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NSF 10-521 **07/14/10**

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University of Maryland College Park
3112 Lee Building
College Park, MD. 207422510

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TITLE OF PROPOSED PROJECT **Environmental Synthesis Center Full Proposal: Environmental Synthesis Center (EnSynC) in Maryland**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **29,969,984**	**60** months	**08/31/11**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____
PHS Animal Welfare Assurance Number _____

☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
_____
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

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EnSynC: An empowering Environmental Synthesis Center

A Collaboration Among: the University of Maryland,
the University of Maryland Center for Environmental Science, and Resources for the Future

Summary

Intellectual Scope: We propose a dynamic center model that will coalesce researchers from diverse natural and social science disciplines to advance discovery and problem solving related to the structure, function, and sustainability of socio-ecological systems. EnSynC will apply a progressive approach, using community-driven Themes to achieve four goals to accelerate discovery and solutions: 1) provide vital support for researchers, including expertise, tools and data; 2) foster a new level of engagement with the policy community; 3) build environmental synthesis capacity among students and researchers, and 4) nurture and improve the synthesis *process*.

Through our primary funding program, we will achieve our vision using an evolving thematic system in which center activities tackle community-identified, 'big issues' on a sequential basis. At any given time, multiple synthesis **Pursuit projects** under a given thematic umbrella will be managed as a portfolio designed to make advances consistent with what is articulated in the strategic plan for that theme. To manage this process, Theme Leaders from the external community will work with the EnSynC Synthesis council which is a group of high-level scholars and educators charged with facilitating synthesis efforts by implementing a structured process to assist project teams. A second, smaller program, called the **Ventures program** will fund projects that are particularly novel, high-risk or time-sensitive yet not tied to a center Theme. We will complement these with structured activities and projects that target our goals for policy, capacity building, and growth of the synthesis *process*.

EnSynC is committed to serving the community in new ways and at high levels and the EnSynC Synthesis Council is responsible for ensuring synthesis researcher needs are met. We will have cyberinfrastructure staff at the center full-time including high-level positions filled by people dedicated to assisting with spatial analyses (GIS analyst), assisting in the aggregation and integration of diverse databases (Digital Information Research Specialist). We will deploy the latest IT to provide services to accelerate discovery, science translation, and collaboration. We will support storage, management, and integration of heterogeneous datasets, and of computationally intensive analysis, modeling, and visualization across environmental datasets. To enhance interactions between researchers and the policy community we will support a Policy Scholars Exchange program with Resources for the Future as well as implement regular roundtable discussions with policy makers.

The EnSynC facility will be located in historic Annapolis, Maryland, on the shores of the Chesapeake Bay, a location with easy access to 3 airports. The core leadership will be provided by the Executive Director, four Directors who oversee major areas, and three Assistant Directors who are responsible for organizing Center resources to facilitate data aggregation, integration and analysis. Faculty coordinators from diverse institutions will develop and implement education and outreach programs.

Broad Impacts. The center will advance environmental science from a basic research perspective and from a public policy, social science and science translation perspective. Policy scholars from RFF, and, policy makers, natural resource managers, and federal scientists from the Washington D.C. region and surroundings will be integral to the development of EnSynC projects and opportunities for engaging the public, students, and legislators. We will engage undergraduates, graduate students, postdoctoral fellow and faculty in activities specifically targeted at building capacity to undertake environmental synthesis. A founding education project will test methods for teaching high school and college students to apply a synthesis approach to environmental problems and large research questions; this project will involve building capacity across a diverse spectrum of students including hearing impaired, inner-city urban students, and returning students. We will design and populate a database using metrics on center functioning, project activities & outcomes, participant experiences and external assessment outcomes. This will grow over time and data that can be used to enhance our understanding of what promotes effective synthesis.

EnSynC: An empowering Environmental Synthesis Center

Project Description

Environmental problems and their associated drivers and feedbacks are complex, involving tightly coupled social and ecological processes, many of which researchers are only beginning to understand (Walker et al. 2004; Liu et al. 2007). Synthesis research to advance this understanding must involve both the natural and social sciences. Environmental synthesis research can help distill complicated information to discover patterns, identify linkages controlling feedbacks within socio-ecological systems, and promote the translation of scientific results into actionable policy (Carpenter et al. 2009). Synthetic research produces findings that are more comprehensive and persuasive than the component pieces (Rhoten & Pfirman 2007). NCEAS has championed the development of ecological synthesis as a discipline, thereby substantially advancing ecology (Reichman 2004; Hackett et al. 2008). However, moving beyond ecological synthesis to *environmental science* synthesis requires understanding that socio-ecological systems are acutely interdisciplinary and that each problem will dictate which disciplinary specialists—anthropologists, computer scientists, ecologists, economists, engineers and other design scientists, geoscientists, policymakers, sociologists, etc.—must collaborate in and coordinate research. Ecologists have a history of working with interdisciplinary natural science teams, and there have also been strong recent syntheses within the social sciences (Ostrom 2003, 2009). The fastest progress toward solving current environmental problems will come through extensive collaborations between the natural and social science communities.

The Environmental Synthesis Center (EnSynC) we envision will coalesce researchers from diverse natural and social science disciplines to advance discovery and problem solving related to the structure, function, and sustainability of socio-ecological systems. The Center will apply a progressive approach, using community-driven Themes to achieve four key goals to accelerate discovery and solutions: 1) provide vital support for researchers, including expertise, tools and data; 2) foster a new level of engagement with the policy community; 3) build environmental synthesis capacity among students and researchers, and 4) nurture and improve the synthesis *process*.

Box 1: EnSynC Approach

- Apply a thematic program to aid discovery and address problems
- Provide unparalleled support to the community
- Provide mechanisms for strengthening the science–policy linkage
- Provide mechanisms for Horizontal Synthesis across projects and Themes
- Provide mechanisms to build environmental science synthesis capacity

The first three goals, although necessary, are not sufficient. Activities designed to achieve the fourth goal are essential. Successful environmental synthesis to meet future challenges will require not only creativity and knowledge but continual growth of the *process* of environmental synthesis—i.e., how we undertake synthesis including the people we engage and the methods and approaches we use. Throughout, we refer to the EnSynC activities we propose for growing and advancing this *process* as "Horizontal Synthesis" activities; a full description is in Section 2.5.

With these goals, we developed the EnSynC Approach, its programs, and its management structure (Box 1, Fig. 1). The model is progressive for a number of reasons besides its approach. First, the high level of institutional and financial support contributed by the University of Maryland and its partners not only enables us to provide a high level of service to the community, but it indicates the commitment to ensure EnSynC is successful even beyond the 10-year NSF window. Second, EnSynC is a joint effort between two "Research 1" academic institutions and a nonprofit international leader in social science and policy research and the management team features individuals who are not only internationally known scholars and educators but also experienced leaders dedicated to advancing science and its impact. Third, EnSynC programs are designed to support curiosity-driven individual and group synthesis research as well as problem-driven synthesis. This work may lead to discoveries associated with a Theme or open a unique line of inquiry. Finally, the EnSynC model includes specific activities and a deep commitment to evaluate, learn, and adapt to advance *the process of environmental synthesis.*

Section 1. EnSynC in Brief

1.1 Lead Institutions and Location. The lead institutions for EnSynC are the University of Maryland College Park (**UMCP**), the University of Maryland Center for Environmental Science (**UMCES**), and Resources for the Future (**RFF**)**.** UMCP is the state's flagship campus and brings to EnSynC all the resources, expertise, and experience associated with a major Research I institution. UMCES is a multi-campus research institution that is a world leader in the study of coastal environments and their watersheds, producing knowledge to guide natural resource management and policy. P.I. Margaret Palmer has a joint appointment with UMCES and UMCP. RFF is a nonprofit/nonpartisan organization that conducts independent research—rooted primarily in economics and other social sciences—on national and international issues related to the environment, energy, natural resources, and public health. James Boyd, senior fellow with RFF, will lead the EnSynC policy programs; he previously has collaborated with faculty from UMCP and UMCES. EnSynC's central facility will be in Annapolis, MD, with satellite facilities at RFF in Washington, D.C. Three major airports, UMCES facilities, and UMCP are all only a short drive away.

1.2 Who Will Use the Center? Ecologists will always be central to environmental synthesis. However, synthesis-driven discoveries related to basic ecological issues such as the strength of species interactions or the link between dispersal and biogeography can be informed by and facilitate discovery in a broad range of natural sciences. Thus, ecologists will be partnering with geoscientists, engineers, and computer scientists to develop new insights and answer difficult questions. Social scientists are also critical because humans are a major driver of environmental change, shaping ecosystem dynamics from local to global scales, yet humans simultaneously depend on the goods and services provided by ecosystems. Disciplines such as environmental psychology (Mira & Deus 2005), economics (Boyd & Krupnick 2009), geography (Bergin et al. 2009), history (Merchant 2004), planning (Nassauer 1995), and public policy are essential to advance our understanding of the link between human dimensions and ecosystem processes (Berkes et al. 2003). **Thus, throughout this proposal when we refer to "the community," we are referring to those who will use EnSynC—i.e., the cadre of ecologists, social scientists, and scientists from other natural science disciplines who bring important knowledge and tools to the study of socio-ecological systems.**

1.3 How EnSynC Will Promote Diversity. We will strive for equitable representation across activities and through time, particularly in leadership roles (e.g., advisory board members, Theme Leaders, Directors, Faculty Coordinators). Only workshops and other proposals that have seriously considered equity issues will be funded. Our commitment to inclusivity will be posted prominently on the EnSynC homepage, which will also feature updated disciplinary, geographic, gender, and ethnicity statistics on Center participants. Our educational programs also include an explicit focus on three groups traditionally underrepresented in science: urban minority, hearing-impaired, and non-traditional ("returning") college students.

1.4 Primary Funding Programs and Activities. We have designed funding programs and activities to accomplish each of our four goals. Our primary funding program for synthesis projects will be the **Thematic Pursuits program**. This will fund research projects following community-selected Themes. A second, smaller program, called the **Ventures program**, is designed to fund projects that are particularly novel yet not tied to a current center Theme. Novel projects are those that are high-risk, yet potentially high-reward or that will develop tools or approaches that could markedly advance the synthesis process. The Ventures program also will accept proposals arising for unexpected reasons (e.g., a species for which large amounts of data exist is accidentally introduced into a new ecosystem, thereby providing opportunities to make predictions using synthesis and modeling). As described below, we will complement the primary funding programs with structured activities and projects that target our goals for policy, capacity building, and growth of the synthesis *process*.

***1.5 The Organizational Structure*.** The core scientific leadership will be provided by the Executive Director, four Directors who oversee major areas, and three Assistant Directors who are responsible for organizing Center resources to facilitate data aggregation, integration and analysis. Faculty coordinators from diverse institutions will develop and implement the education and outreach programs.

