run the machine and maintenance was said to be greater than the cost of transporting materials and even scientists to a central machine. The shortage of technicians led some to consider the purchase of similar pieces of large equipment at multiple units as a "colossal mistake" and "waste of money." Interviewees said, "Potentially there are pieces of equipment that people would want to share … We buy these things for individual departments."

Some scientists viewed standardizing equipment across similar labs as an area in which the Institution could create economies of scale—"we say get the exact same machine we have. Then you don't need me onsite there to tell you how to run it; if it breaks, you call me up. I know what kind of machine you have. I know where everything is on the machine." One researcher explained that beyond maintenance, if each unit purchased the same model, the Smithsonian could purchase supplies centrally and act as a warehouse, since each unit would need the same filters, chemicals, tubes, test supplies, etc. Also, units would be able to purchase partial orders of expensive chemicals, and without having to do their own purchase orders, collectively the Institution would save on shipping costs.

Some interviewees spoke of opportunities to purchase equipment through grant funding. Coordination of these efforts, they maintained, can provide win/win situations in which sharing the costs of purchase, technicians, supplies, and service contracts provides the individual scientist with the capacity to execute analyses for the project in the short term; leads to a long-term acquisition of an expensive piece of equipment for the lab; and provides the Smithsonian community with added capacity. While this has occurred, it has been ad hoc, because "there's a lack of communication … nobody is wandering amongst the scientists with their finger on everything that's happening."

In addition to scientific equipment, some labs provide users with computer workstations and software to crunch data and conduct analyses. A centralized facility can realize economies of scale with hardware and software purchases and licensing. For example, at the Laboratory for Analytical Biology (LAB) in Suitland, MD, there are

> *half a dozen Macs and PCs, top-end, massive screens, 30-inch cinema display, double monitor displays. You can look at a ton of data all at once. People don't need to bring their own computer; we've got that for everybody. We have tons of very expensive software. We buy a site license for 15 copies; if you're the 16th one coming on, it will tell you all the copies in use and that you have to wait. It will prompt you when one is available. If that happens with frequency, we will up it to 20 copies. The software alone is tens of thousands of dollars a year.*

Technicians

> *Technology is allowing us to address bigger-scale problems that require much more data more rapidly, to take on new capabilities and capacities to do things. The problem is that it takes increasingly skilled technical support to sustain and support those actions.*

A number of interviewees commented on how important the human factor is to realizing the potential of equipment—"It's not just all equipment. In some cases, what you need to do is attract someone from the outside who is up-to-date, current, and a bona fide expert in the field, so that you can realize the advantages of all this great new technology." As one person noted about even the most sophisticated machines, "The greatest strength of those instruments is not the instrument itself—it is the people who know how to use them."

According to a number of interviewees, a shortage of technicians was the biggest problem when it came to lab equipment. One researcher lamented, "In a sense we're occupying a bit of a backwater here—we're not using the tool … we have no staff, and we haven't been able to make the argument that this is a priority staff position." Another stated, "While we could probably

come up with the instruments, we don't have the technicians to support operation maintenance, calibration, and data retrieval."

There was some support for the idea of centralization of technicians. One scientist suggested, "Maybe it is moving somebody from one bureau to a central facility ... It's not new. I think universities have been going toward this model now for a couple of decades." Another mentioned an instance where the opposite happened: "We pulled the support off of [one] lab—the only person who really knew how to run all that equipment. I think that's a terrible shame … It was being used and should have been used more by more departments … we should have been building up its use instead of pulling off the person."

Technical staff must be part of any strategic planning equation for labs and equipment—"At least for the higher end things you really do need to plan personnel cost for skilled technicians." In describing a piece of equipment he was hoping to procure for his lab, one Smithsonian scientist noted, "If we get a donation of one of these machines, we would try to build into it five years of tech support."

Data Use and Access

The key issue is integrating the information.

Data Sharing

Smithsonian scientific research has generated huge amounts of data, and it was common to hear people criticize the lack of accessibility to the data. Researchers said greater data sharing across the Institution would stimulate more collaboration and IDR, and that integration of datasets into a single system would enable them to find out a lot more about what data the Smithsonian does have. One researcher explained, "For the community of systematists and ecologists, it doesn't make sense to take one small piece of that puzzle and know it really well when you can know all of those pieces [and] how they fit together." Another interviewee estimated that 90% of the data generated by Smithsonian scientists was not fed to the intranet in a usable form. Researchers said they can put data up on the web, but the Institution does not have policies or procedures in place that would mandate it and provide guidance. The fact that journals increasingly don't publish the data underlying an article reinforces the importance of this issue.

Interviewees conjectured that in part it was a cultural issue. Smithsonian scientists tend to think of data as their own, as opposed to the Smithsonian's, and they fear someone else will use it and publish before they do. However, some said this was a generational trait that is changing. One researcher offered that, "Part of it is education, and part of it is telling people that they have to put their data up in a way that it can be accessed by others."

Some scientists believed that the issue may be moot as the technology is increasingly in place to share data. Others contended that while the collections information systems are a big step forward, surprisingly little of the data is actually within those systems—it's on people's hard drives and private databases.

Data Standards

Try to figure out how we can fold all of these datasets together.

While it was generally acknowledged that greater access to different data might lead to synergies, researchers said a major obstacle was that the data was not in a standard format that everybody could easily access. Creating, for example, standards for biodiversity data where the "worm data" and the "moth data" all go into a single system would enable the Smithsonian to create a reservoir of data that people could use to address bigger societal questions.

External interviewees described some successful efforts to encourage data sharing by scientists. One said that at his agency, "It took some re-tooling of the databases to standardize collection protocols, but now they've formed this rather imposing network where they can use each other's data, cross-publish and things." Another said that when her center's data repository was created, the standards were made for ecology, but they were also made to be generalizable to other sciences, including social sciences—"There's no reason [why] you couldn't generalize all the infrastructure to other fields." Still another external interviewee said searchable data repositories were a significant issue—"I couldn't possibly overstate that. Standardizing metadata—that's making metadata and their data interoperable—is a huge problem and needs to be taken really seriously."

Both internal and external interviewees referenced NSF's DataNet program, a $100 million effort that will fund five centers to explore ways to fold a multitude of data repositories together to create one massive repository. NSF's goal in funding the initiative is to ultimately make all of its principal investigators share their data publicly. At the Smithsonian, OCIO is currently collaborating with Rensselaer Polytechnic Institute and San Diego Supercomputer Center on a grant proposal for funding under this program.

Informatics Capacity

It's taking all those databases and being able to run problems, define correlations.

Bioinformatics is a huge, huge vacant black hole … We need more dedicated people who only want to do the bioinformatics portion of it. Other places that are starting to surge ahead have that. They built it in early. We haven't built it in anywhere.

A number of interviewees stressed that building an informatics capacity within the Institution is critical for its success—"The Smithsonian has the potential to have what we do online—our collections, images, linking DNA data and scientists' research—but it won't get there without bioinformatics help." Some saw great potential and promise with the EOL, CBoL, and ITIS projects, but suggested lost opportunities for the Smithsonian since all were built using external IT capacity. These respondents believed that greater investment in an internal capacity was needed:

> *[These programs] can continue what they're doing for the next 10 years, and progress will be slow, and the product will be average at best. If we invested in bioinformatics, progress would be fast, and the quality of the product would be what I would like to see from SI, that we are THE place."*

One researcher pointed to an effort to create "field management applications" such that collections data can be entered at the time specimens are collected, "because the further you're removed from when you collect it, the fuzzier the data get." The researcher wanted a "whole informatics umbrella" to capture data from where and when an item was collected, to photos and analyses that were performed, to where the item ended up. To accomplish this capability, the Smithsonian will need to hire informatics experts.

Central Informatics Office. Again, the question came up whether an informatics capability should be centralized or decentralized. A number of interviewees thought that the Smithsonian should invest in informatics as a central resource rather than placing informatics responsibility upon individual scientists. One interviewee talked about the "glue offices" that are necessary to go to a higher, big picture level—"people who can see across disciplines and bring people together—the informatics part—those are the things we are truly lacking at the Institution." Similarly, a researcher said the Institution needed an office that was empowered to say, "I have five people asking for very similar things—if we pull this together, we actually have a much stronger informatics base to use the data coming out for multiple purposes." Another commented, "It's silly for us to work on something that doesn't enable and have a cascading effect Institution-wide."

The need for greater informatics capacity was raised in a 2004 Smithsonian proposal for NSF funding of a Center for Synthesis in Biological Evolution, to be housed at NMNH. The proposal, which ultimately did not prevail in securing NSF funding, called for a coordinated effort to remove barriers to data synthesis by providing informatics resources—"be they datasets, tools, references and journals, network access or communication lines"—through a center that would function as a resource hub. The proposal cited the wealth of information currently available as both a challenge and an opportunity that required new tools to analyze and filter the information and allay the risk of drowning in data. Center functions would include making

needed reference datasets and databases; modeling software; developing new informatics tools for synthesis; and scripting programs and algorithms for the comparison, statistical treatment, and visualization of results available through remote access to existing systems, as well as a central repository of results, methods, discussions and drafts (Smithsonian Institution, National Museum of Natural History, 2004).

Some interviewees were not convinced that a central office was necessary; rather, they saw the issue as "how do you use the information and the informatics across the museums? Yes, you need a few core people whose main expertise is in informatics, and whose secondary expertise is biodiversity. That's probably what we're missing. We [only] have a couple of people." Ultimately, whether established as an office or a decentralized capability, the goal would be for Smithsonian scientists to be able to ask different and interesting questions and start synthesizing the masses of data related to those questions to understand the bigger picture.

IT Support for Informatics.

> *We have a database where all of this information is kept; we have a couple of full-time programmers; and we've developed special software for informatics. People can access the raw data and the published results. It's very powerful. (External interviewee)*

Informatics work cannot be completed without computational facilities and computer programmers. Models are the synthesis centers whose work emphasizes on informatics. For example, NCEAS has as both a Director of Computing and Director of Informatics who have successfully secured NSF grants and appealed to private foundations to work on ecological informatics. Their focus is on

> *thinking about database management, interoperability of data, making data public, and open source analytical techniques that will help scientists to collaborate and do the sort of synthetic research that we do. That's become a huge part of NCEAS, and I think a lot of people think it's a little invisible. [But it's] a huge undertaking.*

As noted, some Smithsonian researchers had utilized outside partnerships to avoid issues with IT security and intranet access, as well as hiring and contracting policies. Interviewees said promoting a collaborative framework with good information flow butted up against security aspects of the computer systems and opening ports. Successful informatics, one researcher maintained, will require IT systems with freedom of access and information flow that overcome the security risks of wireless access so that data can be entered into a central server from the field. He acknowledged that having such points of entry is a challenge.

Smithsonian interviewees said the Institution has not adequately invested in IT support for informatics and bemoaned what they saw the Smithsonian as losing ground in being at the vanguard of research and missing opportunities for funding—

> *I think that our tendency to late adoption is hampering us certainly in terms of getting money. There is no doubt about that. You only have to look at EOL going out and getting all of their IT expertise from outside … Funding goes to the people who are doing innovative stuff, and that includes IT nowadays.*

One interviewee suggested that funding for IT support should be imbedded into grants to finance the IT components of projects and build an internal capacity.