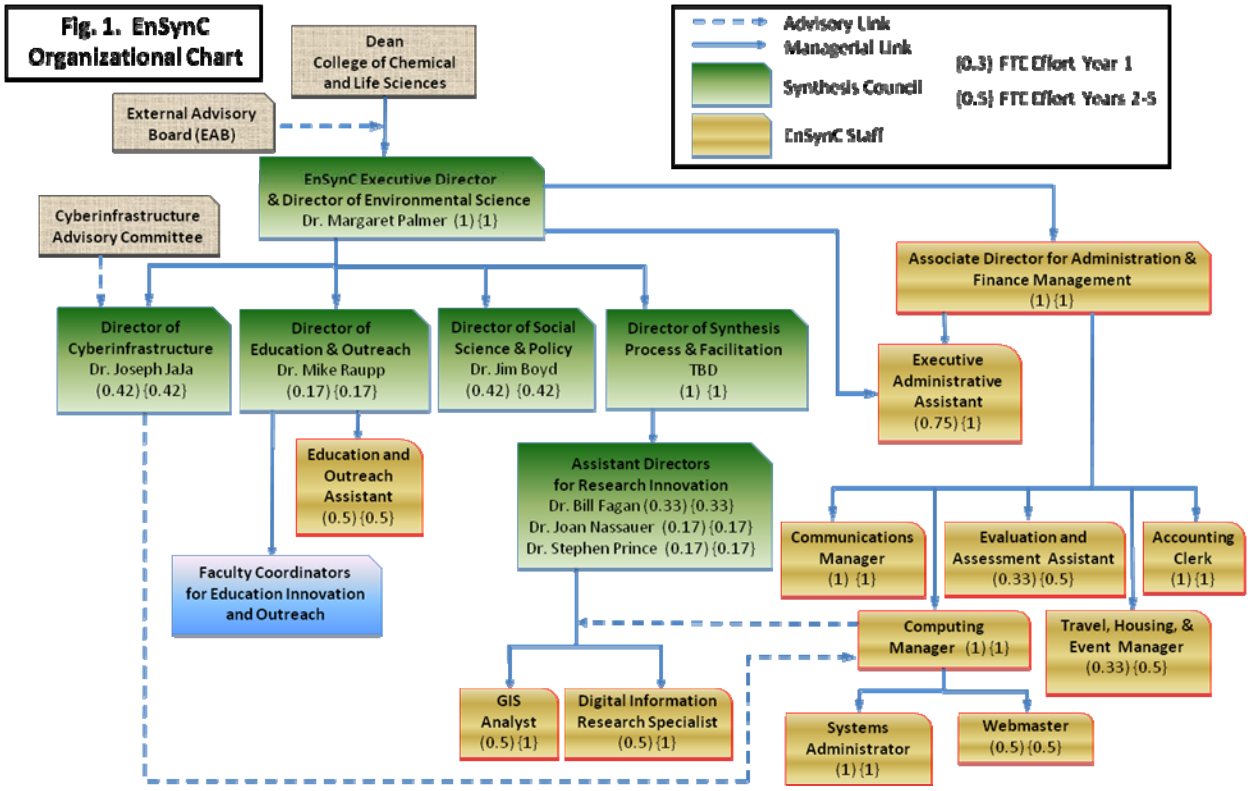


Fig 1. EnSynC organizational structure showing the Center reporting & advisory structure (grey), the administrative support (tan), the faculty Synthesis Council (green), and faculty partners from other institutions who will help coordinate & innovate Education & Outreach activities (blue). The number and type of staff demonstrates EnSynC's commitment to serve the community in advancing environmental synthesis. Individual duty details are in Section 4.

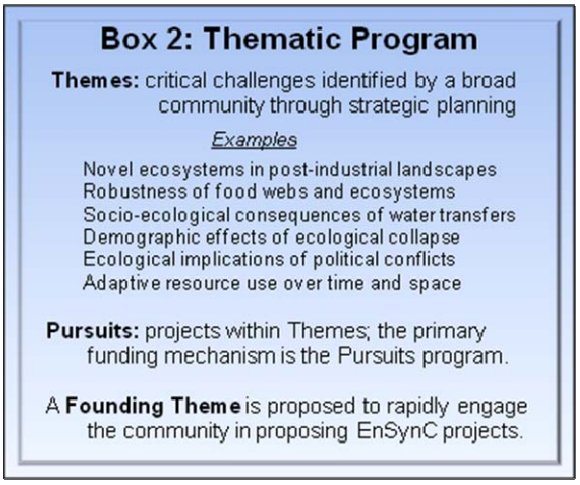
Section 2. Elements of the EnSynC Design to Innovate Environmental Synthesis

As emphasized, EnSynC will implement a progressive model for synthesis that leads to advanced, high-impact outcomes using a thematic approach. The Center will include high levels of support, programs focused on policy, and programs and activities to promote synthesis on key topics as well as activities to support the growth of the process of environmental synthesis.

2.1 Thematic Approach and Unparalleled Support for the Community. We will support synthesis activities within an evolving set of *Themes* identified by the community; proposal solicitations for each Theme will result in funded **Pursuits**. Our other funding mechanism, the **Ventures** program, will support additional activities. We chose the Pursuits and Ventures terminology because we do not want to pre-define the approach investigators may take. We will foster and facilitate diverse methods of collaborative research, embracing alternative approaches. For example, some researchers may wish to work in a distributed fashion, possibly with "coached" collaborators (Sollers et al. 2005), whereas others may wish to try crowd-sourcing methods (Vander Schee 2009), bringing collective knowledge from a broad constituency. Others, such as managers or policymakers, could define environmental challenges and ask the center to support a visual analytics approach, in which a combination of data analysis and visualization are used to understand complex relationships (Keim et al. 2008). We suspect teams of 8 to 15 will be common, but we will also support groups of other sizes, including sole investigators.

Thematic Pursuits Funding Program. A thematic approach for our major funding program will provide a strategic basis for the integrated selection of synthesis projects. These will constitute a "portfolio"

of Pursuits that together will generate greater progress within a Theme; selected Pursuits will span critical questions and will be synergistic with other Pursuits within the Theme. We believe that this structured approach in which community-identified themes are used to solicit proposals for Pursuit projects is well suited for synthesis addressing complex problems at the boundary between natural and social science. We chose to use a thematic approach because it concentrates researcher groups with a common thread of interest in time and place. The groups' research activities may be quite distinct, but the presence of a common thread combined with the physical proximity of Pursuit teams working at the Center will promote communication and knowledge spillovers, which may enhance productivity (Fischer et al. 2005). This is consistent with an R&D portfolio approach used broadly in industry (Chien 2002) and also in focused funding programs (e.g., NSF's Dimensions of Biodiversity program [NSF 2010]).



Each center Theme—as many as three at a time—will represent "big issues" (e.g., as in Box 2) identified and defined by the scientific community. Progress on a Theme will be coordinated by leading scholars from the external community (Theme Leaders). Thus, the EnSynC model in funding synthesis is, in effect, combining a top-down approach (Themes, coordinators of Themes) with a bottom-up approach (community-selected Themes, community-driven Pursuit projects within a Theme). Additionally, through the Ventures program, we will fund projects that are not necessarily related to a current center Theme, so there is an additional "bottom-up" avenue to provide great flexibility and to foster the best ideas floating up. For example, even with a Theme such as the water transfer example in Box 5, a project could at the same time be funded through the Ventures program on something as unrelated as synthesizing data on environmentally-induced changes in genetic diversity that have cascading effects on ecosystem functions. Clearly, we include mechanisms for funding creative ideas even if they are 'out of Theme'.

To illustrate the Theme and Pursuit portfolio approach we are adopting, consider a Theme on "Predicting Movement Patterns in Socio-ecological Systems." This Theme could lead to Pursuits as diverse as understanding the relationship between rural-to-urban human population movements and natural resource use (Birdsall et al. 2001), demographic responses to soil or water degradation (Ezra 2001) or understanding the migratory patterns of commercially important fish species (Dorazio et al. 1994). Syntheses across two Pursuit projects could combine newly emerging data on natural resource distributions with demographic and economic data to characterize the context-dependence of effective policy mechanisms (e.g., relocation incentives, quotas, taxes, spatial reserve planning). A Pursuit focused on fish migrations could study inner continental shelf species with poorly known spatial ecologies using large volumes of data from new arrays of acoustic receivers (e.g., the self-organized Atlantic Coastal Telemetry Network archives data on telemetry platforms from Florida to Maine). Synthesis could involve studying the movement patterns of individual species and then developing composite species distributions over time to guide ecosystem-based management efforts (Grothues et al. 2005; Palacios et al. 2006).

Ventures Funding Program. While Ventures projects need not be part of a Theme, they must stand out by virtue of their novelty and/or potential. In Section 2.4, we propose a founding Venture that has the potential to result in novel educational approaches to build capacity in environmental synthesis. Similar to our proposed founding Theme (Section 6.3), this Venture is designed to engage the external community immediately in EnSynC. Examples of Ventures may include unorthodox approaches to advancing the synthesis *process,* such as projects on: 1) methods for filtering and selecting information, given the ever-growing quantity of data and the increasingly diverse types of knowledge needed to solve problems (Bawden & Robinson, 2009); 2) the link between information quality (e.g.,

accuracy, reliability) and decision-making (Batini et al. 2009); 3) "information literacy" to help shape environmental synthesis curricula and training (Johnston & Webber 2006); 4) applications of network theory to identify attributes of synthesis projects that map onto productive, long-term collaborations (Aboelela 2007); or, 5) science-policy interactions (Hoppe 2010). Examples of high-risk Venture proposals might include: 1) the use of neuroimaging techniques to measure physical and psychological responses to natural environments, thereby providing insights into the role of these environments in well-being and 2) a multinational exploration of how information technology leads to differences in the manufacture and transport of goods that correspond to environmental impacts.

2.2. Unparalleled Support for the Community. EnSynC is committed to serving the community in new ways and at a high level using the strong and diverse faculty expertise, staff support, and access to resources we will provide. We are able to do this because of the >$12 million in leveraged funding the State of Maryland, the Universities, and RFF have committed. Aside from funding Pursuits and Ventures, our primary mechanism for delivering support to the community will be through the transdisciplinary **Synthesis Council** (Box 3 and Fig. 1)**.** This eight-member council is a high-level group of scholars and educators with extensive research and leadership experience that, together, span the environmental, social, and computational sciences plus education. This Council will facilitate synthesis by implementing a structured process to assist project teams as they initiate work (see 4.1). The Council will also ensure that research needs of EnSynC participants are met and will provide assistance to Theme leaders, including organizing periodic Pursuit team workshops for information sharing, evaluation of progress, and cross-fertilization of ideas. The Council's facilitative role is an important feature that distinguishes EnSynC from other synthesis centers. A growing body of research shows that successful collaborations, particularly those including members from different organizations, require a deliberate strategy for coordination. Without this, communication falls off over time, essential group tasks are less likely to be completed, and researchers may lose interest (e.g., Cummings & Kiesler 2005). The Director of Synthesis Process and Facilitation will chair the Council and lead facilitation efforts. We believe this is a novel position in a synthesis center. It is appropriate because we emphasize facilitating the synthesis process on multiple levels.