> *They don't think about the IT aspects of it until after they've already gotten the money. It happens every time. It happens with great big grants … They really ought to make sure that somebody has discussed with the PIs their IT needs, and make sure that that's built into the grant. How else are we going to get it? We're running on fumes.*

Part of the problem, some interviewees felt, was that the Smithsonian science community did not appreciate the value of science projects that have a large IT component, and this perspective hampered the Institution's ability to locate "interesting synergy with some of the people who could really help out. If you don't get out there and talk to people, that is never going to happen." According to some interviewees the Smithsonian had more informatics capacity in the past when it was part of [OCIO], but it became "bloated" and "they got rid of the whole thing." The NMNH Department of Anthropology review committee addressed the informatics shortcoming in its report, noting that:

> *The number of staff allocated to IT is woefully inadequate. We were told that this is an institution-wide problem, not limited to the Department of Anthropology … The Review committee recommends that institution-wide efforts and resources be directed to IT and the increasingly important field of Museum Informatics (Cordell, et al., 2007).*

Strategies to Facilitate Organizational Change

> *Scientists are stubborn; they want to do what they want to do; they want to study their area of expertise.*

Many of the external interviewees with whom the study team spoke had been involved in major organizational changes, as their organizations attempted to align with the nature of science today and to refocus around critical issues. All noted the complexity of moving an organization away from traditional ways of doing business embedded in organizational and scientific culture. They described strategies that they used to implement new initiatives at whose core was collaboration and IDR. The following strategies suggested by interviewees are not presented in any particular order, so implications of effectiveness, ease of application, etc. should not be drawn.

Head off Resistance; Get Buy-in

Organizational change, even in times of crisis, always meets with resistance, and the culture within the scientific community, as expressed by interviewees, exacerbates that natural tendency. Many interviewees emphasized that scientists strongly oppose being told what to do; any effort at change involving scientists will have to deal with a strong belief in academic freedom. Many of the strategies described by interviewees and found in the literature addressed ways to minimize resistance and get buy-in while moving forward with change.

- ***Use a mix of top-down and bottom-up.*** Providing scientists opportunities for input, ranging from large meetings to small working groups, was a common strategy to get buy-in. In some cases of organizational change described by interviewees, the scientists were asked for input and ideas, but in other cases they were given a role in defining goals and objectives, developing strategic plans, designing programs and initiatives, and creating action plans. This strategy offered two benefits—it helped overcome the likely resistance of researchers, and it led to the emergence of exciting ideas. According to Metzger and Zare (1999), "The best ideas often come from the bottom up: that is, from researchers themselves; and some of the most spectacular ideas come from young researchers who are newly tenured or untenured."

  A Federal science administrator described the process whereby his agency developed its strategic plan internally and got scientists to have confidence in it—"the fact is that they own the strategy … It required the scientists to take risks, to get outside their comfort zone. So culturally they had to have confidence we were going in that direction, [and they did] by seeing the relevance of the strategy, [and] the fact that it's filling gaps that no one else is doing right now effectively." Through many meetings and discussions, he

convinced the scientists that a science strategic plan was important, vetted the strategy through them, and committed the agency to it.

Even while emphasizing the inadvisability of forcing collaboration and IDR, some interviewees acknowledged that the top must play a strong role and take responsibility for final decisions. It's a matter of finding the right balance.

> *You need the real commitment from the top, but that commitment from the top must not be overly prescriptive. So it's not a matter of the top dictating, and the people down in the trenches just following orders. The top needs to establish the commitment that, yes, we really mean this, and when push comes to shove, we're going to back this, and we're going to make it so that those silo barriers don't get in the way. But having said that, now it's up to you folks in the trenches who are really going to be expending the blood, sweat, and tears on this. Now it's up to you to come up with the ideas and shape this thing and really make it work. That's the combination that you want.*

At one organization, senior leadership defined the overall plan and direction, but then involved the various units in how best to implement it.

> *We [the leadership] really tried to say what should this program be like, and we came up with a plan. Then we went and worked with each of the labs and centers as to what their role might be, and they participated in terms of developing the plan further in a whole variety of areas, coming up with actual research and implementation plans from the strategy … We broke down the silos and stovepipes, so to speak, by trading this sort of holistic view of something that everybody had some role in.*

A few interviewees spoke to a longstanding practice at the Smithsonian that has scuttled many initiatives—reliance on consensus decision making, which goes on endlessly because everyone wants a piece of the pie. Instead, leadership must be prepared to make the hard decisions in timely manner. Another feature of decision making that some Smithsonian interviewees decried was the endless chain of approvals before a decision could be made.

- ***Use leaders/influence brokers.*** Interviewees talked about involving people within the organization whose status, professional and personal, would lead others to join the effort—"You don't need buy-in from everybody. There are different players at different levels in all these units, with different amounts of influence … If they buy in, everyone else will go along with it." In one example, an external interviewee described how his agency used one scientist to sell the initiative to other scientists:

He does a really good job saying [to researchers] that it still works to be a scientist but work with a big team; he argues that it makes you more successful. He sat down and de-bunked all the arguments against this kind of work. He says, when you start out working with the team, you have to define the outcome big enough so that you know you'll have a lot of publications that come out of it, and you decide ahead of time who will be the first author on each type of paper, and everyone else gets the other authorship. He tells them it really works because you actually get more publications out of it.

Akin to using influence brokers is to encourage the "development of an advocacy network among faculty, students, staff, and post-doctoral fellows engaged in interdisciplinary activity (Dubrow, n.d.).

- ***Inspire scientists to become part of something bigger.*** A number of people emphasized that if you offer scientists compelling research questions or opportunities, couched so that each individual believes in the importance of the endeavor and of being part of something bigger than themselves, they will readily join in. This strategy works well when coupled with incentives, said one interviewee: "If it is made clear to them that we really need people to be working in this region and there are certain rewards that will come to you if you do that, then you can influence them." Another interviewee talked about how the leader or manager should model collaboration by making clear that he or she is not out to grab power or resources, but to act for the good of the venture and organization. The tradition at this manager's organization had been "The doors were closed, the budget was closed, access was difficult, users had to pay for everything." The manager "opened it up and made it transparent." He made clear that he was putting his personal interests aside so "there will be no conflicts. None of this money will be mine. Anything I do I'll bring in money for."

- ***Create win-win situations.*** In describing a Smithsonian program that had great potential for cross-unit collaboration, one interviewee explained why not many researchers in his unit chose to participate—the program was presented to them as "you can participate if you play by our rules and give us what we ask for." In this case, researchers felt they were being asked to provide a service function and that there was nothing in it for them. What would have worked better, the interviewee said, was to offer something they valued in exchange for their participation, such as the opportunity "to go in the field and do some major collecting for themselves the way they feel they need to do it. That will be a win-win … as opposed to just being handed something and being told, 'Here, we need you to do this.'"

  A number of people pointed to funding as a critical motivator. Dubrow (n.d.) discussed two approaches used at the University of Minnesota: "Incentives for cross-college

collaboration as part of the budget compact process that guides central investments in the colleges [and] … New investments to foster collaboration across research, training, and graduate education functions." Bozeman and Boardman (2003) suggested using seed money

> *as a way of diffusing competition over center funds. If there is no central decision making, then it is difficult to develop a center research niche or a strategic research portfolio. One of the ways to develop a strategic approach to research but, at the same time, mitigate conflict is to have a set-aside for competitive award, perhaps complete with peer review.*

One caveat about funds for IDR initiatives emerged strongly from Smithsonian interviewees—it should not come out of existing unit or department budgets. This point was acknowledged in the discussion about funding sources in a Smithsonian proposal for a new NMNH center:

> *Funding for such a center was a concern of most of the Chairs, several of whom felt that such a center could reduce funding for departmental activities. Initial funds will have to be provided by SI/NMNH, but we do not view this as a zero-sum game. To be successful the center will need external funding including a combination of NSF, NASA, and other targeted grants. We also encourage the museum administration to include Center initiatives among Development activities.*

- ***Build in—and on—early successes.*** A common change strategy that some interviewees and the literature espoused was finding things that could be carried out quickly, easily, and without a lot of resources in the early stages of a new initiative, because "If things turn out successful … people will usually go toward success." Examples were bringing performance evaluation criteria into line with the nature of collaborative and interdisciplinary research, changing a thesis requirement to permit multi-authored theses, and leveraging resources through strategic partnerships.

Build Collaboration and IDR Capacity

As noted earlier, not all organizations have adequate capacity to support collaboration and IDR, be it the culture, evaluation measures, risk acceptance, support for cross-department or unit interaction, etc. Interviewees described a range of ways in which their organizations had to create or strengthen their capacity to foster and sustain collaboration and IDR. Techniques included: developing a system for reviewing IDR proposals and evaluating collaborative and interdisciplinary research; creating common physical spaces and facilities and means of linking

scientists to one another; establishing reward systems and incentives, monetary and other; providing better administrative support, tailored to the needs of interdisciplinary science; giving staff flexibility to work at different units; and paying attention to IDR skill building.

Address the Silos and Inadequate Communication

What one scientist hated about the university's bureaucratic structure was that the deans saw their role as sequestering as many resources as they could for their own colleges; they saw other colleges only as competitors and not co-operators. In contrast,

> *For me, the level was wanting the university to be good. You want the university to have a good reputation, to provide the resources to its faculty that allow them to achieve the most that they possibly can. That means that sometimes you have to improvise, realize that while the College of Engineering won this one, somebody else will win it next time. When new positions come up and you are fighting for those positions, you are going to win some and lose some.*

Perhaps one of the most challenging aspects of organizational change at academic-oriented organizations is breaking down the rigid divisions across departments, schools, etc. The universities that have set up IDR centers have, as discussed, used a range of approaches: developing new buildings, labs, and common spaces designed to maximize interaction; allowing researchers to remain within their home camp while also working in the new IDR camp; arranging regular social get-togethers; facilitating the natural inclination of younger researchers to be collaborative and cross boundaries; sharing staff across departments/units through joint appointments and sabbaticals; including collaboration and IDR in performance plans and performance evaluation criteria; providing financial incentives at the individual and unit/department level; establishing varied means of communication and information-sharing across boundaries; forming cross-department/ unit teams, working committees, and advisory groups; and giving priority access to funds for post-docs. The University of Washington developed a board of senior professors which "harnesses university-wide support, serves as a resource for suggestions for potential faculty for the project, and protects team from unsympathetic senior faculty in departments from which the team might want to recruit" (Saxberg and Newell, n.d.).

Bozeman and Boardman (2003) commented that "it is easy enough for participating institutions to become absorbed by local concerns, with the result that the joint concerns of the collaboration do not receive ample attention. It is important to provide multiple communications opportunities among multiple communications media."

The 2002 NAPA study described a number of mechanisms for breaking down silos and bringing diverse scientists together. Aside from the traditional means of lectures and workshops, the following were mentioned: bringing researchers from various disciplines together to create a "coffee table" book for the public that described the organization's diverse science; establishing two principal investigator positions that would receive funding as long as the incumbents worked on cross-organizational projects; and establishing "virtual" organizations based on long-term interdisciplinary themes or initiatives that might attract diverse researchers (National Academy of Administration, 2002).

A number of the comments that emerged from the 2002 survey of Smithsonian biologists focused on the need to fix the very inadequate communications across the Institution. For example, "There is currently no clear SI-facilitated mechanism for interaction, or communication among SI scientists. How can you find out how many scientists are working in the geographic area and what they are doing?" This scientist suggested a centrally facilitated mechanism to improve communications. Other ideas were "periodic get-togethers between selected people from other Bureaus to let loose what they do and why they find it interesting," "workshops and meetings uniting scientists with common research interests," and a listserv—"For the seeds of such initiatives to be planted, we should start with a list, updated annually, of the research projects currently being worked on by SI scientists, and this list should be e-mailed to every scientist."

Eliminate the Culture of Winners and Losers

One interviewee spoke of a highly respected manager at the Smithsonian who got key leaders from across the Institution to sit down and negotiate resource allocation. They would agree who would get their request this year, and who would get it the next year, and so forth. An external interviewee talked about the role a strategic plan plays: "We learned it's not so much the plan … it's the process. By making sure they sit down around the table and discuss what they are trying to do, what's the bigger vision, which direction are we marching [in]." Commenting on these types of approaches, a Smithsonian researcher observed, "We have never done it that way. We are not set up to do it that way. From the beginning we are set up to compete with our neighbors."

An external museum interviewee offered that a culture of competition is generally caused by people who are threatened by change, and the best scientists are not like that. The best scientists are always reaching out to see how they can leverage things up. A younger Smithsonian scientist observed that everybody wants their own little piece of the pie so they can hire a post doc or a technician—

How do we share a technician, or how do we build more collaboration that's more distributed as opposed to getting one grant or one post-doc every year and they distribute it amongst [departments], and usually you get one, and it goes to a particular person as opposed to being more distributed across the department?"

Cultivate Trust and Respect for Diversity

In setting up interdisciplinary grant programs at NSF, project managers described cultural differences across the different directorates and then across the researchers in different disciplines. "So we had to deal with the differences, and actually it wasn't dealing with as in bulldozing over them, but rather bringing out the best practices." This was accomplished with a team comprised of representatives from all directorates and programmatic offices of the foundation. Success was attributed to the trust that grew among team members—

I think there is a tendency for protecting ourselves, and that's what leads to silos. But we were successful in breaking that and the reason why those walls dissolved was because there was a trust among the team members across all the directorates. If you can persuade people, get them to really believe down deep that you're really trying to look past your turfy kinds of interests and to do the right thing for the global program, if people believe that, then they will follow you and buy into that culture.

Many Smithsonian interviewees talked about the lack of cooperation among science units stemming from insular attitudes and years of built-up ill-will—

As soon as you detect disrespect on the part of people you're talking to, that's what they get back. So you could start with a little bit of mutual respect, with everyone understanding what everybody else's job is. And I just don't see that, that's one of the failures. The one thing that the administration could do is simply to tell everyone who works for them, you're going to come back with win-win solutions.

One interviewee commented,

We are an extremely tribally divided community. We have an idea of a common identity, we are the Smithsonian, but we are a tribal people with very little knowledge of each other. A lot of the problems come from ignorance, plain and sheer ignorance of who other people are, how they work, and what their rules are. Ignorance translates into arrogance because we are trying to impose our regulations on other people.

Another person spoke of the importance of building diverse teams—"gender balance, career stage, geographic distribution … people from lots of research viewpoints … interdisciplinary."

Still another called for having different disciplines represented on steering committees or using "rotating leadership … even rotating the positions of science fields on the list."

Be Flexible

Interviewees stressed the need to balance an overall strategy and plan with the need for flexibility and an ability to adapt to rapid changes in science with new tools and new ways of thinking. Talking about the development of an NSF program, one interviewee said, "We had to have a uniform process, the review process, the principles, values, spirit of the program—that had to be uniform without sacrificing the flexibility and recognizing the different cultures and best practices across the foundation."

Choose the Right Start-up Timeframe

One organization opted for a "shock approach" because of a short timeframe in which to institute changes, but also because the organization's leadership believed that "a team will coalesce when under high stress." The working group, which started from scratch, had two months to complete the program design and implementation plan. "Once people bought into the idea of what you are trying to do, everybody knew this was all hands on deck. There was no time for pettiness and the sort of obstacles that often show up when people have too much time on their hands." The group also established a valuable rule:

> *Problems were not allowed—just bring solutions because when somebody raises a problem, more often than not they have a solution in their back pocket. All of these are our colleagues; the team as a whole has many hundreds of hours of program management experience, they are all high-powered, there is a reason why they were appointed for the task, so negative sentences were not allowed.*

Verdin and Van Heck (in Conceição, et al., 2000) discussed a shock versus a slow and steady approach to integrating knowledge across dispersed units of three corporations active in Europe. Considerations that emerged were "the degree of consensus needed for change … the pressure of the market and how powerful the resistance will be." An interesting conclusion of the study was that a medium-paced process worked least well. Whatever path is chosen, the authors emphasized the importance of management preparing the way: "Whichever path is chosen, it has to be carefully prepared and monitored. In the absence of such preparation, the quick route becomes dirty, while the slow and steady route involves high costs for little result, leading to lots of frustration and even more resistance to change in the future." Such preparation includes involving those "who will be most involved in producing the intended results or affected by them" to achieve buy-in, and building a learning culture.

Other interviewees recommended a gradual process in which participation was voluntary, based on the theory that committed scientists were more likely to succeed, and their success would draw others in. Along the same lines, an interviewee told how his agency had come, based on lessons learned, to recognize the need for a clear-cut start-up phase with sufficient time to lay the required foundation:

> *It takes the first year to do the management, to get ready in terms of management, get organized, and get all the people hired. We require that they [the centers, each of which consists of several partners] have a [full]-time education director or coordinator, and a person who manages the day-to-day activities 100% of their time. That person is not the center director … but a different person who will coordinate throughout the partnerships and at the lead institution. It takes awhile to get grounded, to get well-organized.*

Hire the Right People

One Smithsonian scientist offered this strategy –"the way you get more collaborations is to hire more people who want to collaborate and who think about what they do as solving problems rather than becoming an expert on something. It's more a frame of mind of the researchers than it is any sort of institutional structure." A university center director said, "We just simply don't recruit faculty who aren't interested in interdisciplinary research and scholarship." This university also pointed to the importance of the leadership in influencing culture. At his university, the vast majority of faculty had been hired during the past 15 years when an IDR proponent had been in the leadership position—"That means you have somebody who's in the provost's office who is singing from the interdisciplinary hymnal all the time. That ends up having a pervasive effect across the institution.

Reward Contributions to Institutional Goals

One science manager reflected that there is too much history of the Smithsonian functioning like an academic institution that lets everybody do their own thing. While scientists should have a high degree of freedom, sometimes they may also be asked to do some things that they may not particularly want to do but which are good for the organization. People need to expect to contribute to the Institution and its goals—

> *I'm totally into the independent scientist thing and creativity and scientific freedom and so on, but that doesn't mean you get to do whatever you want. That isn't the same thing … Most of us are pretty proud of being part of the Smithsonian and have got to be willing to contribute something to making it great. I don't think it's doing your own thing all the time and being great for yourself. There needs to be some other level of expectation, and*

most people will respond favorably to that if the right person puts the expectation forward and then either rewards or penalizes appropriately.

Appendix A. Bibliography

Ackerman, Mark, Volkmar Pipek, and Volker Wulf, eds. 2003. *Sharing Expertise: Beyond Knowledge Management.* Cambridge: The MIT Press.

Aldrich, Howard, and Diane Herker. 1977. Boundary Spanning Rroles and Organization Structure. *The Academy of Management Review* Vol. 2, No. 2, April, 217-30.

Angier, Natalie. 2008. "Curriculum to Unite Art and Science." *New York Times*, May 27.

Atkinson, John, and Malcolm Crowe, eds. 2006. *Interdisciplinary Research: Diverse Approaches in Science, Technology, Health and Society.* Chichester: John Wiley & Sons, Ltd.

Bisby, Frank A., Yuri R. Roskov, Thomas M. Orrell, David Nicolson, Luvie E. Paglinawan, Nicolas Bailly, Paul M. Kirk, Thierry Bourgoin, and Jorrit van Hertum, eds. 2008. *Species 2000 & ITIS Catalogue of Life: 2008 Annual Checklist.* The University of Reading.

Borden, Carla M., ed. 1992a. "Knowledge Collaboration in the Arts, the Sciences, and the Humanities: Edited Excerpts from a Smithsonian Seminar Series—Part 2: The Sciences." *Knowledge* Vol. 13, No. 4, June.

_____. 1992b. "Knowledge Collaboration in the Arts, the Sciences, and the Humanities: Edited Excerpts from a Smithsonian Seminar Series—Part 3: The Humanities and Social Sciences." *Knowledge* Vol. 14, No. 1, September.

_____. 1991. "Knowledge Collaboration in the Arts, the Sciences, and the Humanities: Edited Excerpts from a Smithsonian Seminar Series—Part 1: The Arts." *Knowledge* Vol. 13, No. 2, December.

Bozeman, Barry, and P. Craig Boardman. 2003. *Managing the New Multipurpose, Multidiscipline University Research Centers: Institutional Innovation in the Academic Community*. IBM Center for the Business of Government. November.

Bozeman, Barry, and Sooho Lee. 2003. *The Impact of Research Collaboration on Scientific Productivity.* Paper prepared for presentation at the Annual Meeting of the American Association for the Advancement of Science, February.

Briant, Clyde L. (Vice President for Research). 2007. Interdisciplinary Research at Brown University. Institutional Statements on Interdisciplinarity. Consortium on Fostering Interdisciplinary Inquiry. August 1. https://www.myu.umn.edu/metadot/index.pl?id=3605679&isa=Category&op=show.

Brooks, Daniel P., and Eric R. Hoberg. 2006. "Systematics and Emerging Infectious Diseases: From Management to Solution." *The Journal of Parisitology*. Vol. 92, No. 2, 426-29.

Calado, Jorge C.G. 2000. "Art and Space." In *Science, Technology, and Innovation Policy: Opportunities and Challenges for the Knowledge Economy*, 547-59. International Series on Technology Policy and Innovation. Pedro Conceição, David V. Gibson, Manuel V. Heitor, and Syed Shariq, eds. Westport: Greenwood.

Cech, Tom. 2008. A Season for Change. *HHMI Bulletin* Vol. 21, No. 2, May.

Clark, Beth. n.d. Letter from Laurie Beth Clark, Vice Provost, Faculty and Staff, Office of the Provost and Vice Chancellor for Academic Affairs, University of Wisconsin-Madison, to Gail Dubrow, Dean and Vice Provost, The Graduate School, University of Minnesota-Minneapolis. Institutional Statements on Interdisciplinarity. Consortium on Fostering Interdisciplinary Inquiry. https://www.myu.umn.edu/metadot/index.pl?id=3605679&isa=Category&op=show.

Commission on Fostering Interdisciplinary Inquiry. n.d. Report for the Consortium of Ten Public and Private Research Universities Dedicated to Fostering Interdisciplinary Activity. University of Minnesota, The Graduate School. Unpublished.

Commission on the Future of the Smithsonian Institution. 1995. *E Pluribus Unum: This Divine Paradox: Report of the Commission on the Future of the Smithsonian Institution*. May.

Committee on Institutional Cooperation: Twelve Universities Collaborating. http://www.cic.uiuc.edu. Accessed May 19, 2008.

Conceição, Pedro, David V. Gibson, Manuel V. Heitor, and Syed Shariq, eds. 2000. *Science, Technology, and Innovation Policy: Opportunities and Challenges for the Knowledge Economy*. International Series on Technology Policy and Innovation. Westport: Greenwood.

Cordell, Linda S., Leslie Aiello, Jane E. Buikstra, Ira Jacknis, and Jason Baird Jackson. 2007. External Review Committee Report for the National Museum of Natural History, Department of Anthropology, Smithsonian Institution, June.

Dean, Cornelia. 2008. "If You Have a Problem, Ask Everyone." *The New York Times*, July 22.

Deutsch, Claudia H. 2007. "A Threat So Big, Academics Try Collaboration." *The New York Times*, December 25.

Dollinger, Marc J. 1984. Environmental Boundary Spanning and Information Processing Effects on Organizational Performance. *Academy of Management Journal* Vol. 27, No. 2, 351-68.

Dubrow, Gail, Vice Provost and Dean of the Graduate School. Fostering Interdisciplinary Activity at University of Minnesota: A Brief Overview. Institutional Statements on Interdisciplinarity. Consortium on Fostering Interdisciplinary Inquiry. https://www.myu.umn.edu/metadot/index.pl?id=3605679&isa=Category&op=show.

Ducklow, Hugh W., James R. Gosz, Diane Ebert-May, and Scott W. Nixon. 2005. Review of the Smithsonian Environmental Research Center Roles in Research Networks. Review Committee report, June 3.