Box 3: EnSynC Synthesis Council

Organizes and Leads Synthesis and Education Activities

8 members:
Executive Director (Palmer)
Director of Cyberinfrastructure (JaJa)
Director of Education and Outreach (Raupp)
Director of Social Science and Policy (Boyd)
Director of Synthesis Process and Facilitation (TBD)
3 Assistant Directors for Research Innovations
(Fagan, Nassauer, Prince)

Roles:
Apply a structured process to assist Pursuit teams
Assist Theme Leaders in tracking progress
Facilitate interactions across Pursuits and Themes
Ensure researcher needs (expertise, data) are met
Facilitate and support Horizontal Synthesis

A second major form of support for synthesis Pursuit or Venture teams will be through interactions with postdoctoral and graduate fellows. As part of their mentoring/training programs, fellows will be expected to spend about 1/3 of their time on center activities. They may choose to work with a Pursuit or Venture team for this part of their training. As such, they represent a rich source of expertise and intellectual energy that can be brought to a project. Fellows will actively engage in projects and not serve just as technicians, as their own research and growth as scientists are primary.

The third major form of support for Pursuit and Venture teams comes directly from EnSynC staff. We will have cyberinfrastructure staff at the center full-time (e.g., systems administrator), available to assist participants, and will have high-level positions dedicated to 1) assisting with spatial analyses (GIS analyst) and 2) assisting in the aggregation and integration of diverse databases (Digital Information Research Specialist) (Fig. 1).

2.3 Mechanisms for Enhancing the Environmental Science-Policy Link. Policy audiences already demand synthetic natural and social science research that is applicable and understandable to non-scientific audiences. Our interactions with the policy world are, therefore, an important test of our success and a potential source of intellectual inspiration for the center. Many policy audiences are already familiar with the hurdles faced in environmental synthesis and the challenge of turning

ecological science into practical resource management decisions (Boyd & Banzhaf, 2007). Scientists have historically assumed science to policy translation is a linear process: if they identify a problem, conduct research, and "deliver a solution," a change in management will follow (Lawton 2007). To the contrary, policy is formed and applied recursively and in light of competing social, cultural, political, and economic factors (Pielke 2007). These problems can be overcome, but only if planned for and built into the research process. EnSynC's satellite facilities at RFF in Washington and its structured policy programs are specifically designed to ensure that, in addition to fostering fundamental discovery, EnSynC will also foster a new level of interaction among environmental scientists and the very people who are central to national environmental policies and regulations. RFF has one of the largest environmental social science research staffs in the world, with broad expertise in ecological systems, non-market economics and valuation, and policy design. They have repeatedly demonstrated success in linking academic research to practical policy influence, including 1) development of the Forest Carbon Index to target carbon sequestration investments and 2) assessment of human health benefits in support of tighter air quality standards.

RFF will work with EAB members and EnSynC faculty advisors in the social sciences (e.g., Dr. Joan Nassauer, ecological design, Univ. of Michigan, and Dr. Michael Paolisso, cultural anthropology and environmental change, UMCP) to engage a broad cross-section of the social science and policy community in EnSynC activities. Senior RFF Fellow James Boyd will lead these efforts, spending part of his time in Annapolis and part in Washington. As an example of RFF's role as a bridge to social science partners, RFF has recruited the University of Gothenburg's (Sweden) Environment for Development (EfD) initiative group to partner with EnSynC. EfD is a capacity-building program in environmental, economic, and policy sciences, with centers in China, Central America, Ethiopia, Kenya, South Africa, and Tanzania. We will draw upon EfD's access to a network of researchers, data, and audiences across the developing world to provide guidance as we define Themes and advertise Requests for Proposals (RFPs) for topics in which global research and data are important.

We will build on RFF's existing hub of interactions with political, agency, NGO, and corporate stakeholders to create "policy interactions" with EnSynC scientists at various stages of the EnSynC process, including Theme identification, RFP design, and, as appropriate, Pursuit and Venture projects. Once research products have been delivered by EnSynC Pursuit or Venture teams, policy interaction will involve the communication of results to the appropriate audiences (Section 2.4 under "Public Outreach"). RFF will provide and manage key programs and activities (Box 4):

Box 4: Mechanisms for Strengthening the Science–Policy Linkage

Scholars Exchange Program

Mission Meetings

Environmental Science Briefings

Scholars Exchange Program. EnSynC will fund at least two "policy postdocs" and, as appropriate, "policy sabbatical visitors," who will spend part of their time in Annapolis and the rest in Washington at RFF. They will contribute to the creation of policy outreach products and facilitate interactions between EnSynC's natural and social sciences researchers. Policy postdocs will have earned degrees in the natural sciences, but be interested in science translation and policy impact. Ideally, their expertise will complement the Themes, Pursuits and Ventures underway during their appointment. These postdocs will be well positioned to learn from the EnSynC experience and lead science and policy synthesis into the next generation. The postdocs, and EnSynC more broadly, will also benefit from RFF's recent recruitment of a new scholar, Dr. Rebecca Neill, who has expertise in economics, spatial ecology, and invasive species. RFF has provided funding for her to work with EnSynC.

Mission Meetings. RFF will host quarterly policy roundtables, in which small groups of environmental scientists engage with federal scientists, NGO leaders and policymakers to discuss pressing policy needs and the potential role of synthesis science. These meetings will ensure two-way, regular interactions between Theme and Pursuit leaders, EnSynC management, and policy audiences.

Environmental Science Briefings. The policy team will also organize Environmental Briefings that involve members of Pursuit teams and other EnSynC participants including international scientists.

These briefings will be organized around topics that are ripe for discussions with the policy, federal science, and NGO communities. Members of these communities can request priority topics for briefings. The EnSynC Synthesis Council will also identify important topics where the science is advancing rapidly. The briefings will be for those people/groups that have an interest and stake in a particular environmental policy issue. Thus, invited attendees will vary with the issue but would include congressional staff as well as senior and mid-level leaders from government agencies, NGOs, or corporate entities with an interest in or impact on the environment.

2.4. Mechanisms to Build Environmental Science Synthesis Capacity. In the last 10 years, environmental science education, supported increasingly by research, has expanded across grades K-20 (e.g., Ecological Society (ESA) *TIEE* publication, http://tiee.ecoed.net/). However, most current work on scientific/environmental literacy does not emphasize either science synthesis or critical evaluation of claims based on synthesis (but see Jordan et al. 2009; Berkowitz et al. 2005). By focusing on synthesis as a process, EnSynC's education efforts, which fall into five categories (Box 5), will complement and synergize existing programs sponsored by ESA and the LTER network.

Box 5: Mechanisms to Build Environmental Science Synthesis Capacity

Founding Ventures effort on the synthesis process

Engaging undergraduates

Public outreach through communication

Local education programs

Graduate student, postdoctoral, and sabbatical programs

Founding Ventures effort on the Synthesis process. In Year 1, we will launch a founding Ventures effort to develop and test methods for teaching high school and college students to apply a synthesis approach to environmental problems and large research questions. "Synthesis approach" in this context, as distinct from the literature on synthetic and systems thinking (e.g., Barton & Haslett 2007), refers specifically to a method that includes: finding the relevant existing information (data), evaluating the quality of that information (e.g., accuracy and reliability), distilling the data to identify patterns, and then arriving at conclusions or opinions. The synthesis approach goes beyond the current inquiry-based science education approach, which also uses evidence to answer/understand questions (Krajcik & Southerland 2010), by developing higher-level thinking (DeHaan, 2009) and new skills. It requires, for example, that students become "information scientists" able to retrieve, manage, and process information in new ways. Older students may learn new computational, modeling, and statistical methods. Younger students may simply need to master the evaluation of information quality and understand the concept of scientific consensus. While some such skills are part of existing curricula, we argue that addressing new questions by searching for, manipulating, and integrating existing datasets is a scientific *approach* that is rarely taught.

To engage the community we will host a **workshop** to: 1) identify the key questions this Venture should address; 2) produce a summary outlining the key questions and rationale behind them; and 3) develop an **RFP** for projects targeting those questions. Possible questions include: What methods exist to train students from pre-college and college in the process of environmental synthesis? What groundwork could be laid in high schools and built on during college? The ~40 participants, determined through both invitation and open application, will include education scholars, environmental science teachers, and researchers from diverse fields (e.g., sociology & psychology of learning, cognitive processes). We anticipate interactions with and involvement of participants from some of NSF's Science of Learning Centers and certainly our Gallaudet partners at the Visual Language and Visual Learning Center.

The workshop report will be vetted by the Synthesis Council and EAB, and then will be web-posted along with the RFP so we can begin accepting proposals to synthesize existing studies, data or theories. To maximize exchange across projects, we will stipulate that meetings for research teams funded for this founding Venture will be held during Summer 2012. We anticipate funding 2-6 proposals, depending on their scope and the number of participants. Dr. Alan Berkowitz has agreed to lead this workshop and contribute to the ensuing proposal review. The **products** from this Ventures effort will include scholarly articles (e.g., on pedagogy) and curriculum development materials. With

this initiative we also seek to alert the community that we are eager for novel education proposals and want to continue to fund in this area throughout the life of the center.

Engaging Undergraduates in Environmental Synthesis. We will actively involve undergraduate students in EnSynC activities as well as support the development of environmental science course material to engage students in conducting environmental synthesis projects or exercises.

1. During the first two years of EnSynC, a team of "Faculty Coordinators for Education Innovations" (Fig. 1) along with several undergraduate students will lead a project to develop environmental science synthesis course material. The Coordinators are: 1) Dr. Karen Lips from UMCP, where undergraduates represent a broad mix in terms of gender, ethnicity, age, and learning abilities that are typical of large state schools; 2) Dr. Caroline Solomon from Gallaudet University (GU), an institution that leads the world in educating the deaf and hard of hearing (DHH); 3) Dr. John Bishop from Washington State University-Vancouver (WSUV), an institution whose student body is dominated by non-traditional undergrads (i.e., those who started college late and/or work more than 35 hrs per week and/or enroll only part-time); and 4) Dr. Mintesionot Jiru from Coppin State University (CSU), which is a Historically Black University in inner city Baltimore. These individuals were selected to represent a cross-section of faculty and institutions that teach diverse types of students, including groups under-represented in STEM areas (National Academies 2006; Hurtado et al. 2007).

These four groups will work jointly during meetings at EnSynC over a period of ~ 1.5 years. The **products** will include new environmental synthesis modules and course materials (syllabi, exercises, etc.) as well as results from "test implementation" of their modules at their home institutions. We hope educators at other institutions will also participate in this testing and thus we will organize a future meeting to synthesize and publish: 1) results from the implementation tests, 2) the commonalities and unique aspects of teaching environmental synthesis across this diverse spectrum of students, and 3) recommendations for subsequent Ventures education efforts that will engage a new group of leaders and participants.