Duke Institute for Genome Sciences & Policy (IGSP). Strategic Plan 2007.

Epton, S.R., R.L. Payne, and A.W. Pearson, eds. 1983. *Managing Interdisciplinary Research*. Chichester: John Wiley & Sons, Ltd.

Erickson, Mark. 2005. *Science, Culture and Society: Understanding Science in the 21st Century*. Cambridge, UK: Polity Press.

Erwin, Douglas H. 2004. Proposal to the National Science Foundation for a National Center for Synthesis in Biological Evolution. National Museum of Natural History, Smithsonian Institution.

European Science Foundation. Various websites. http://www.esf.home.html
Accessed May 16, 2008.

Fennell, Mary L., and Jeffrey A. Alexander. 1987. Organizational Boundary Spanning in Institutionalized Environments. *Academy of Management Journal* Vol. 30, No. 3, September, 456-76.

Group on Earth Observations (GEO). 2007. *The Full Picture*. "Smithsonian Institution Global Earth Observatories," 82-84.

Graybill, Jessica K., Sarah Dooling, Vivek Shandas, John Withey, Adrienne Greve, and Gregory L. Simon. 2006. "A Rough Guide to Interdisciplinarity: Graduate Student Perspectives." *BioScience* Vol. 56, No. 9, September, 757-63.

Guston, David H., and Daniel Sarewitz, eds. 2006. *Shaping Science and Technology Policy: The Next Generation of Research*. Madison: The University of Wisconsin Press.

Gwinn, Nancy E., and Constance Rinaldo. 2009. The Biodiversity Heritage Library: Sharing Biodiversity Literature with the World. *Official Journal of the International Federation of Library Associations and Institutions* 35, 25-34.

Hacket, Edward J., and Diana Rhoten. 2008. *The Snowbird Charette: An Experimental Study of Interdisciplinary Collaboration in the Design of Environmental Research.* Social Science Research Council White Paper. New York, NY.

Haseltine, Sue. 2008. DOI-USGS Disease Capabilities: Understanding the Environmental and Wildlife Context of Disease. U.S. Department of the Interior, U.S. Geological Survey. Presented at the Office of Science and Technology Policy (OSTP) meeting, February 26.

Hays, Timothy. 2008. Research, Condition, and Disease Categorization (RCDC) Project at the National Institutes of Health. Office of Portfolio Analysis and Strategic Initiatives, Office of the Director, National Institutes of Health. Presented at the Office of Science and Technology Policy (OSTP) meeting, February 26.

Hearn, Kelly. 2008. Smithsonian's slippery slope. *The Washington Times,* September 14.

Heifetz, R., *Leadership Without Easy Answers*, Cambridge, MA: Belknap Press, 1994, as cited in Snyder, William M., and Xavier de Souza Briggs. 2003. "Communities of Practice: A New Tool for Government Managers." IBM Center for the Business of Government Managers: Collaboration Series. November.

Hellinger, Steve, and Doug Hellinger. 2008. *The Harmonization of Wildlife Habitat and Human Livelihood Imperatives: Addressing Common Root Causes Through a Participatory, Collaborative and Sustainable Approach.* The Development GAP.

Henson, Pamela M. 2008. Interdisciplinary Offices at the Smithsonian. Report prepared for the Office of Policy and Analysis. Smithsonian Archives Institutional History Department, Smithsonian National Archives, August.

Hinds, Pamela, and Sara Kiesler. 1995. Communication Across Boundaries: Work, Structure, and the Use of Communication Technologies. *Organization Science* Vol. 6, No. 4, July-August, 373-93.

Hollingsworth, J. Rogers, Karl H. Muller, and Ellen Jane Hollingsworth. 2008. "The End of the Science Superpowers." *Nature*. Vol. 454, July 24, 412-13.

Howard Hughes Medical Institute. 2008. "HHMI collaborative innovation awards help bring researchers together to tackle new ideas. November 20.

_____. 2006. HHMI's Experiment in Changing Scientific Culture. 2006. *Research News*, April 20.

Issues Related to Interdisciplinary Inquiry at UC Berkeley. 2007. Institutional Statements on Interdisciplinarity. Consortium on Fostering Interdisciplinary Inquiry, October 1. https://www.myu.umn.edu/metadot/index.pl?id=3605679&isa=Category&op=show.

Jones, Benjamin F., Stefan Wuchty, and Brian Uzzi. 2008. "Multi-University Research Teams: Shifting Impact, Geography, and Stratification in Science." *Science*. Vol. 322, No. 5905, November 21, pp. 1259-62.

Kafatos, Fotis C., and Thomas Eisner. 2004. "Unification in the Century of Biology." *Science* Vol. 303, No. 5662, February, 1257.

Kitt, Margaret M., MD, MPH. 2008. Health Information Sharing. National Institute for Occupational Safety and Health. Emergency Preparedness and Response Office. Presented at the Office of Science and Technology Policy (OSTP) meeting, February 26.

Klein, Julie Thompson. 2005. "Interdisciplinary Research in Science and Technology: National Reports Give Evidence of Changing Dynamics." *Association for Integrative Studies Newsletter* 27, October, 4-7.

_____. 1998. "Notes Toward a Social Epistemology of Transdisciplinarity." *Bulletin Interactif du Centre International de Recherches et Études Transdisciplinaires* No. 12, February.

Kurilla, Michael G., MD. 2008. Interagency Disease Information Sharing. National Institute of Allergy and Infectious Diseases, National Institutes of Health. Presented at the Office of Science and Technology Policy (OSTP) meeting, February 26.

Lagace, Martha. 2006. "Open Source Science: A New Model for Innovation." Q&A with Karim R. Lakhani. Harvard Business School Working Knowledge, November 20.

Lakhani, Karim R., Lars Bo Jeppesen, Peter A. Lohse, and Jill A. Panetta. 2007. *The Value of Openness in Scientific Problem Solving*. Harvard Business School Working Paper 07-050.

Lattuca, Lisa R. 2001. *Creating Interdisciplinarity: Interdisciplinary Research and Teaching among College and University Faculty*. Nashville: Vanderbilt University Press.

Leshner, A. 2004. "Science at the Leading Edge." *Science* Vol. 303,729.

Lok, Corie. 2008. "Harvard Under Review." *Nature* Vol. 454, August 7.

Lyal, Chris, Paul Kirk, David Smith, and Richard Smith. 2008. "The Value of Taxonomy to Biodiversity and Agriculture." *Biodiversity: Journal of Life on Earth* Vol. 9, Nos. 1 and 2.

Lyall, Catherine, and Laura Meagher. 2007. A Short Guide to Building and Managing Interdisciplinary Research Teams. The University of Edinburgh, Institute for the Study of Science Technology and Innovation. ISSTI Briefing Note No. 3, September.

Lyall, Catherine, Ann Bruce, Joyce Tait, and Laura Meagher. 2007. Short Guide to Reviewing Interdisciplinary Research Proposals. Institute for the Study of Science Technology and Innovation,The University of Edinburgh. ISSTI Briefing Note No. 2, May.

Lyall, Catherine, Laura Meagher and Joyce Tait. 2008. A Short Guide to Supervising Interdisciplinary PhDs. The University of Edinburgh, Institute for the Study of Science Technology and Innovation. ISSTI Briefing Note No. 4, January.

Mace, Georgina M. 2004. "The Role of Taxonomy in Species Conservation." *Philosophical Transactions of the Royal Society* (London) No. 359, March 23, 711-19.

Mapel, Michelle. 2008. *Smithsonian Institution: An Analysis of Partnerships in Corporate Social Responsibility*. White Paper, July 22.

Marty, Gail. 2008. Cooperation as a Key to Achieving Excellence; Leading Research Universities Cooperate to Remove Barriers to Interdisciplinary Scholarship. University of Minnesota, The Graduate School website, http://www.grad.umn.edu/news-events/cfii_recap.html. Accessed March 30, 2009.

Metzger, Norman, and Richard N. Zare. 1999. "Science Policy: Interdisciplinary Research: from Belief to Reality." *Science* Vol. 283, No. 542, January, 642-43. http://www.sciencemag.org/cgi/content/full/283/5402/642.

Minton-Package, Corinne. 2005. "Profiles in Leadership: Elias A. Zerhouni, M.D." *The Business of Government.* http://www.businessofgovernment.org.

Murray, Suzan, DVM, DACZM, and Timothy Walsh, DVM, DACVP. 2008. Smithsonian's Reporting of Health and Disease. Presented at the Office of Science and Technology Policy (OSTP) meeting, February 26.

National Academy of Public Administration. 2002. *Scientific Research at the Smithsonian Institution.* October.

National Academy of Sciences. 2007a. *Innovation Inducement Prizes at the National Science Foundation*. Committee on the Design of an NSF Innovation Prize, National Research Council. National Academies Press.

_____. 2007b. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology. National Academies Press.

_____. 2004. *Facilitating Interdisciplinary Research*. Committee on Facilitating Interdisciplinary Research. National Academies Press. http://books.nap.edu/openbook.php?record_id=11153&page=114.

National Institutes of Health. 2008. The NIH Roadmap for Medical Research. http://www.nihroadmap.nih.gov. Accessed summer 2008.

_____. 2007. NIH Launches Interdisciplinary Research Consortia." *NIH News*, September 6. http://www.nih.gov./news/pr/sep2007/od-06.htm.

National Research Council. 2008. *The Role of Theory in Advancing 21st Century Biology: Catalyzing Transformative Research*. Committee on Defining and Advancing the Conceptual Basis of Biological Sciences in the 21st Century. http://www.nap.edu/catalog/12026.html.

_____. 2003. *Funding Smithsonian Scientific Research*. http://www.nap.edu/catalog/10540.html.

National Science Board. 2007. *Enhancing Support of Transformative Research at the National Science Foundation*. NSB-07-32. May 7.

National Science Foundation. 2008. Websites for the following programs: Cyber-Enabled Discovery and Innovation Program (CDI); Integrative Graduate Education and Research Traineeship (IGERT); Partnerships for Enhancing Expertise in Taxonomy (PEET); Research Experiences for Undergraduates (REU); and Science and Technology Centers (STC) Integrative Partnerships. Accessed Fall 2008.

_____. 2006. Investing in America's Future: Strategic Plan FY 2006-2011. September.

National Science and Technology Council. 2008. *Science in 5 Dimensions: Harnessing the Power of Digital Data for Science and Society*. Report of the Interagency Working Group on Digital Data to the Committee on Science of the National Science and Technology Council, April.

Office of Science and Technology Policy. 2009. 2009 Federal R&D Budget Highlights.

Page, Scott. 2007. "Diversity Should Power Science." *Science Progress*, October 4.

Palmer, Carole L. 2001. *Work at the Boundaries of Science: Information and the Interdisciplinary Research Process*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Payton Adina, and Mary Lou Zoback. 2007. "Crossing Boundaries, Hitting Barriers: Interdisciplinary Research May Be Lauded, But It's Not Yet Rewarded." *Nature* Vol. 445, February 22, 950.

Perrone, Vincenzo, Akbar Zaheer, and Bill McEvily. 2003. Free to Be Trusted? Organizational Constraints on Trust in Boundary Spanners. *Organization Science* Vol. 14, No. 4, July-August, 422-39.

Pines, Maya. 2003. "Bringing the Sciences Together." *HHMI Bulletin* June, 24-28.

Rhoten, Diana. 2004. "Interdisciplinary Research: Trend or Transition." *Items & Issues* Vol. 5, No. 1, 6-11

_____. 2003. *A Multi-Method Analysis of the Social and Technical Conditions for Interdisciplinary Collaboration.* Final Report to the National Science Foundation. San Francisco, CA: The Hybrid Vigor Institute.