2. We will partner with SimBiotic Software to develop Cyber Laboratories in environmental science that will be suitable for EnSynC-sponsored course development. SimBiotic, a leading developer of science education software (e.g., *EcoBeaker*, *EvoBeaker*, *NerveWorks*), has had NSF and NIH awards for research on biology cybereducation, and their virtual laboratories are used in hundreds of high schools and colleges (Meir et al. 2005; Abraham et al. 2009). They will use a new "SimUText" active learning system to develop 2-3 interactive educational units based on EnSynC research.

Public Outreach through Communications. Communication kits using web-based and printed materials will be developed for the public and key stakeholders in Washington (NGO's, Capitol Hill staff, etc.), in state and county governments (e.g., natural resource managers and planners), and internationally (e.g., the UNEP "audience"). Dr. Bill Dennison, Director of the UMCES "Integration and Application Network" (IAN) program will lead these efforts. IAN's communication experts are well known for their image and symbols library, environmental science communication materials such as the Chesapeake Bay Report Cards, and instructional programs in communicating science. Two or three IAN staff will be housed in EnSynC facilities. IAN will also work with EnSynC staff and RFF to communicate policy-related results of EnSynC initiatives, tailoring reports for project-specific audiences. RFF already develops policy "products" including short research summaries, briefing materials, stakeholder-specific research reports, and public meetings capitalizing on RFF's Washington D.C. location and network of policy audiences.

Local K-12 Activities. Through a partnership with The Nature Conservancy (TNC) we will provide paid internships for students from predominantly minority high schools located in Washington, D.C., Baltimore, and Prince Georges County, MD. EnSynC will act as the "match-maker" to place students with environmental researchers at EnSynC or at universities close to the students' schools. The students' experiences will vary but will likely involve collecting and organizing data for synthesis projects, working with graduate students to develop communication kits, and/or assisting with lab or field research. The Ecological Society is already a partner with TNC in this program and will help de-

velop educational materials. EnSynC's contribution will be well leveraged because TNC already has significant funding from Toyota, Inc. EnSynC will also take advantage of an existing environmental Summer Children's Program at UMCP to test the efficacy of environmental synthesis exercises in programs for young children (7-11 year olds). EnSynC will provide modest funds for a graduate student to work with Dr. Earlene Armstrong to develop modules that challenge children to use a synthesis process to solve problems, i.e., they will identify available sources of information, determine which are most relevant to the question, evaluate the quality of that information, and combine the best information in new ways to reach a conclusion.

Graduate Student Programs. Among EnSynC's diverse opportunities for graduate students will be: 1) funding for short visits to interact with EnSynC faculty or Pursuit groups; 2) participation in EnSynC workshops or short-courses, on topics such as novel modeling or computational methods, sponsored by funded Ventures; and 3) paid assistantships working with the Synthesis Council. Graduate students working at EnSynC for a week or more will also be included in our postdoc mentoring program (Section 3.3). We seek to build the technical and communication skills of graduate assistants *and* to mentor and support them as they pursue their own research.

Postdoctoral Fellowships. EnSynC will award four or five new two-year fellowships each year, resulting in a steady state of 8-10 resident postdocs. Postdoctoral fellows will be expected to conduct original synthesis research and to become 'students of synthesis' by direct involvement in center activities. Applicants will be required to propose a synthesis project within one of the current Themes and to identify a synthetic activity that interests them. Applications will be evaluated by the EAB and leadership team based on their credentials and proposed synthesis activities. Given equal credentials, awardees will be chosen to maximize disciplinary diversity and gender, ethnic, and geographic balance. The mentoring plan is fully described in Section 3.3, but we emphasize that postdoctoral research efforts would be treated like Pursuits, hence given full access to Synthesis Council support.

Sabbatical Fellowships. Awarded competitively through the Pursuits or Ventures program, these fellowships will carry up to $45K of salary plus a monthly allowance. We will seek a diverse group of fellows representing the natural sciences, economics, policy, and other social sciences. In addition to their synthesis research, sabbatical fellows will be expected to run one or more sessions, related to their research methodologies, for Postdoctoral fellows and graduate assistants.

2.5 Facilitating Synthesis Both Vertically and Horizontally. In addition to supporting individual Pursuits and Ventures, our center will expand synthesis efforts to integrate across projects and Themes, and, through Horizontal Synthesis, by quantitative and qualitative analyses of the synthesis process itself. Thus EnSynC is promoting two categories of synthesis*: vertical* and *horizontal*. Pursuits and Ventures are examples of vertical synthesis (see Box 6).

Vertical Synthesis is the coupling of knowledge, tools and people from the natural, social, engineering and computational sciences leading to new discoveries as well as solutions to environmental problems that are intractable without a transdisciplinary synthetic approach. The Pursuits and Ventures programs are the primary vehicles for this; however, other proposed activities will play a role in discovery. For example, the Ventures education workshop (Section 2.4) should lead to the development of fundamentally new ways (i.e., "*discovery*") to teach students to gather and distill complicated environmental information to reach conclusions.

Box 6

Vertical Synthesis

to advance environmental science through discovery and solutions

Pursuits

Ventures

Horizontal Synthesis

to advance the synthesis *process*

Synthesis across Themes, Ventures & Pursuits
to identify transferable theories, methods, & tools

Qualitative & Quantitative Analyses
of Center-collected data, participant-generated data, and external evaluations to contribute to Center evolution and contribute knowledge on what promotes effective environmental synthesis

Horizontal Synthesis for Discovery and Center Evaluation – Horizontal synthesis requires that we evaluate what has been accomplished, and then use those results to further those accomplish-

ments. Our focus on promoting Horizontal Synthesis corresponds to the well-established principles of single- vs. double-loop learning (Argyris & Schon 1978), in which an organization doesn't just rely on an *ad hoc* process to grow and improve, but instead builds an organizational learning and adaptation process into its structure. Therefore, horizontal synthesis involves "looping back" to what has been or is being done at the center and is fundamental to accomplishing the fourth EnSynC goal outlined on the first page of this proposal. We employ horizontal synthesis in two ways: 1) synthesizing across Themes, Pursuits or Venture projects to identify approaches (e.g. modeling, computational), theories, or data that may be transferable to other questions and systems, and 2) completing qualitative and quantitative analyses of data we gather on the center, its users, their experiences, and data from external evaluations. Effectively, these two Horizontal Synthesis activities (identifying transferable knowledge; data analyses) constitute a significant form of center evaluation. However, because these activities are integral parts of the EnSynC center model, Horizontal Synthesis will be recursive and result in center adaptations while simultaneously producing findings that can apply to other centers and the research projects they sponsor far more than would a routine evaluation tool.

Horizontal Synthesis across Themes and Projects. Approximately 18 months after the center's inception, Theme Leaders will convene with the Synthesis Council to discuss unique discoveries being made ***and*** commonalities emerging among all ongoing Pursuits and Ventures. Facilitated discussions will focus on developing opportunities to leverage these results in new ways that enhance individual efforts and thematic impacts. Results will be communicated to Pursuit teams and the EAB. At the beginning of the third year, we will convene a full EnSynC conference, similar in design to the highly successful Gordon Conferences. Pursuit Team leads will present their findings, as will Theme Leaders, who have a broad view of progress made within their portfolios. Presentations will be followed by facilitated sessions among researchers, EnSynC leadership, students, and invited participants from the policy sector. Outcomes of facilitated sessions will be summarized in a series of EnSynC white papers that will be widely distributed and will provide critical input to our next strategic planning process.

Horizontal Synthesis Database Analyses. Within the first three months of the center's inception and as part of the Strategic Planning Process we will begin building a database to archive information in two categories: 1) center, project, and participant data; and 2) data generated from participant-reported experiences and from external assessments. The former will capture attributes of participants, synthesis projects, and synthesis approaches. The goal is to gather information over time that will allow us to ask questions such as: Are there attributes of a project or its team that are associated with the successful development of high-impact synthetic products? Where do environmental data sources typically originate (national repositories, individual scientists, etc.) and how can access to them be enhanced? Do particular types of coordination and leadership achieve stronger outcomes both across Themes and within thematic portfolios?

For the second category of data, we will use well-accepted qualitative research methods (e.g., Braun et al. 2006) to design surveys for all EnSynC participants to assess their experience at EnSynC (e.g., as in Hara et al. 2003), their description of and views on the synthesis process that was employed by them/their group, their assessment of the value of the project outcome, etc. We will also use a Peer Review process to gather qualitative data from members of the external community asked to evaluate research project quality, center effectiveness, value of center resources, etc. The full design (e.g., data fields, survey questions) will be completed during strategic planning. At that time, we will also invite other NSF centers, such as iPlant, NESCent and NIMBioS, to collaborate with us by applying a similar evaluative effort in their centers.

To facilitate early progress in developing an understanding of effective synthesis, EnSynC will partner with NIMBioS to formally analyze the database that NCEAS developed regarding the purpose, composition, process, and outcomes of working groups funded by that center. Rhoten (2003) and Hackett et al. (2006) studied group network dynamics at NCEAS, which yielded interesting findings, but an in-depth analysis of the detailed NCEAS database, which is housed at NIMBioS, has not been completed nor published (L. Gross, pers. comm.). It is ripe for exploration as a case study of

Horizontal Synthesis as we seek to promote the growth and maturation of synthesis. NIMBioS Director Lou Gross has expressed interest and willingness to provide access and input on the project.

Outcomes from Horizontal Synthesis: All of these evaluation processes and data analyses will contribute to Center evolution so EnSynC can adapt its processes to advance environmental synthesis. EnSynC will thus function both as a catalyst to engage the broad community and as a "laboratory" in its own right, to facilitate learning about and improving the process of environmental synthesis. By analyzing data about the synthesis process, over time we will learn more about the factors that promote effective synthesis and an effective center (Rhoten et al. 1999). This focus on process is at the core of Horizontal Synthesis, and it is grounded in the successes of related approaches in other disciplines. For example, social networking analyses have been employed to understand what types of lasting collaborations emerge from working groups and other types of center-facilitated research teams (Aboelela et al. 2007). The Synthesis Council and Theme leaders will play pivotal roles in overseeing Horizontal Synthesis efforts and inaugurating the EnSynC Database; however, answering the critical questions related to center effectiveness and the process of synthesis really constitutes a longitudinal study that will require time and the involvement of outside expertise, especially social science scholars interested in how interdisciplinary approaches can be better developed to solve complex problems.

Section 3. Mechanisms for Selecting, Funding, and Facilitating Projects

The EnSynC leadership is committed to providing a transparent and fair process for including the community in activities and funding projects. We also are committed to providing extensive support for EnSynC participants and a strong mentoring program for Postdoctoral Fellows. Here, we describe the mechanisms for ensuring these commitments are met.