Rhoten, Diana, and Stephanie Pfirman. 2007. "Women, Science and Interdisciplinary Ways of Working." *Inside Higher Ed*, October 22.

Rubin, Gerald M. 2008. Sowing Seeds of Collaboration. *Uncommon Curiosity*. 2008 Annual Report. Howard Hughes Medical Institute.

Rubinoff, Ira, Eldredge Bermingham, Charles Lydeard, and Stuart J. Davies. 2007. "Smithsonian Institution Global Earth Observatories." In *The Full Picture*. Group on Earth Observatories. Geneva, Switzerland.

Rubinstein, Albert H. 1964. Organizational Factors Affecting Research and Development Decision-Making in Large Decentralized Companies. *Management Science* Vol. 10, No. 4, July, 618-33.

Russell, M.G. 1983. Peer Review in Interdisciplinary Research: Flexibility and Responsiveness. In *Managing Interdisciplinary Research*, S.R. Epton, R.L. Payne, and W.W. Pearson, eds. Chicester: John Wiley & Sons.

Saxberg, B.O., and W.T. Newell. n.d. "Interdisciplinary Research in the University: Need for Managerial Leadership." University of Washington, Seattle.

Schindel, David E. 2002. "NSF Europe Office Update 02-02: The Growth of European Research Center Programs," February 11.

Sharp, J.M. n.d. "A Method for Peer Group Appraisal and Interpretation of Data Developed in Interdisciplinary Research Programmes." Gulf Universities Research Consortium. Houston.

Smithsonian Institution. 2009. Installation Remarks by Secretary Wayne Clough, January 26.

_____. 2006. Smithsonian Directive 204. *Evaluation Guidelines for Professional Accomplishments*, November 30.

_____. 2005a. Smithsonian Directive 701. *Smithsonian Institution Academic Appointments with Stipend*, revised July 29.

_____. 2005b. Exploring the Concept of a Smithsonian Planetary Science and Education Center: A Feasibility Study Presented to the Under Secretary for Science, May 24. Draft.

_____. 2001. Smithsonian Directive 205. *Research Associates*, revised June 7.

_____. 1989. The Wholeness of Knowledge: Interdisciplinary Studies at the Smithsonian. Pamphlet. June.

Smithsonian Institution. Diversity of Life Theme Team. n.d. Preserving Life's Diversity: The Biology of Extinction-Prone Species. Proposal for a Smithsonian Center for Conservation Biology.

Smithsonian Institution. Executive Committee of Scientists Throughout the Smithsonian. 2006. *Pacific Science Network.* White Paper, April.

Smithsonian Institution. Harvard-Smithsonian Center for Astrophysics. 2007. *Science Strategic Plan*, March 28. Draft.

Smithsonian Institution. Museum Conservation Institute. 2007. *Our Next 10 Years: MCI Strategic Plan 2007-2017*, January.

Smithsonian Institution. National Air and Space Museum. 2006. NASM Professional Accomplishments Evaluation Committee, May 16.

_____. n.d. Building Our Legacy: Smithsonian Institution National Air and Space Museum Strategic Plan 2008-2012.

Smithsonian Institution. National Museum of Natural History. 2008. Professional Accomplishments Evaluation Plan. Office of the Associate Director for Research and Collections, December 10.

_____. 2007. *CCRE Reports 2006.* Caribbean Coral Reef Ecosystem Program, August.

_____. 2005. Integrative Centers at the National Museum of Natural History. Report by a Taskforce on Integrative Centers.

_____. 2004. *Understanding Our World: Strategic Plan for the National Museum of Natural History 2004-2009*.

_____. 2001. Memorandum of Understanding between the USGS Patuxent Wildlife Research Center and the National Museum of Natural History, January.

_____. 2000. The Project on Diversity in the Sierra Tarahumara Concept Paper.

Smithsonian Institution. National Zoological Park. 2006a. *Moving Forward: the Next Ten Years at the National Zoo*.

_____. 2006b. *Zoo Directive ZD 235: Non-Employee Affiliates*, revised October 12.

_____. 2003. Professional Accomplishments Evaluation Committee (PAEC). NZP General Memorandum No. 230, revised April 1.

Smithsonian Institution. National Zoological Park. National Zoological Park (NZP) Science Council. 2008. *NZP Research Science and Administrative Procedures: Improving Our Productivity*, July 23.

Smithsonian Institution. Office of Fellowships. 2008. *Unit Appointments.* December 17. Revised.

Smithsonian Institution. Office of Policy and Analysis. 2007. Overview of Undergraduate Programs Relating to Conservation and Sustainability. February 7.

_____. 2005. *Concern at the Core: Managing Smithsonian Collections.* Appendix E: Interagency Facility. April.

Smithsonian Institution. Office of Research, Training, and Services. n.d. *Smithsonian Opportunities for Research and Study in History, Art, and Science. 2007-2008.*

Smithsonian Institution. Office of Sponsored Projects. 2009. Proposal and Award Activities Annual Report Fiscal Year 2008.

Smithsonian Institution. Office of the Under Secretary for Science. 2004. Marine Science Network.

Smithsonian Institution. Smithsonian Astrophysical Observatory. 2003. HR: Professional Accomplishment Evaluation Committee (PAEC), June 26, revised.

Smithsonian Institution. Smithsonian Center for Materials Research and Education. 1997. Evaluation Plan for Professional Accomplishments of Research Staff. February 1.

Smithsonian Institution. Smithsonian Environmental Research Center. 2005. Review of the Smithsonian Environmental Research Center Roles in Research Networks. June 2-3.

_____. 2003. Policy for Professional Reviews of Principal Investigators. September 2, 1998. Updated terminology October 10, 2003.

_____. n.d. *Strategic Plan 2005-2010*.

Smithsonian Institution. Smithsonian Tropical Research Institute. 2006. An Assessment of the Scientific Productivity of the Staff of the Smithsonian Tropical Research Institute. Visiting Committee Report, June.

_____. n.d. *Strategic Plan 2008-2013*.

_____. n.d. STRI Scientific Staff Professional Evaluation System Description for External Reviewers.

Smithsonian Institution. Under Secretary for Science. n.d. *Science Matters: Priorities and Strategies 2005-2010*.

Smithsonian Science Commission. 2002. *Report of the Smithsonian Institution Science Commission.* Presented to the Board of Regents of the Smithsonian Institution and the Secretary of the Smithsonian Institution, December.

Snyder, William M., and Xavier de Souza Briggs. 2003. *Communities of Practice: A New Tool for Government Managers.* IBM Center for the Business of Government Managers: Collaboration Series, November.

Stocks, Gabriela, Lisa Seales, Franklin Paniagua, Erin Maehr, and Emilio M. Bruna. 2008. "The Geotropical and Institutional Distribution of Ecological Research in the Tropics." *Biotropica* Vol. 40, No. 4.

Tait, Joyce, and Catherine Lyall. 2007. Short Guide to Developing Interdisciplinary Research Proposals. Institute for the Study of Science Technology and Innovation, University of Edinburgh. ISSTI Briefing Note No. 1, March.

Theil, Stefan. 2008. "The Campus of the Future." *Newsweek*, August 18-25.

Tress, B., G. Tress, and G. Fry. 2003. Potential and Limitations of Interdisciplinary and Transdisciplinary Landscape Studies. In B. Tress, G. Tress, A. van der Walk, and G. Fry, eds. *Interdisciplinary Landscape Studies: Potential and* Limitations, 182-91. Wageningen (The Netherlands): Delta Program.

Tushman, Michael L., and Thomas J. Scanlan. 1981a. Boundary spanning individuals: their role in information transfer and their antecedents. *The Academy of Management Journal* Vol. 24, No. 2, June, 289-305

_____. 1981b. Characteristics and External Orientations of Boundary Spanning Individuals. *The Academy of Management Journal* Vol. 24, No. 1, March, 83-98.

Tuunainen, Juha. 2005. Contesting a Hybrid Firm at a Traditional University. *Social Studies of Science* Vol. 35, No. 2, April, 173-210.

U.S. Department of the Interior. U.S. Geological Survey. 2007a. *Facing Tomorrow's Challenges—U.S. Geological Survey Science in the Decade 2007-2017*.

_____. 2007b. Understanding Ecosystems and Predicting Ecosystem Change. Fact Sheet 2007-3107. December.

U.S. Global Change Research Program (USGCRP). 2007. *Our Changing Planet. The U.S. Climate Change Science Program (CCSP) for Fiscal Year 2008.* A Report by the Climate Change Science Program and the Subcommittee on Global Change Research. A Supplement to the President's Budget for Fiscal Year 2008. http://www.usgcrp.gov/usgcrp/Library/ocp2008/default.htm.

U.S. Veterans Health Administration. Office of Research and Development. 2008. Activities that Support Interagency Sharing of Information About Diseases. Presented at the Office of Science and Technology Policy (OSTP) meeting, February 26.

Vastag, Brian. 2008. "Assembly Work: Graduate Students Can Be Key Links in Interdisciplinary Science, but Training Them for This Role Is a Challenge." *Nature* Vol. 453, May 15, 422-23.

Verdin, Paul, and Nick Van Heck. 2000. "Knowledge Integration Across Borders: How to Manage the Transition." In *Science, Technology, and Innovation Policy: Opportunities and Challenges for the Knowledge Economy*, Chapter 4. Pedro Conceição, David V. Gibson, Manuel V. Heitor, and Syed Shariq, eds. International Series on Technology Policy and Innovation. Westport: Greenwood.

Whitfield, John. 2008a. An Indifference to Boundaries. *Nature* Vol. 451, No. 21, February, 872-73.

_____. 2008b. Group Theory. *Nature News* Volume 455, No. 9, October 8, 720-23.

Zeder, Melinda. 2007. Smithsonian Network for Human Ecology Research and Education. Memo from Melinda Zeder to Cristián Samper and Ira Rubinoff. November 12.

Zepeda, Yolanda. 2007. Research Collaboration: Opportunities for CIC Universities. Committee on Institutional Cooperation. May 15.

Zerhouni, Dr. Elias. 2005. Interview with Dr. Elias Zerhouni, Director, NIH. The Business of Government Hour. IBM Center for the Business of Government, Arlington, VA. Monday, April 25.

Appendix B. List of Interviewees' Organizations

Smithsonian Institution

Museum Conservation Institute
National Air and Space Museum
National Museum of American History
National Museum of Natural History
National Postal Museum
National Zoological Park
Office of the Chief Information Officer
Office of Development
Office of Fellowships
Office of Human Resources
Office of Interdisciplinary Studies (former)
Office of International Relations
Office of Sponsored Projects
Office of the Under Secretary for Science
Smithsonian Astrophysical Observatory
Smithsonian Institution Archives
Smithsonian Environmental Research Center
Smithsonian Institution Libraries
Smithsonian Tropical Research Institute

External Organizations

Academia

Duke University, Nicholas School of the Environment, Institute for Genome Sciences & Policy, and National Evolutionary Synthesis Center (NESCent)
Harvard University, Center for the Environment
Massachusetts Institute of Technology, Operations Research Center
Stanford University, Bio-X Program
University of California, San Francisco, California Institute for Quantitative Biosciences (QB3)
University of California, Santa Barbara, National Center for Ecological Analysis and Synthesis (NCEAS)
University of Maryland, Behavior, Ecology, Evolution, and Systematics Program
University of Michigan, Life Sciences Institute
University of Minnesota, The Graduate School

Consortia

Consortium for the Barcode of Life
Consortium on Fostering Interdisciplinary Inquiry
Encyclopedia of Life

Federal Agencies

National Aeronautics and Space Administration
National Institutes of Health
National Institute of Standards and Technology
National Oceanic and Atmospheric Administration
National Science Foundation, Science and Technology Centers Program and Cyber-Enabled Discovery and Innovation Program
U.S. Department of Agriculture, Agricultural Research Service
U.S. Department of Defense
U.S. Department of Energy, Office of Science
U.S. Department of the Interior, Fish and Wildlife Service and U.S. Geological Survey
U.S. Environmental Protection Agency, Ecological Research Program

Museums

American Museum of Natural History
Field Museum
Museum of Comparative Zoology (Harvard University)

Private Research Organizations and Foundations

Janelia Farm (Howard Hughes Medical Institute)
H. John Heinz III Center for Science, Economics and the Environment
Indo-US Partnership for Science and Technology
National Academies, Keck *Futures Initiative*

Appendix C. Types of Interdisciplinary Research Entities

During the course of this study, the study team researched, and in many cases interviewed, a multitude of organizations that conduct or support interdisciplinary research (IDR). This appendix contains snapshots of 35 such organizations, including universities, museums, Federal government agencies, foundations, and private research organizations. To better understand the various types and functions of IDR entities, the study team grouped them into five broad, and to varying degrees overlapping, categories derived from the predominant purpose of the IDR organization, funding source, and location at which the research is conducted: pan-institutional integrative unit; incubator for commercial products; visionary/transformative research; Federally sponsored research; data synthesis center; and advocacy.

Pan-Institutional Integrative Unit

A number of universities, government agencies, and other research organizations have created internal centers, institutes, and other interdisciplinary research and/or teaching units that bridge the boundaries of established discipline-specific departments, schools, and offices. The bridging entities facilitate the conduct of interdisciplinary research and, in the case of higher education, expand the menu of courses and programs of studies offered to students. In addition, the critical mass created by the centers allows them to go after grants for a wider range of research opportunities than would otherwise be available. Many of the entities also have external partners. Beyond supporting research and education, the entities may provide important services to the larger professional/research community. IDR organizations established for this reason include:

- ***BEES (Behavior, Ecology, Evolution, and Systematics), University of Maryland.*** BEES is an interdepartmental, interdisciplinary graduate program at the University of Maryland, College Park, that offers courses on a variety of bio-related topics, with an emphasis on fundamental and applied research in the areas of behavior, ecology, evolution, systematics, and related disciplines. The program draws on faculty from across the University of Maryland, as well as from its collaborating partners, including the Smithsonian Institution, U.S. Department of Agriculture's Agricultural Research Service, the Patuxent Wildlife Research Center of the U.S. Department of the Interior's U.S. Geological Survey, and other organizations. http://www.life.umd.edu/grad/bees/index.html

- ***Center for the Environment, Harvard University (HUCE).*** HUCE encourages research and education about the environment and its many interactions with human society, recognizing that the complexity of problems facing our natural environment often requires collaborative investigation by scholars from different disciplines. HUCE faculty members and students are drawn from across the university and from diverse fields including chemistry, earth and planetary sciences, engineering and applied sciences, biology, public health and medicine, government, business, economics, religion, and the law. http://environment.harvard.edu/index.htm

- ***Center for Environmental Science, University of Maryland (UMCES).*** UMCES comprises the Maryland Sea Grant College (affiliated with the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce), Appalachian Laboratory in the upland reaches of Chesapeake Bay, Chesapeake Biological Laboratory near the mouth of the Patuxent River, and Horn Point Laboratory on Maryland's Eastern Shore. UMCES faculty and partners focus on the Chesapeake Bay region but also conduct environmental research around the world. Research results and other environment-related information are shared via the UMCES Integration and Application Network to facilitate solutions to environmental problems. UMCES offers undergraduate and graduate programs of study and provides significant outreach to the public and in support of K-12 education. http://www.umces.edu

- ***Center for Health and the Global Environment, Harvard University.*** The Center for Health and the Global Environment was founded in 1996 at Harvard Medical School to expand environmental education at medical schools and promote awareness of the human health consequences of global environmental change—that "human beings are an intimate part of the environment and that we cannot damage it without damaging ourselves." The center organizes programs for physicians, scientists, policy makers, the media, and the general public; its affiliates include Harvard-based centers and such varied external organizations as the Chef's Collaborative, New England Aquarium, and World Health Organization. http://chge.med.harvard.edu

- ***Center for Research in Environmental Sciences (CRES), Indiana University (IU).*** CRES was established to provide environmental scientists at IU with a collaborative and supportive environment to develop multidisciplinary projects that enhance research productivity, acquisition of external funding, and recruitment of top graduate students. CRES does not have permanent faculty but draws its members from a variety of other IU schools and departments. It offers its own academic programming, including an undergraduate major, several MS programs, and a PhD program. http://www.indiana.edu/~cres1/index.shtml

- ***Climate Change Science Program, Office of Science & Technology Policy (OSTP).*** The U.S. Climate Change Program was launched in February 2002 as a collaborative interagency venture under a new cabinet-level organization designed to improve government-wide management of climate science and climate-related technology development. Its specific role is to integrate the individual Earth and climate science missions of its participating agencies and departments, and their national and international partners, through a set of linked interdisciplinary research elements and cross-cutting activities. http://www.climatescience.gov

- ***Donald Bren School of Environmental Science and Management, University of California, Santa Barbara (UCSB).*** The Bren School was established to "play a leading role in researching environmental issues, identifying and solving environmental problems, and training research scientists and environmental management professionals." The school's faculty includes resident, affiliated UCSB, and external visiting members, and consists of a range of natural and social scientists, as well as law and business professors who contribute the intellectual perspectives of their professional schools. The school pursues its research and education mission at Bren Hall, a cutting-edge structure that was recognized as the "greenest" laboratory facility in the United States when it was completed in 2002. http://www.bren.ucsb.edu

- ***The Earth Institute, Columbia University.*** The Earth Institute's focus is environmental sustainability in the context of the world's challenges—"from rapid population growth and climate change to extreme poverty and infectious disease." The institute offers undergraduate/graduate and professional courses; under its auspices are cutting-edge research projects that involve over 850 scientists, students and post-doctoral fellows from more than 30 Columbia University-based research centers and programs. http://www.earthinstitute.columbia.edu

- ***Keck Center for Interdisciplinary Bioscience Training, Rice University.*** The Keck Center is the training arm of the Gulf Coast Consortium, comprised of six academic institutions that together seek to build interdisciplinary research teams and training programs in the biological sciences at their intersection with the computational, chemical, mathematical, and physical sciences, with the ultimate goal of applying resulting expertise and knowledge to the treatment and prevention of disease. The Keck Center currently has over 270 affiliated faculty engaged in ten training programs. http://cohesion.rice.edu/centersandinst/gcc/keck.cfm

- ***Nicholas School for the Environment, Duke University.*** The Nicholas School merged three units—the School of Forestry and Environmental Studies, Marine Lab, and Department of Geology (renamed the Division of Earth and Ocean Sciences)—to become

an interdisciplinary, university-wide academic department with three research divisions and 11 research centers and programs. Some of its 105 faculty are members of the school, while others are affiliated faculty members of other Duke departments. The Nicholas School offers undergraduate, masters, and PhD programs, and a variety of certificate and other executive-type professional education programs. http://www.nicholas.duke.edu

- ***Princeton Environmental Institute (PEI), Princeton University.*** PEI is an interdisciplinary center for environmental research, education, and outreach and is the locus for several high-profile research initiatives such as climate change, energy, conservation, biodiversity, water, and infectious diseases. It has 65 associated faculty members representing 17 academic disciplines and offers an undergraduate certificate program in environmental studies that brings together students from the natural sciences, engineering, social sciences, and humanities. http://web.princeton.edu/sites/pei/index.html

- ***Yale Institute for Biospheric Studies (YIBS), Yale University.*** YIBS is the focus for Yale's research and training efforts in the environmental sciences. It encompasses seven research centers and laboratories: Center for Earth Observation, Center for Eco-Epidemiology, Center for Ecology and Systematics of Animals on the Verge of Extinction (ECOSAVE), ECOSAVE Molecular Systematics and Conservation Genetics Laboratory, Center for Field Ecology, Center for Human and Primate Reproductive Ecology, Center for the Study of Global Change, and Earth System Center for Stable Isotope Studies. YIBS' interdisciplinary programs are guided by a faculty council that draws from schools and departments across Yale's campus, as well as an external advisory board with representatives from public and private sector research organizations, foundations, and industry. http://www.yale.edu/yibs

Incubator for Commercial Products Based on Interdisciplinary Research

The creation and marketing of commercial product "spin-offs" based on academic research are not uncommon at many academic organizations. Some pan-institutional centers, in addition to pure research and education goals of fostering interdisciplinary research and broadening curricula choices, have an explicit goal of facilitating the commercial "incubation" process, particularly in the biomedicine/pharmaceutical arena. Examples of these entities include:

- ***Biodesign Institute, Arizona State University.*** The university created the Biodesign Institute five years ago to provide a better way to address urgent problems and global challenges in biomedical research and development. Since its inception, it has generated

millions of dollars in grants from Federal agencies, private sources, and industry partners; launched hundreds of interdisciplinary research projects; received more than a dozen patents; and created several spin-off companies (two of which have since been acquired by multinational bioscience companies). Projects undertaken under the aegis of the Biodesign Institute have included vaccines, clean water technology, renewable energy, and systems to protect against epidemics/bioterrorism. http://www.biodesign.asu.edu

- ***Bio-X, Stanford University*.** Bio-X was organized at Stanford in 1998 to manage the pooling of interdisciplinary multischool resources in order to leverage Federal funding; optimize technology transfer to Stanford's Office of Technology Licensing; and prioritize research themes and resource objectives for donor interest. Bio-X funds investigators from across Stanford on a variety of "seed"-type projects (the academic equivalent of venture capital); offers fellowships to support visits by early- and mid-career scientists from outside Stanford; and, through the Bio-X Corporate Forum, builds relationships between companies and Stanford researchers. Bio-X has already stimulated more than 200 partnerships, resulting in numerous biomedical inventions that have made their way to the commercial market. http://biox.stanford.edu

- ***California Institute for Quantitative Biosciences (QB3), University of California, San Francisco*.** QB3, established in 2000, is an interdisciplinary partnership between UC Berkeley, UC San Francisco, and UC Santa Cruz. It facilitates interdisciplinary biomedical research and "bio-entrepreneurship" in the same manner as the Bio-X program at Stanford. QB3 does not offer graduate or undergraduate programs, but does sponsor professional workshops and seminars, almost all geared to the entrepreneurial aspects of biotechnology and biotech research. A subset of QB3, the "Garage," supports research-based biomedical startups and other commercial technology transfer. http://qb3.ucsf.edu

- ***Institute for Genomic Science & Policy (IGSP), Duke University*.** IGSP was established in 2003 based on the conviction that successful scientific advancement in genetics and genomics requires exploration and scholarship at the intersection of traditional disciplines in the life and health sciences, social sciences, and engineering, all embedded in a thorough discussion of the relevant social, ethical, legal, and public policy issues. IGSP has become an integrated interdisciplinary network of centers, research programs, and educational activities that together constitute a campus-wide approach to advancing the genome revolution and addressing its implications for science, health, and society. IGSP offers courses, certificate programs, and other learning opportunities, including an Entrepreneur-in-Residence program designed to augment the translation of research results into commercial products and services. http://www.genome.duke.edu

- ***Institute for Systems Biology (ISB).*** The Seattle-based ISB, founded in 2000, is a private research institute that brings together multidisciplinary groups of scholars and scientists—from biologists, mathematicians, and engineers to computer scientists and physicists—in an interactive and collaborative research environment. The research has resulted in the publication of important papers in genomics, proteomics, and systems biology and their applications. In addition to its pure research mission, ISB creates and distributes specific databases and software tools as a service to the broader biological sciences research community; conducts education and public outreach via its Center for Inquiry Science; and seeks to spin off commercial products from its research. http://www.systemsbiology.org