3.1 Mechanism for Selecting Pursuit and Venture Projects to Fund*. S*ynthesis proposals will be solicited through a Request for Proposal (RFP) process that will differ among the funding programs.

Requests for Proposals for the Pursuits Program. RFPs will be announced twice per year (once in Year 1); each RFP will focus on a different Theme. The Theme leader will develop a description of the Theme and its goals, which will be vetted by the Synthesis Council and EAB prior to posting. Additional, smaller, more-focused solicitations on a Theme may be released as work progresses and additional needs are identified. The solicitations will request short (<5 pages) proposals from individuals or small groups of researchers (2-3) that address the following proposal evaluation criteria:

- The importance of the proposed Pursuit to the Theme--why addressing the problem or question outlined in the Pursuit proposal is critical to making progress on the "big issue" (Theme);
- Possible areas of inquiry within the Theme that would complement the Pursuit proposed;
- Possible data issues, computational needs, or other resource requirements;
- Metrics that will be used to gauge project success in the context of the Theme;
- Potential target end-users and, when appropriate, an outline of the study's broader policy context;
- Time commitment of PIs to the project and timeline for meetings, and
- How diversity of participants will be addressed.

Requests for Proposals for the Ventures Program. A standing RFP will be posted on our website and proposals will be accepted at any time. The same criteria as above will be used *except* the proposals need not be related to a current center Theme and the first two criteria, above, will be restated to clarify that proposals must convincingly demonstrate the project is one of the following:

- Novel or urgent (if PIs believe it is high-risk, they should outline why the risk is worth taking);
- Capable of integrating across Themes or contributing substantially to the advancement of the environmental synthesis *process* (new theories, tools, approaches, studies of the process), or
- Likely to lead to new ways to translate information for educators, policymakers or the public.

Venture projects may take a number of forms, including small-scale efforts to develop a cross-cutting tool, workshops to discuss and refine a new translation product(s), or larger efforts that contribute to the development of cybertools to support synthesis (such as Open Cobalt, ResearchGATE, and

Sciencestage). We will also encourage researchers from outside the center, particularly those who articulate novel approaches to examining the synthesis process itself, to study EnSynC. As with other Ventures, these efforts should have the potential for high payback over time. In short, we expect the Venture proposals to engender creativity within the community and expect a subset will lead to major new findings that are "paradigm shifting," or, result in the development of new approaches or tools that are applicable to multiple questions and systems.

Review of Proposals. The EAB, the Synthesis Council, and experts drawn from the external community will evaluate and rank proposals based on each of the above criteria; for Pursuits, the respective Theme leader will also participate. To ensure a broad spectrum of views on proposals that investigators self-report as high-risk/novel, we will rely on a very diverse and fairly large pool of reviewers (Furman et al. 2006). Reviewers will include a team with representatives from the EAB, our postdocs in residence, policymakers, representatives from NGOs, and ad hoc reviewers. Proposal reviews will be discussed by the EAB and Synthesis Council, and a subset of projects will be selected that are highly ranked along the program criteria.

3.2 Synthesis Council Mechanisms for Facilitating and Supporting Synthesis Project Efforts. Lead investigators of the selected Pursuits or Ventures will be asked to join a conference call/video conference with the EnSynC Executive Director, the Director for Synthesis Process and Facilitation (and, for Pursuits, the Theme leader), in which all will develop a shared understanding of anticipated needs, known challenges, and potential target audiences for the work.

PIs will then be invited to Annapolis to work at EnSynC for approximately two days to participate in a series of collaborative design sessions ("charrette") flesh out their ideas, work with members of the EnSynC Council to determine resource needs (e.g., technical or expertise), discuss issues pertaining to data access and formats, and identify individuals who should be invited to participate in the project. Specific milestones will be agreed upon after discussing success metrics PIs proposed. The Synthesis Council will also work with the PIs to understand the broader implications of the work and will begin to identify target audiences for the outputs and potential routes to translate the information, recognizing these may change as the study evolves. Our intent is to create an environment and process through which researchers can grow and refine their ideas using EnSynC resources (funding and leadership expertise) before they commit themselves to an approach and a full synthesis team. Further, we know from previous experience with interdisciplinary research projects, as well as with NCEAS projects, that it is not always easy to identify either the most suitable participants or potential resources for a project. For example, projects may benefit from having participants outside of the intellectual circles of the project leads, projects may require expertise that the leads know little about, or there may be unrealized computational or visualization tools that could be brought to the project. The Synthesis Council and staff can provide vital input by offering advice, providing requisite expertise, and/or enlarging the pool of potential participants.

We recognize that different projects will have different needs. For example, some may require intensive computational support, whereas others may benefit most from a facilitated group process or expert elicitation methods. Some PIs may come to the Center with a very specific, well-formed idea and a robust approach that simply requires technical expertise (e.g., computational) or help with translating results to non-scientific audiences. For technical needs that EnSynC cannot meet, we will work to identify outside experts, resulting over time in an expanding network that will build capacity in the research community and beyond. We will calibrate our involvement as needed in the early stages of the effort. We seek to attract both senior and junior scholars interested in synthesis, and to help them forge new connections between environmental and social sciences.

3.3 Mechanisms for Mentoring Postdoctoral Fellows. Members of our leadership team have long records of mentoring postdoctoral researchers on to successful careers. Building on this experience, EnSynC will provide both individualized and group mentoring.

Individual Mentoring. Postdoctoral Fellows will be paired with two local mentors: one to offer advice on their core research and one to help grow their synthesis skills. The research mentor will be se-

lected in consultation with the Fellow based on his/her general research area; the synthesis mentor will be selected for optimal match between the postdoc's synthesis interests and the activities that members of the leadership team oversee. For example, a postdoc who proposes research to synthesize migrations and hotspots of highly migratory fish, but has interests in the use of emerging telemetry and visualization tools, might take Bill Fagan as research mentor and Joseph JaJa as synthesis mentor. Fellows will be expected to spend approximately 1/3 of their time on some aspect of synthesis at the center. Examples might include working with the Synthesis Council, designing communication kits for outreach, assisting with the application of geospatial analyses to specific Pursuits, or working with RFF to organize Science Briefings or Mission Meetings.

Group Mentoring. The mentoring program for EnSynC Postdoctoral Fellows will span four areas that we believe are critical to a successful career in environmental science or allied areas in policy, social science, or education: 1) Publications and Grant Writing – Biweekly group meetings will focus on topics such as writing techniques and time management of writing vs. other research tasks; deconstruction of scientific papers and proposals, and learning to see a document as a reviewer or panelist would; assessing journals to which papers and proposals should be submitted based on the topic, desired audience, and impact factor; how to best illustrate papers and proposals; and the peer-review process (and how to be a constructive reviewer). The Fellows will organize the mentoring schedule to best suit their needs, but all members of the Synthesis Council will devote time each year to these meetings. 2) Communicating and Translating Science to Diverse Audiences – EnSynC faculty will provide guidance on such topics as constructing effective oral presentations for technical audiences or classrooms, preparing materials for policymakers, speaking to the press and writing for general audiences. Director of Education M. Raupp has extensive experience in teaching and mentoring students in science translation; he will provide opportunities for Fellows to engage directly with the media. EnSynC team member Bill Dennison has written books on this topic and co-teaches a class on science communication; he will lead periodic workshops with input from others. 3) Teaching and Mentoring the Synthesis Process – We expect relevant materials to emerge from the Year 1 education research project on how to teach synthesis, how to mentor students undertaking synthesis efforts, and how to integrate synthesis in outreach activities (Section 2.4). Fellows meet periodically with A. Berkowitz to discuss how *they* can best mentor their future students in synthesis methods; 4) Juggling Competing Demands, Workload and Personal Time. No simple formula exists for mentoring young scientists on how to cope with the immense time pressures they typically face. Our experience suggests, however, that explicitly focusing on these issues helps young scientists to better organize their time and say "no" to requests that do not reflect their priorities, thereby achieving peace of mind. Multiple demands are a particular issue for women, minorities and disabled scientists, who are disproportionally at risk for committee work, panel service, and the like. The EnSynC director will organize relevant panel discussions.

Section 4. Management: Partners and Staff

We will strive to be a vital platform that helps the scientific community answer what have previously been unanswerable questions and to translate those findings to stakeholders. This requires an approach designed to foster synthesis in vertical and horizontal "dimensions" and a committed leadership with expertise in the natural, social, and computational sciences and policy realms, as well as expertise in facilitation and organizational management (see Fig. 1).

4.1 *EnSynC Leadership and External Advisory Board*

Executive Director. Dr. Margaret Palmer will serve as the **Executive Director and Director of Environmental Science** for EnSynC. In addition to a distinguished scientific career, Palmer has extensive management experience directing large research programs and synthesis teams, and a track record of effectively managing a large center budget and personnel. She has served as chair of the NCEAS advisory board, as a past program officer at NSF, and on the National Ecological Observatory Network (NEON) design group. She is director of the Chesapeake Biological Laboratory (CBL), where she oversees an annual budget of approximately $14M for a stand-alone research lab with 22

buildings and 120 resident staff. If this proposal is successful, Palmer will step down as CBL director to become EnSynC executive director.

Synthesis Council. Additional strategic leadership is from the transdisciplinary **Synthesis Council**, an eight-person team that includes Palmer, the four directors and three Assistant Directors, described below (and in Section 2.1). Directors will have personal responsibility for the multifaceted aspects of EnSynC's operation; specific roles are given in Box 3. As the central body within EnSynC, the Synthesis Council will contribute to vertical synthesis by directly supporting researchers funded for a Pursuit and will contribute to Horizontal Synthesis by transferring knowledge across Pursuit teams, among Themes, and beyond.

The Director of Social Science & Policy will be Dr. Jim Boyd, Senior Fellow at RFF, who will engage economists, policy science experts and other social scientists in EnSynC activities. Working with the user community, the director will implement novel approaches for engaging policymakers, members of the business community, environmental users and leaders. This director will also identify and recruit experts who can assist Pursuit teams in the design, deployment, and evaluation of synthetic analyses motivated by government, NGO, and private sector conflicts, decisions, and choices.

The Director of Synthesis Process & Facilitation will be recruited to meet the goals outlined for our progressive emphasis on the facilitation of synthesis. This full-time director will chair the Synthesis Council, cultivate the EnSynC process, and facilitate the charrette model of collaborative design to help users fully develop Pursuits and bridge disciplinary barriers. This director will also oversee EnSynC evaluation and assessment activities. We will recruit a PhD level professional with expertise in facilitation, mediation, and team management.

The Director of Cyberinfrastructure will provide advanced data management, computational platforms, modeling and visualization tools, and databases for environmental synthesis to EnSynC, as well as work with other NSF centers to synergize IT efforts. To ensure that service and products are flexible and adaptable, the director must have a broad view of the current state *and* future direction of IT and related fields and how they can aid in synthesis. Prof. Joseph JaJa of the UMCP Depts. of Computer Science and Electrical & Computer Engineering will assume this position. He previously served as director of the prestigious UM Institute for Advanced Computer Studies (UMIACS) and currently is the Interim Chief Information Officer for UMCP, so he is an ideal choice for this position.