- ***Life Sciences Institute (LSI), University of Michigan.*** LSI's unique open-laboratory facility was established as a hub for collaboration among outstanding scientists from a variety of life science disciplines, focusing on the biological problems of human health. It serves as a physical and intellectual bridge linking the basic life science areas with medicine, public health, engineering, law, and business. The institute actively participates in the regional life sciences industry community to promote economic development through the development, licensing, and spin out of new technologies and discoveries, and presently has a $1.5 million grant from the Howard Hughes Medical Institute to develop innovative methods for teaching basic biology. http://www.lsi.umich.edu

Visionary/Transformative Research

Some entities were established to conduct and/or support question-driven basic research that has no short-term objective other than exploration of an important area of interest and the possibility of a major breakthrough or innovation—the scientific equivalent of venture capitalism. Traditional, risk-averse sources of funding rarely support such open-ended objectives. Examples of this type of IDR entity are:

- ***Carnegie Institution for Science (CIS).*** CIS was endowed by Andrew Carnegie to be a unique organization dedicated to scientific discovery "in the broadest and most liberal manner," which would support "exceptional" individuals to explore the most intriguing scientific questions in an atmosphere of flexibility and freedom. Today, CIS supports significant research in the earth, space, and life sciences and serves the astronomical research community by managing the Mt. Wilson and Los Companas (Chile) observatories. http://www.ciw.edu

- ***Janelia Farm, Howard Hughes Medical Institute*.** Janelia Farm is, in some ways, the biomedical equivalent of the basic research component of the former Bell Labs. Its primary focus is facilitation of pure, interdisciplinary research—"offering creative scientists freedom from constraints that limit their ability to do groundbreaking research." Resident scientists conduct research focused on two synergistic areas—the identification of general principles that govern how information is processed by neuronal circuits, and the development of imaging technologies and computational methods for image analysis. Janelia Farm's Science Education Alliance program funds education research, fosters teacher professional development, and encourages use of the latest biomedical research to stimulate learning at all grade levels. http://www.hhmi.org/janelia

- ***Keck Futures Initiative*.** The National Academies Keck Futures Initiative was created in 2003 to break down the conceptual and institutional barriers to interdisciplinary research and to stimulate new modes of inquiry in order to generate significant benefits to science and society. The W.M. Keck Foundation provided a $40 million grant to underwrite the initiative, which funds three core activities annually: Futures Conferences, Futures Grants, and a National Academies Communications Award. http://www.keckfutures.org

- ***Santa Fe Institute (SFI)*.** SFI, founded in 1984, is a private, independent research and education center for multidisciplinary collaborations in the physical, biological, computational, and social sciences. The institute is dedicated to studying the complex adaptive systems that are key to addressing today's environmental, technological, biological, economic, and political challenges. There is a small resident faculty; however, SFI considers itself a "virtual institute," with renowned scientists and researchers conducting the bulk of their work at their home universities, government agencies, research institutes, and private industry. SFI provides educational opportunities in the form of summer school programs, undergraduate internships, and graduate and post-doctoral research. http://www.santafe.edu

- ***Woods Hole Oceanographic Institute (WHOI)*.** WHOI, established in 1930 at the recommendation of the National Academy of Sciences, is a private, independent organization dedicated to marine research, engineering, and higher education. WHOI's primary mission is to understand the oceans and their interaction with the Earth, and to communicate broadly a basic understanding of the oceans' roles in the changing global environment. WHOI maintains a large staff of scientists and technical experts and operates several large oceanographic research vessels, including famed submersibles *Alvin* and *Jason*. Through a partnership with the Massachusetts Institute of Technology, WHOI offers undergraduate, graduate, and post-doctoral research and learning opportunities, and teacher professional development. http://www.whoi.edu

Federally Sponsored IDR Research

A number of Federal agencies provide competitively awarded grants for the establishment of external research organizations to conduct cutting-edge research in particular areas of science, subject to specific criteria, such as a collaborative interdisciplinary approach that involves multiple organizations, and high-risk/high-return research with the potential for scientific breakthroughs. Examples are:

- ***NASA Astrobiology Institute (NAI), National Aeronautics and Space Administration (NASA).*** NAI was established in 1998 to support NASA's exploration of biology as a function of planetary processes, including how those processes give rise to, sustain, or inhibit life. It is a "virtual" organization with a resident director and small support staff at NASA's Ames Research Center. NAI supports 14 research teams' of some 700 members from 150 institutions worldwide through Cooperative Agreement Notices. Graduate advisors at the home institutions support graduate and post-doctoral students. NAI also operates a Postdoctoral Fellowship Program and K-12 education support and public outreach, and serves the planetary science community via workshops, seminars, and conferences. http://astrobiology.nasa.gov

- ***NASA Lunar Science Institute (NLSI), NASA.*** The new NLSI, modeled after the Astrobiology Institute, was established to support larger, more focused research efforts in support of NASA's lunar science and exploration programs. The Iistitute is conceived as an experiment in scientific collaboration across disciplines and within and between the participating teams, irrespective of their geographic distribution. In addition to sponsoring research, NLSI carries out programs to strengthen the lunar science community, support NASA lunar flight missions, train the next generation of lunar scientists, and communicate about lunar science with educators and the public. http://lunarscience.arc.nasa.gov

- ***National Institutes of Health (NIH) Roadmaps Project.*** The NIH Roadmaps Project serves as a funding mechanism that sponsors large-scale, transformative interdisciplinary research among the various institutes comprising NIH and external academic and commercial organizations. Its ultimate goal is to facilitate and speed the process from identification of research needs through the development of health care techniques. An education component includes professional development training for NIH staff on interdisciplinary research concepts and collaborative mechanisms, as well as indirect support for NIH undergraduate, graduate, and post-doctoral researchers at their home institutes. http://nihroadmap.nih.gov/initiativeslist.asp

- ***National Science Foundation Science and Technology Centers (STC).*** The National Science Foundation's Science and Technology Centers Integrative Partnerships program supports innovative, potentially transformative, complex research and education projects that require large-scale, long-term awards. Emphasizing investigations at the interfaces of disciplines, STCs conduct world-class research through partnerships among academic institutions, national laboratories, industrial organizations, and international collaborations. http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5541&org=OIA

- ***NSF Cyber-Enabled Discovery and Innovation.*** The NSF Cyber-Enabled Discovery and Innovation (CDI) program is a five-year initiative to create revolutionary science and engineering research outcomes through innovations and advances in computational thinking that supports science and engineering research and education. The CDI program solicits ambitious, transformative, multidisciplinary research proposals across three thematic areas: enhancing human cognition and generating new knowledge from a wealth of heterogeneous digital data; deriving fundamental insights on systems comprising multiple interacting elements; and enhancing discovery and innovation by bringing people and resources together across institutional, geographical, and cultural boundaries. http://www.nsf.gov/crssprgm/cdi

- ***NSF Integrative Graduate Education and Research Traineeship (IGERT) program.*** The IGERT program, begun in 1997, spans NSF's directorates; since 1998, the IGERT program has made 215 awards to over 100 lead universities in 41 states, the District of Columbia, and Puerto Rico. A principal program goal is to catalyze a cultural change in graduate education for students and faculty alike by establishing innovative new models for graduate education and training in collaborative research that transcend traditional disciplinary boundaries. Other goals include diversity in student participation and a world-class, broadly inclusive, and globally engaged science and engineering workforce. http://www.nsf.gov/crssprgm/igert/intro.jsp

Data Repository and Synthesis Centers

Among the government-sponsored IDR centers is a subset of organizations funded through NSF or private foundations that do not generate original research data but instead emphasize research involving the synthesis and analysis of existing data.

- ***Biodiversity Synthesis Center (BioSynC), Field Museum.*** BioSynC, housed at the Field Museum in Chicago, is a component of the Encyclopedia of Life project. It was established to conduct synthetic research that addresses fundamental questions in biodiversity science and to advance contributions by scientists and broader audiences to

the knowledge base of the Encyclopedia of Life. BioSynC draws on Field Museum curatorial expertise and has a few in-house post-doctoral researchers. One of its principal roles is hosting around 12 synthesis meetings annually on a set of overarching themes in biodiversity. It conducts education and public outreach through the museum. http://synthesis.eol.org

- ***National Center for Ecological Analysis and Synthesis (NCEAS), University of California, Santa Barbara*.** NCEAS does not support or conduct research that involves collection of new data. Rather, it is a data repository/synthesis center that supports interdisciplinary research using existing data to address major fundamental issues in ecology and allied fields, and to make the research available for management and policy making. NCEAS' work is carried out through Working Groups who collaborate at the Center through periodic meetings; Sabbatical Fellow and Postdoctoral Associate appointments; short-term Working Groups; and Distributed Graduate Seminars that allow students and faculty at universities worldwide to collaborate on research projects and convene at NCEAS. NCEAS funds come primarily from NSF. http://www.nceas.ucsb.edu

- ***National Evolutionary Synthesis Center (NESCent), Duke University*.** NESCent, a collaboration of Duke University, University of North Carolina at Chapel Hill, and North Carolina State University, is funded by NSF. Its primary mission is "synthetic" research in evolutionary biology, which includes integrating novel datasets and models to address important problems, developing new analytical approaches and tools, and combining methods and perspectives from multiple disciplines to answer and even create new fundamental scientific questions. NESCent's "Science and Synthesis" program sponsors post-doctoral fellows and sabbatical scholars. The Informatics Program provides state-of-the-art informatics tools to visiting and in-house scientists. The Education and Outreach group communicates the results of evolutionary biology research to the general public and the scientific community. http://www.nescent.org/index.php

- ***NASA Planetary Data System (PDS)*.** NASA's Science Mission Directorate created the NASA Planetary Data System as a service for the planetary science community worldwide. NASA space probes have returned large quantities of data over the past few decades, and the agency needed a mechanism to help researchers find and use the data; establish standards for data format for present/future missions; and help proposers for future instruments plan the data products for which they would be responsible. http://pds.jpl.nasa.gov

Advocacy

The function and goals of some interdisciplinary research organizations are similar to those of advocacy-based think tanks. The organizations may sponsor/conduct research and offer academic courses and programs, but their major objective is to promote a specific point of view, based on research results, with the public and decision makers.

- ***Center for Biodiversity and Conservation (CBC), American Museum of Natural History (AMNH).*** CBC is dedicated to the mitigation of critical threats to global biological and cultural diversity. It operates in a manner akin to that of a research-conducting advocacy think tank—its staff conduct and/or support considerable research—but much of the thrust of CBC's work is to use that research and other information to educate the public and decision makers on biodiversity issues. CBC regularly hosts public lectures and other programming at AMNH, including exhibitions. http://cbc.amnh.org

- ***Woods Institute for the Environment, Stanford University.*** The Woods Institute seeks to create practical solutions and pioneer innovative approaches to meet 21st century environmental challenges—from climate change to sustainable food supplies to ocean conservation—in the same spirit that inspired Stanford's role in Silicon Valley's high tech revolution. The institute sponsors research on global sustainability issues and serves as a hub for the university's interdisciplinary work in environmental research and education and the development of strong environmental leaders. The institute has a strong advocacy component, seeking to infuse science into policies and practices of the business, government and non-governmental organization (NGO) communities. Its Environmental Venture Projects Program provides seed funding to interdisciplinary teams to conduct innovative research. http://woods.stanford.edu

Appendix D. Collaboration Mechanisms

Various types of collaboration mechanisms, which vary in their degree of formality, define the structure and management of partnerships and other collaborations. The types of collaboration mechanisms, ranging from least to most formal, include:

- ***Conversation.*** A private, verbal communication between individuals, ranging in formality from "just talking" to the threshold of legal obligation constituted by a verbal agreement/handshake.