The Director of Education & Outreach will be Prof. Mike Raupp (UMCP), who has received numerous awards for his efforts in environmental education, extension, and media relations. He will organize and orchestrate our education and outreach activities by leading a team of Faculty Coordinators that will contribute to innovative educational and outreach initiatives. He will help with the Education Research project as needed and will directly interface with partners in the undergraduate course development activities, as well as the CyberLab and TNC partnership for urban high school interns.

Assistant Directors for Research Innovation**.** Three faculty members focusing on Research Innovation initiatives will bring expertise in the natural sciences (Prof. Bill Fagan, UMCP), the social sciences (Prof. Joan Nassauer, Univ. Michigan), and the geospatial sciences (Prof. Stephen Prince, UMCP). As members of the Synthesis Council, these faculty members will draw upon their complementary backgrounds and research networks to help guide the development and progress of Pursuit teams. They will also jointly manage the EnSynC Ventures program and provide critical guidance to key IT staff with expertise in GIS and research involving digital information.

External Advisory Board (EAB). Based on nominations from the external community and the advice of the Synthesis Council, the executive director will, in direct consultation with NSF, appoint an EAB. The EAB, which will broadly represent the needs and interests of the user community, will include policymakers, members with technical expertise, and members with experience leading scholarly centers. We anticipate that the EAB will have approximately 15 members to accommodate the anticipated workload, reflect the breadth of disciplines involved, and promote diversity with respect to race, gender, disability status, and ethnicity. We expect initial EAB appointments to be for 2-3 years with replacements staggered to interject new ideas and perspective while avoiding the loss of institu-

tional memory regarding EnSynC's history, operations, and future plans. The EAB will provide guidance in the strategic planning process and review and recommend proposals. Drawing on some of our institutional partners, as well as the broader community, we have identified a suite of potential nominees for the EAB, including: Mr. Paul Allen (Senior VP for Corp. Affairs and Chief Environmental Officer, Constellation Energy), Prof. Arun Agrawal (University of Michigan), Prof. Karin Frank (Helmholtz Centre for Environmental Research-UFZ, Germany), Dr. Peter Groffman (Cary Institute for Ecosystem Studies, Millbrook, NY, and Baltimore LTER), Dr. Tony Janetos (Joint Global Change Research Institute, Pacific Northwest National Laboratory and UMD), Prof. Bonnie McCay (Rutgers University), Prof. David Snyder (Gallaudet University), Prof. Tom Sterner (Environment for Development (EfD) Initiative at Univ. Gothenberg, Sweden), and Prof. Geoffrey Heal (Columbia University).

4.2 Administrative Staff. The administrative infrastructure will fully support EnSynC.
Associate Director for Administration & Finance Management. As a full-time position, the associate director will oversee the day-to-day operations and logistics of the Center, manage Center finances, and coordinate staff activities. We will seek an accomplished professional with extensive experience in academic administration who is familiar with proposal processing, budgeting, human resource issues and personnel management. Ideally this person will be familiar with academic center administration, federal agency sponsored research and the state's budgeting process, all of which will assure a fast-paced but smooth startup.

Administrative Staff. To ensure efficient operations, EnSynC will require five center-resident administrative staff members (4.0 FTE). An Executive Administrative Assistant will provide organizational and office support to the Executive Director and the Associate Director and will serve as the initial point of contact for visitors. A Communications Manager will manage the Center's telecommunications and videoconferencing efforts, coordinate dissemination of results and achievements, and assist the Synthesis Council with outreach and translation. An Accounting Clerk will process reimbursement requests and assist the Associate Director with financial and budgetary matters. A Travel, Housing & Event Manager (0.5 FTE) will plan Center activities, arrange participation of outside visitors and coordinate joint activities with partner institutions. An Evaluation and Assessment Assistant (0.5 FTE) will provide detailed recordkeeping solutions for all Center activities and work with UMCP and outside experts to craft and deploy assessment and evaluation tools. A final administrative staff member, an Education and Outreach Assistant (0.5 FTE), will be based at UMCP to assist the Director of Education & Outreach by coordinating arrangements necessary to implement proposed activities. Supplementary hourly support will be available to meet surges in demand.

4.3 *Cyberinfrastructure Staff.* To meet our cyberinfrastructure and data management goals and provide critical computational and visualization resources and expertise to EnSynC participants, the center will need five IT staff (4.5 FTE): 1) a Computing Manager with expertise in general IT, network administration and scientific computation; 2) a Systems Administrator; 3) a GIS Analyst; 4) a Webmaster (0.5 FTE) and 5) a Digital Information Research Specialist (DIRS), whose duties are detailed below. The computing manager's time will be split between the UM Institute for Advanced Computer Studies (UMIACS) and Annapolis (50-50), whereas the remaining four will be 100% in Annapolis. This structure will allow us to easily transfer expertise/technologies between UMIACS/UM Office of Information Technology (OIT) and Annapolis, and to bring in resources from UMCP as needed on a temporary basis. Managerial and advisory relationships are presented in Fig. 1.

4.4 Strategically Selected Partners. The EnSynC collaborators from UMCP, UMCES and RFF strategically identified and then recruited external partners from other institutions that have areas of strength that will enhance EnSynC capabilities. We sought: 1) international partners with a presence in the developing world plus expertise in the social sciences, environmental modeling and/or unique digital data resources; 2) US educational partners that collectively serve a highly diverse community of students and 3) preeminent organizations in the conservation, academic, and business communities whose expertise complements that of the EnSynC leadership and other partners. Eleven partner institutions have enthusiastically agreed to collaborate with EnSynC in one or more critical focal areas: The Helmholtz Centre for Environmental Research-UFZ in Leipzig, Germany, was selected

because it undertakes a variety of projects using a data-synthesis approach as part of its research program and it provides particular expertise in data-based environmental modeling bridging the natural and social sciences. The UFZ also will provide EnSynC users full access to their high-performance computing and visualization facilities, and they will work with us to identify international partners for specific projects (see letter of commitment). The Environment for Development Initiative (EfD) at the University of Gothenburg (Sweden) was selected because of its focuses on sustainable development and environmental economics that are grounded in the premise that social and/or economic mechanisms must go hand in hand with technical solutions proffered by the natural and physical sciences. This is a fundamental aspect of the EnSynC model, and EfD's focus on developing countries brings an important perspective to EnSynC. Our strong European partnerships place EnSynC in a unique position to study socio-environmental problems of joint US-EU concern, such as the production of biofuels and the impact of melting Arctic sea ice on trans-Atlantic shipping.

We also formed partnerships to enhance our programs on pedagogy and curriculum, which focus on teaching the synthesis *process* to diverse student groups. We call the faculty who fulfill these roles Coordinators of Education Innovation & Outreach. The partner organizations include: 1) Washington State University Vancouver, which is a premier non-residential undergraduate institution (with RUI status) that serves nontraditional undergraduate students and has strengths in environmental education and research, 2) Gallaudet University, Washington, DC, which is the world leader in liberal arts education and career development for deaf and hard of hearing (DHH) students (nearly 40% of their DHH students are also minorities); 3) the Baltimore Ecosystem Study (BES), administered by the Cary Institute for Ecosystem Studies, which has outstanding environmental science education programs, and 4) Coppin State University, a Historically Black University in inner city Baltimore with historic strengths in curriculum review and improvement.

We sought a collaboration with The Nature Conservancy because they are the leading conservation organization working around the world to protect ecologically important lands and waters for nature and people. They have committed to making all of their conservation data available to EnSynC and will cooperate with us in several areas, including ecoinformatics, conservation meta-analysis and an innovative environmental science education and internship program focusing on inner city high school students (with funding from Toyota; see letter from P. Kareiva). We also welcomed our neighbors in College Park, the Joint Global Change Research Institute (JGCRI), because they will provide links between EnSynC activities and integrated assessments of global change, such as those underlying the IPCC, US national assessments and, potentially, the new IPBES.

Finally, to ensure strength in the social sciences beyond what is present at the lead institutions, we invited Prof. Joan Iverson Nassauer, who heads the Landscape Ecology, Perception and Design Lab at the University of Michigan, because of her expertise in landscape aesthetics. Because we hope, in the future, to build bridges with the business community on issues, a key leader from Constellation Energy, Inc, Paul Allen, accepted our invitation to provide guidance as we learn more about business needs and perspectives on the issues researchers study through EnSynC.

Section 5. Cyberinfrastructure

To create new opportunities for synthesis while minimizing duplication of resources available and research efforts underway elsewhere, EnSynC's digital efforts will focus on three areas. First, in keeping with the center's emphasis on research facilitation, EnSynC will focus on data aggregation, integration, and access for innovative synthesis. Second, EnSynC will quickly establish a robust, reliable, and cost-effective cyberinfrastructure to ensure smooth operation of the Center and facilitate synthesis. Third, EnSynC will deploy the latest IT to support the Center's innovative organizational structure and provide services that accelerate research discovery, science translation, and collaboration. Initial infrastructure will support storage, management, and integration of heterogeneous datasets, as well as computationally intensive analysis, modeling, and visualization across diverse environmental datasets. Advanced collaborative and visualization environments, high performance

computing, data analysis and mining technologies, and knowledge integration and access technologies will be gradually introduced when called for as part of the Pursuits and Ventures programs.

EnSynC will draw heavily on the technical expertise and resources available through UMIACS and OIT. A Cyberinfrastructure Advisory Committee, which will include representatives from EnSynC, UMIACS/OIT, and IT units of selected national centers, will meet twice per year to guide the evolution of the Center's cyberinfrastructure in accordance with the Center's Strategic Plan (see Fig. 1).

5.1 Aggregating, Integrating & Providing Access to Digital Information. Each EnSynC Theme will require large amounts of data from diverse sources, spanning the ecological, environmental, climatological, economic, and social arenas. The Center will hire a dedicated, Ph.D.-level **Digital Information Research Specialist (DIRS)**, who will support research activities at EnSynC via the assembly, organization, documentation, and maintenance of all the various datasets and attendant metadata needed for EnSynC's user community. The Center will have a central web-based digital data collection, complemented by Theme-specific collections. The DIRS will build and maintain collections, which will serve as data portals for Center activities. Where external sources of data exist in stable archives, the data portal will link to the original archive; where data have been developed "in-house" or external sources of data are not stable, the portal will link users to information. Each Theme will have its own "vertical information portal" that will link users to a stable, annotated and searchable index of relevant data. The DIRS will follow industry standards for digital curation, defined as "the active management and appraisal of data over the entire life cycle…emphasizing opportunities for added value and knowledge through annotation and continuing resource management" (Pennock 2006).

EnSynC's data portals will include a comprehensive collection of social and economic data. Domestic data on demographics, infrastructure and economics are available from the US Census Bureau, Bureau of Labor Statistics and Bureau of Economic Analysis. Our partner, the University of Michigan, is home to the Institute for Social Research, which includes the Population Studies Center, the Inter-university Consortium for Political and Social Research (the largest US archive of quantitative social science data) and data from the National Opinion Research Center. EnSynC participants will also be able to access international social science data from the US Census, the World Bank's Open Data Initiative, United Nations Statistics Division, the Organization for Economic Cooperation & Development, and the Council of European Social Science Data Archives (CESSDA).

The DIRS will also integrate a host of biological and environmental monitoring datasets into the data portals. The Long-term Ecological Research (LTER) network provides multidisciplinary datasets for each of its 26 research stations. More-focused monitoring efforts that can be tapped for data include NEON (providing future data on US land use change and natural resources), the Global Lake Ecological Observatory Network (GLEON, providing lake and reservoir observation data), the Arctic Observing Network (AON, providing cross-disciplinary environmental data for the Arctic), the Global Terrestrial Observing System (GTOS, providing networked observation & modeling of terrestrial ecosystems) and NOAA's Integrated Ocean Observing System (IOOS, providing ocean and coastal data). Regional or continental-scale analyses often require remote sensing data, such as those captured by earth-orbiting satellites and aggregated by the Global Land Cover Facility (housed at and co-sponsored by UMCP). The Department of Geography (UMCP) is a world leader in the generation and analysis of remotely sensed data. EnSynC will have access to TNC's data assets, including conservation data from their 1000+ projects worldwide and their collection of GIS data and maps.

The central and Theme-specific data portals curated by the DIRS will link directly to the relevant data themselves, rather than simply to the homepages of the various data sources. Where data are available in a non-standard format, the DIRS will repackage data to make them easily accessible to EnSynC users using software available at or through EnSynC. Where possible, data will be exported to formats that are open-source and/or freely available for multiple platforms so that data accessibility is no barrier to the exchange of information within or across Pursuits. When necessary, the DIRS will work with the Director of Cyberinfrastructure to leverage technical expertise from UMIACS and OIT to assist with especially challenging problems of data fusion and integration. The DIRS will ensure

that all metadata and/or documentation materials are available in English. These efforts at computational and literal translation will be key features of EnSynC's data portals because the breadth of disciplines and international focus can create roadblocks to data synthesis. The DIRS will also harvest relevant data from the published literature including, but not limited to, Data Papers published in *Ecology* and Supplementary Materials published online for many other journals. Where additional unpublished but Theme-relevant data exist, the DIRS will seek to partner with the original researchers to integrate such data into EnSynC's data archive and to participate in Pursuit teams, as appropriate. The Theme-based data portals will provide a natural opportunity for Pursuit teams to include international experts, including those coming from EnSynC's European partners. In turn, such geographic diversity will be a resource for the DIRS as new data resources are identified, as it will quickly expand EnSynC's efforts beyond what can be offered in its initial phase. Leveraging the community's skills and expertise to greatly enhance data aggregation, integration, and access will be built into the center's strategic plan.

The thematically structured digital data collections used in the context of EnSynC's work plan will also be integrated into a set of external digital data collections, such as those stemming from the NSF's DataNet program (e.g., DataONE, the Data Conservancy). DataNet is to support open access to secure, peer-reviewed, and stable digital data for use in the practice and education of science and engineering. In this way, the outputs of each Theme will include not only the research and analysis outputs, but also a comprehensive, Theme-based collection of datasets and associated metadata that can facilitate additional synthesis by the community. By aggregating, integrating, and providing access to Theme-specific data, EnSynC can have a multiplicative effect on the research community and can serve a number of cyberinfrastructure efforts that are currently underway or about to begin.

We emphasize that EnSynC's plan for digital data resources is unique in its Theme-based but cross-disciplinary approach. Whereas other digital asset collaborations, such as NatureServe or the Global Biodiversity Information Facility, aggregate information on a particular subject (e.g., species occurrence data), EnSynC's approach will be to broaden the discussion and give researchers from all participating disciplines direct access to data from diverse sources, with the data portals creating a Theme-based context for the analysis. With social, physical, and environmental scientists coming together over thematically structured databases of information, true synthesis and creativity will flourish.

5.2 ***Robust, Reliable and Cost-Effective Initial Infrastructure.*** Within Yr 1, we expect to establish a robust operational IT infrastructure that provides core services efficiently and reliably, including:

Services within a Virtualization Environment. These include email, shared calendaring, file sharing, Web & ftp servers, conferencing software, source code control and management, online project management, online community sites and Web application hosting. The environment will have reliable shared storage and servers supported by a virtualization environment, such as VMware vSphere (Palo Alto, CA).

Networking. EnSynC will set up a Local Area Network (LAN) that will support at least a gigabit (Gb) Ethernet to each desktop and at least a redundant 10-Gb Ethernet between each telecommunication closet. EnSynC will also establish a wireless network with full coverage of its space and enhanced coverage for meeting areas, which will be expected to support groups of 30+ people. In addition, the wireless network will support access for both authenticated users and registered guests.

Analysis and GIS Resources. EnSynC will provide approximately eight technical workstations and two large memory multiprocessor systems to support analysis, visualization and GIS tools.

Data Center. EnSynC will acquire at least 50 TB of storage to be shared between administrative and research computing systems. All the servers will be located in the data center under a virtualized environment that will provide resilience, high performance, and economies of scale. The data center will set up database servers (relational and spatial) to support GIS processing, mapping, and metadata management. A cost effective backup and data protection strategy will be developed to leve-

rage large IT infrastructures available through UMIACS and OIT. During Year 2 we expect to set up a small cluster in the data center to support Pursuits and Ventures.

Interested readers can access tentative detailed configurations of the initial core cyberinfrastructure and a tentative list of the Year 1 software tools and packages.

5.3 *Advanced Technologies for Accelerating Research Discovery and Collaboration.* During the past two decades, dramatic progress has been made in the generation of environmental datasets; the development of new models, algorithms and methodologies for analyzing and mining complex datasets; and the creation of novel computer architectures and software technologies. These combined achievements allow for new approaches to major research challenges in environmental science. Unfortunately, advanced computer technologies and algorithms have a restricted client base because of their significant complexities and the fast pace at which they are evolving. We will draw on the latest advances in computing technologies to gradually introduce tailored tools and services to support transformational advances in Pursuits and Ventures (see Example in Box 7).

UMIACS will lead EnSynC's efforts in training researchers and developing appropriate tools in close coordination with the Center's investigators. UMIACS has extensive experience in setting up and supporting novel high-end computing systems and applications. UMIACS technical staff currently supports > 50 faculty members across 14 labs and centers; their activities involve the use of the latest high-end parallel and distributed computing platforms and the most advanced storage and networking technologies. In the past 10 years, UMIACS has been a partner to a number of major efforts in environmental science and computational biology at Maryland, including, 1) the establishment of the Global Land Cover Facility (GLCF), which currently holds over 15TB of heavily downloaded land cover datasets; 2) the establishment of the Center for Bioinformatics and Computational Biology (CBCB), a leading center in bioinformatics and genomic research, and 3) the newly established NVIDIA CUDA Center of Excellence that includes unique, high-end visualization and computing capabilities supporting data-intensive applications in science and engineering. UMIACS has substantial expertise in five key areas (below), and EnSynC can draw upon these to support Pursuits and Ventures, when appropriate.

High Performance Computing (HPC). UMIACS's key innovations in this area include the use of multicore Graphics Processing Units (GPUs), which are evolving at an unprecedented rate and offer more general-purpose programmability and much better performance/power ratio than standard multicore processors (e.g., peak performance rates of 4 Teraflops and 16 GB of memory).

Data Intensive Analysis, Mining and Visualization. Recent advances in machine learning and data mining algorithms using a variety of learning models, such as Bayesian networks, support vector machines, and association rules, open up major new possibilities for extracting information to discover patterns and trends in complex environmental datasets. UMIACS has deep expertise in the broad area of machine learning and statistical analysis of biological datasets, which is complemented by a strong national presence in visualization through the well-known Human-Computer Interaction Lab (HCIL) and through the Department of Computer Science Graphics group.

Box 7: Synthesis Example

Statistical Physics and Food Web Dynamics

Quantifying the robustness and resilience of real-world food webs is a long-standing, yet unsolved challenge in community ecology. Fitting coupled, nonlinear, ordinary differential equations that model trophic interactions to time-series data on species and resource abundances is a key challenge that has thus far been limited to simple laboratory food webs (see, e.g., Cao et. al. 2008). However, a novel approach to parameter estimation in complex systems has emerged in statistical physics (Brown & Sethna 2003), and it holds promise for use with poorly resolved data on large, empirical food webs with tens to hundreds of species, such as the well-studied Chesapeake Bay food web (Baird & Ulanowicz 1989). Leveraging related, recent datasets from UMCES and Smithsonian scientists, intensive computational analyses based on the venerable LSODA integrator would be trivial to parallelize and distribute on the UMIACS high performance computing cluster. Drawing on analyses designed to gauge the robustness of the Bay food web to external stressors, such as nutrient inputs, results could then be interfaced with economic and social science models to assess the interplay of farmland runoff, exurban sprawl, and other anthropogenic disturbances on ecosystem services.

Cloud Computing and Virtualization Services. Cloud computing presents a paradigm shift for cost effective computational resources as services over the commodity networks. UMIACS has experience in building and managing cloud-computing environments using Hadoop and Eucalyptus (Eucalyptus Systems, Goleta, CA). A possible EnSynC direction is to virtualize a large computing and storage cluster that can simultaneously serve two primary functions: 1) support a reliable large storage system and relational database systems built on MySQL, PostgreSQL, and PostGIS; and 2) serve as a private cloud built on the Eucalyptus Platform in which researchers can access Infrastructure as a Service (IaaS) to support user-developed virtual servers and virtual clusters.

Data Management, Access and Preservation. Given the extensive experience gained through the establishment and technical support of the GLCF, UMIACS can move almost immediately to establish data repositories and common-use databases for EnSynC and to provide tools for curating, annotating, and publishing datasets. A common, easy-to-use, and efficient interface for resource discovery will be designed and built as a component of the Founding Theme. Working with the DIRS, UMIACS will develop tools to integrate access to and analysis of the expected heterogeneous datasets, and to generate value-added scientific data products from these datasets. The EML (Ecological Metadata Language) standard will be adopted for capturing the metadata of datasets generated by EnSynC. Using EML, we will register our data holdings at existing repositories, such as the Knowledge Network for Biocomplexity and DataNet. Output spatial data will be exposed using Web Mapping Services (WMS) and Web Feature Service (WFS). MapServer, an open source web-based tool to display and dynamically render maps, will facilitate browser-based visualization, leveraging WMS and WFS capability. Via MapServer extensions, we can generate KML files combining all registered data sets to facilitate visualization of datasets in Google Earth™.