- ***Meeting.*** Discussion/action by a group of people with the same range of formality that occurs between individuals, but with the potential for slightly more formality in that a number of people are working together.

- ***Task force.*** Task forces are groups with an action plan and that meet often, so their level of formality is expected to be higher.

- ***Intergovernmental Personnel Act agreement (IPA).*** IPAs provide for the temporary assignment of personnel between the Federal government and state and local governments, colleges and universities, Indian tribal governments, federally funded research and development centers, and other eligible organizations. See http://www.opm.gov/PROGRAMS/IPA/Mobility.asp.

- ***Gift agreement.*** Gift agreements are usually specific about their financial terms but less formal with respect to particular goals to be met or products to be produced as a consequence of the gift. As an example, a large donation to a Smithsonian unit would require that a gift agreement be executed; however, the expectation on the part of the donor would be only that the Institution use the gift "wisely," with no restrictions on use or legal mechanism for enforcement.

- ***Grant.*** Grants, on the other hand, tend to be specific about both the terms and conditions of the financial side of the exchange, and their goals, products, and timetables. An example of grant-type support was the funding of NASM's Heritage Month Family Day Program for 2008 and 2009 by the Northrop Grumman Corporation, which restricted use of the funds to support of specific events.

- ***Letter of Agreement (LOA), Memorandum of Agreement (MOA), Memorandum of Understanding (MOU), and Cooperative Agreement Notice (CAN).*** These instruments outline the responsibilities of partnering organizations with some level of formality, including in some cases specifics about partnering finances and other resources.

However, they tend to be fairly general and do not include detailed terms and conditions governing the partnership. Examples of this type of agreement in organizations examined in this study include:

- The Gulf Coast Consortium, parent organization of the Keck Center for Bioscience Training at Rice University, which was assembled via the use of MOUs between consortium members.

- NASA's Astrobiology and Lunar Science Institutes, which support their research staff via CANs between NASA and the researchers' home institutions.

This mechanism usually governs joint programming by Smithsonian units and outside entities. It is also used for "no-cost visiting scientist" academic appointments that come in a variety of types and levels of formality. At the Smithsonian, this type of appointment pertains to research associates, whose affiliation does not offer salary or other payment (otherwise the position would be a fellowship or have another designation), but it does open doors, allow for participation as though the visitor were Smithsonian staff, etc.

- ***Joint venture and strategic alliance.*** These types of longer term partnerships often involve considerable "seed money" and other resources, and tend to be set up under a more formal agreement structure; however, there are notable differences. A joint venture is a new entity formed between two or more parties that contribute equity to and share in the revenues and expenses and control of the enterprise. In contrast, a strategic alliance involves no equity stake by the participants and is a much less rigid arrangement that is established so that the partners can pursue a set of agreed upon goals while remaining independent organizations.

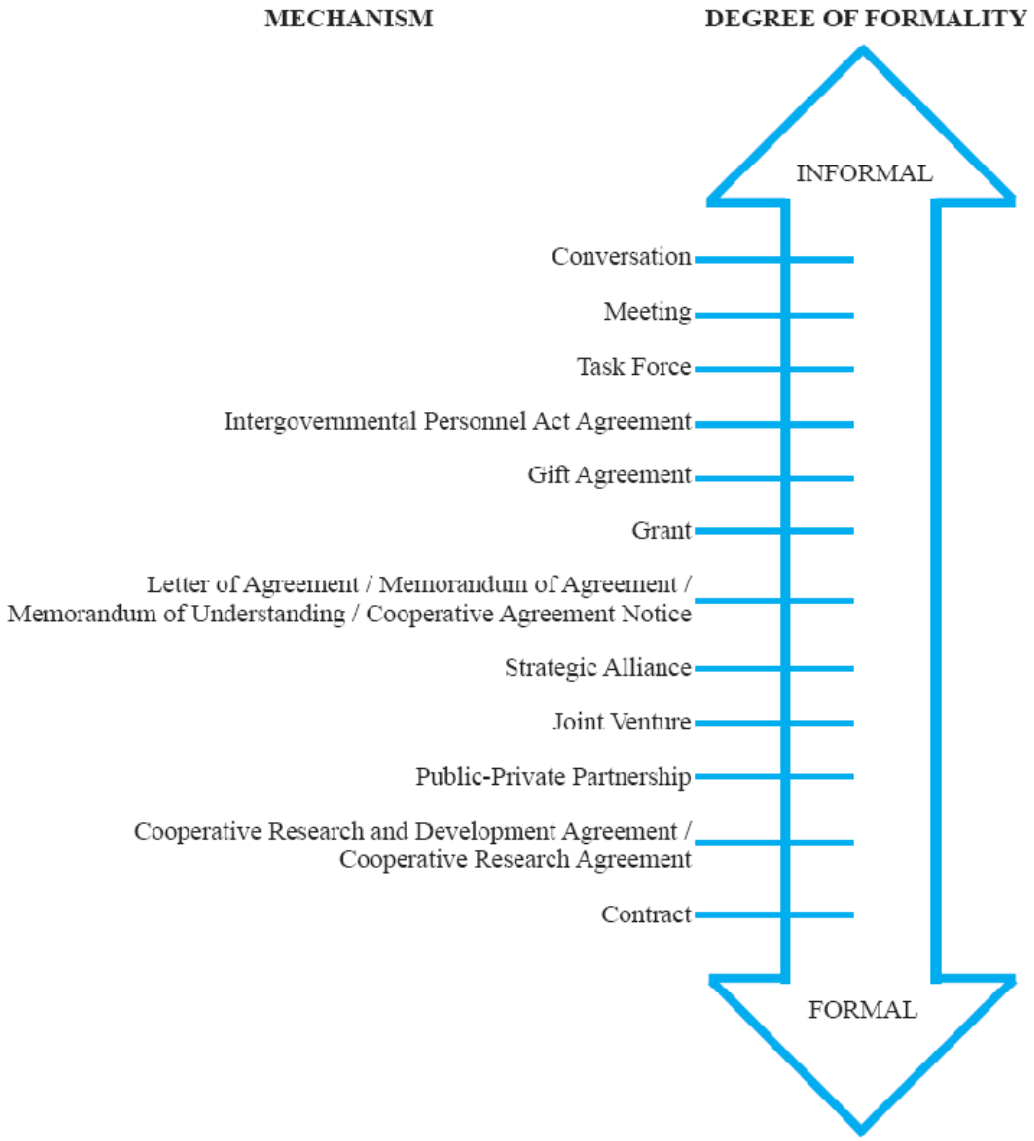
- ***Public-Private Partnership (PPP).*** PPP-type partnering arrangements take a variety of forms covering a broad range of formality, but typically have some type of legal underpinning that governs the partnership. PPPs can be found in many fields, including international health, where private foundations and corporate entities will support governmental/international programs. An example is the support of the Gates Foundation and the pharmaceutical industry for much of the United Nation's World Health Organization budget.

- ***Cooperative Research and Development Agreement (CRADA) and Cooperative Research Agreement (CRA).*** These written agreements between a Federal research organization and one or more Federal or non-Federal parties to work together are designed to facilitate the commercialization of technology, optimize resources, and protect the interests of private partners. Private corporations participating in a CRADA

are allowed to file patents and retain patent rights on inventions developed by the CRADA, while the government gets a license to the patents. CRADAs include general provisions in a standardized format that provide the legal framework for the agreement and a statement of work describing the objectives, tasks, and deliverables of the collaborative project. (See the Stevenson-Wydler Technology Act of 1980 and the Federal Technology Transfer Act of 1986.)

- ***Contract.*** Contracts are created to establish the precise legal boundaries, obligations, and prohibitions that formally govern a partnership arrangement, leaving as little "wiggle room" as reasonably possible.

Figure D-1. Collaboration Mechanisms and Degree of Formality



Appendix E. The Smithsonian Workforce at Selected Smithsonian Science Units

Figure E-1. National Museum of Natural History Science Research Employees, January 1993 to January 2008

Figure E-2. Smithsonian Astrophysical Observatory Science Research Employees, January 1993 to January 2008

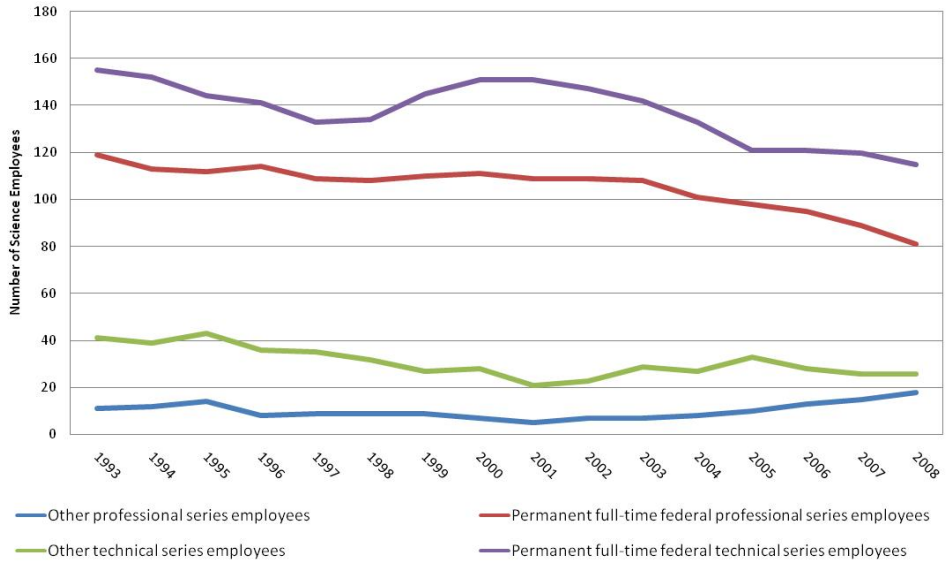


Figure E-3. Smithsonian Environmental Research Center Science Research Employees, January 1993 to January 2008

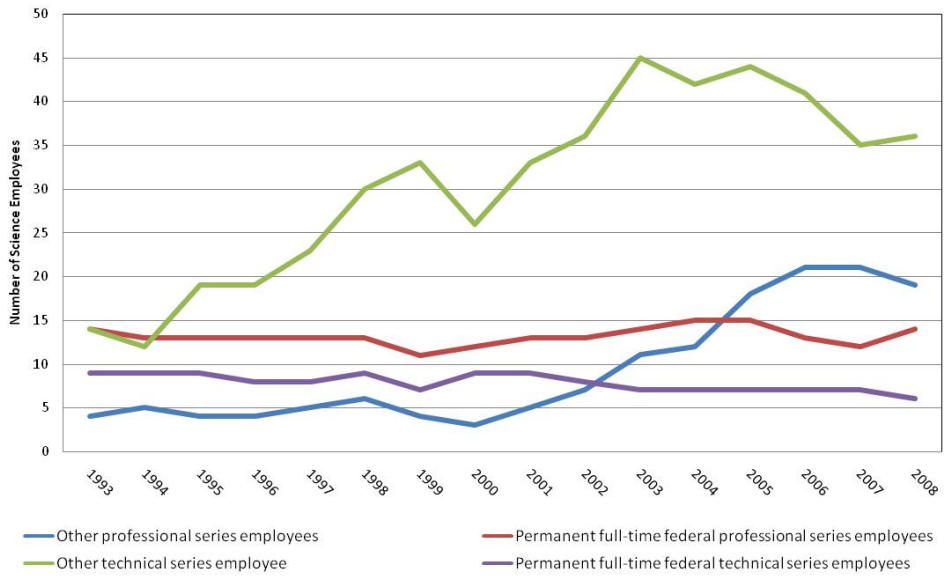


Figure E-4. National Zoological Park Science Research Employees, January 1993 to January 2008