Long-Term Data Preservation. UMIACS has extensive expertise in this research area (which includes long-term data protection and access) via the ADAPT group led by Dr. JaJa, which has developed novel tools and methodologies to monitor and manage data archives to ensure long-term data integrity, preservation, and access. Some of these tools are in use by the community, including the Library of Congress NDIIPP (National Digital Information Infrastructure & Preservation Program).

Regular tutorials covering advanced tools and services, including HPC programming environments, advanced visualization, data management, and preservation will be offered in conjunction with the Pursuits and Ventures projects and to support EnSynC's broad outreach efforts. These tutorials will be offered by teams that include EnSynC postdoctoral fellows, graduate students, and UMIACS personnel. Moreover, we will disseminate the best technology practices and tools to the scientific community after extensive testing and validation.

Section 6. Strategic Planning, Founding Projects and Timeline

EnSynC will be guided by a strategic plan articulating overarching goals that will frame Center efforts and establish metrics for use in evaluations (Section 2.5, Horizontal Synthesis). An ongoing part of the strategic planning process is to work with the community to identify research Themes; however, the strategic plan is a much larger project that will develop 1) a detailed implementation plan with rigorous milestones, 2) specific performance metrics, 3) a formal internal evaluation process (using the Horizontal Synthesis Database), and 4) a definition of organizational values and operating principles. The Executive Director and Director of Synthesis Process & Facilitation will co-lead strategic planning efforts. Input will be obtained through direct interactions with a broad cross-section of the environmental science and policy community at professional meetings, workshops and through web forums. We next outline specific steps and a timeline for major tasks for the first two years.

6.1 *The Planning Process will extensively focus on Selection of Themes and Theme Leaders*. Because the thematic approach is so central to EnSynC's design, our strategic planning process must include a major focus on Theme selection. Themes should be relevant both scientifically and to diverse constituencies of end users; thus, it is essential that we bring multiple communities into the planning process. To do this, we will employ a multistep process similar to that used to develop

priorities for global sustainability research in earth system science, with the addition that our efforts will be extended through open forums at conferences. First, members of our leadership team will host forums at key meetings of scientific societies and meetings attended by policymakers and environmental consultants. The goal will be to "introduce" EnSynC and its goals, as well as solicit input to identify important Themes. Second, we will host a two-month-long web-based consultation process in which we request suggestions of the most critical environmental questions today. EnSynC staff will synthesize the results from the web forum and results from similar visioning processes that have been undertaken in the last three years. Third, we will hold a workshop that includes individuals from multiple levels (senior to early-career natural and social scientists), environmental policy experts and representatives from NGOs and federal agencies. The goal will be to develop a draft document with the Themes considered most important. This document will be distributed to the community along with a survey and a request for comments. Finally, the EnSynC leadership and EAB will integrate the results in a small, facilitated workshop that ends by identifying a set of Themes, their subsidiary goals, and the timing of each Theme as a Center focus. This will be distributed as part of the EnSynC strategic plan ensuring that the community will be aware of the results of their input and the relative timing of different Themes. During this extensive Theme-planning process (which will occur more than once during EnSynC's lifetime), key leaders in various areas will emerge. However, Theme leaders will ultimately be selected by the EAB and EnSynC leadership team using a nomination and application process. Selection criteria will be based on candidates' scholarly and leadership credentials as well as their proposed ideas for managing the Theme and interacting with Pursuit groups.

6.2 Performance Metrics and Evaluations for Center Operations & Staff. We have already described a form of evaluation that focuses on the synthesis process and uses the Horizontal Synthesis Database. The results from this will certainly be part of the Center evaluation process; however, it is also critical that we have a well designed process for evaluating internal aspects of the center (e.g., staff performance, adequacy of facilities) as well as overall effectiveness of the center in advancing environmental synthesis. The performance metrics chosen must effectively inform annual work plans, mid-term internal evaluations, and, ultimately, accumulate for long-term assessments. The EnSynC leadership team will be responsible for developing a draft set of metrics for their respective program areas—environmental science, social science and policy, cyberinfrastructure, education and outreach and synthesis process. While EnSynC is unique, in many respects there is a solid foundation to draw upon for evaluation of centers such as EnSynC. On a broad, center-wide scale, we need to optimize environmental, organizational and institutional factors to ensure that we meet our strategic and thematic goals (Stokols et al. 2003).

In terms of overall center effectiveness, the initial framing of synthetic questions (Meyer 2007) and clear metrics to measure the many factors that support integration of different kinds of knowledge (Porter et al. 2006) are essential. Klein (2008) outlined seven evaluation principles for interdisciplinary studies that may be pertinent here. In addition, evaluation needs to understand how well the collaborative process is implemented for different groups. We will consider these and other approaches as we fully develop our evaluation process.

6.3 Founding Projects. Part of the planning process is to be prepared to engage the community and initiate projects quickly after our doors open. To accomplish this, we propose one founding Venture and one founding Theme. The former is the founding Venture on the synthesis process and education (Section 2.4). For the founding Theme, we propose: "Placing and Replacing Ecological Wealth" because it is important, timely, and feasible to launch quickly given our leadership and partners. In particular, we have the expertise to move forward immediately in developing specific goals and key questions for the Theme, which can then be vetted by members of the EAB and others. We will develop an RFP to solicit Pursuit proposals under this Theme from the external community.

"Placing and Replacing Ecological Wealth" - Ecological wealth refers to ecological goods and services that benefit people such as wood, food, clean water, and flood protection. The production of this natural "wealth" depends on the relationship between specific ecosystem features (e.g., nutrient rich soils, diverse plant assemblages, the spatial arrangement of habitats) and a wide array of ecological processes (e.g., propagule dispersal, biogeochemical transformations, carbon storage). Interest in ecosystem services has grown exponentially in the last decade because such services are viewed as a potentially powerful tool for use in environmental policy (Daily et al. 2009; Ruffo & Karieva 2009). While research to develop methods for the economic valuation of goods and services is progressing, scientific consensus on ecosystem service production functions and how they vary spatially and with scale, is in its infancy (Nelson et al. 2009; Wainger & Boyd 2009). This theme focuses on advancing our understanding of ecosystem service production functions and their link to humans who are simultaneously redistributing ("placing') ecosystem services and substituting natural services ("replacing") with technology or engineered ecosystems. Examples of the former include concentrating plant biodiversity in suburban areas and creating aggregations of high-productivity farming belts. Examples of the latter include desalination plants to produce more freshwater and creating wetlands where they did not previously exist.

Box 8: Synthesis Example

Soil Ecosystem Services

Although Dust Bowl scenes of barren farmland seem remote, soil degradation continues to be a major concern in the US and abroad. Soil erosion on agricultural lands is influenced strongly by tillage practices (Montgomery 2007), which are a function of agricultural economics and land management policies, and are of increasing importance as the market value of soil as a carbon sink is debated (Marland et al. 2001). Degradation of soil is a complex process involving chemistry, hydrology, meteorology (rain & wind), and landcover changes (such as loss of forest for farmland or loss of farmland to dryland degradation or salinity). EnSynC Pursuit teams could use existing datasets (e.g., Soil Climate Analysis Network, USDA's Web Soil Survey, erosion data from USGS's Vigil network) on these drivers to predict areas of risk for future declines of soil quality and to develop ideas to protect or restore topsoil in these high risk areas. Pursuit teams could conduct synthesis to understand how socio-ecological systems experience transformational landscape change that influences soil fertility in comparison with incremental landscape change. Relevant policy components include agricultural policy in the developed world and policy to remediate soil contamination and degradation.

RFPs for Pursuits under this Theme will solicit proposals for projects that integrate disciplinary perspectives to quantify relationships between the structure and functions of natural systems and the benefits they provide people. Bayesian networks or other statistical modeling frameworks combined with expert opinion elicitation methods (HaDoung 2008) could be used to probabilistically model how ecosystem functions and structures produce ecosystem services. Syntheses across the multitude of studies, models, and unmined environmental, economic, and social science data could address questions like: What are the social and biophysical mechanisms by which land use and land value influence the production of ecosystem services? What is the relationship between the spatial production of specific services and the distribution of human need for these services? Are there landscape or local scale attributes (social or biophysical) that can be used to predict the flow of specific ecosystem services? What conservation and restoration prioritization frameworks can be developed to maximize the delivery of multiple ecosystem services? This theme is ripe for synthesis, and a number of outstanding environmental and social science researchers and educators are engaged in work on ecosystem services or in fundamental research that is central to biophysical production of ecosystem services (e.g., the relationship between genomic or functional diversity and ecosystem process).

Sources of digital data that may be integrated into the data portal for the founding Theme of "Placing and Replacing Ecological Wealth" include the Millennium Ecosystem Assessment, UK National Ecosystem Assessment, EU Water Framework Directive, Australia's Ecosystem Services Project, the US RIBITS Wetland Bank Information Site, BioFresh, FLUXNET, and BioMERGE, among many oth-

ers. In consultation with the Synthesis Council and the Theme and Pursuit leaders, the DIRS will identify and prioritize relevant subsets of data, seeking to understand and anticipate challenges associated with data fusion and integration, while streamlining researcher access.

6.4 Timeline for Years 1 and 2

Box 9: Time Table

YEAR 1

Establish External Advisory Board (EAB)
Begin hiring staff; advertise postdoctoral fellowship opportunities
EnSynC leaders visit relevant NSF Synthesis, Learning, and Cyberinfrastructure Centers
Initiate strategic planning (conference visits, develop web forum, solicit Theme ideas, etc.)
Hold workshop to initiate the education synthesis Venture
Founding Theme Leaders develop goals and RFP; release solicitation for Pursuit proposals
Hold workshop to evaluate results from community input into Theme priorities
EnSynC leaders and EAB complete and distribute strategic and implementation plans
Conduct first internal evaluation session with focus on "start-up"; discuss results with EAB
Review Pursuit proposals for Founding Theme

YEAR 2

Populate postdoctoral fellowship programs and get them underway
Solicit Ventures proposals
Initiate Pursuits for Founding Theme and get them underway
Leaders for Themes 2 and 3 meet to develop Theme goals and RFPs
Initate policy engagement and mission meetings
Get educational programs underway
Conduct second internal evaluation session
Conduct 24-month formal external evaluation

Section 7. Intellectual Property Policies and Knowledge Management Plan

The essence of our stance on intellectual property, inventions, creative works, and models resulting from EnSynC activities is **open access**, including public distribution on Center web pages, restricted only as required by the policies of the employers of the individuals involved.

The University System of Maryland (USM) Policy on Intellectual Property is spelled out in Section IV-3.20A of the USM Policies and Procedures Manual. Intellectual Property is defined in Section IIIC of the Manual. Particularly relevant are Article V "Copyrights" and Article VI "Inventions and Patents," which detail the governance of intellectual property. For sponsored research, USM provides (Article IV. E.) for waivers from the rule that all Intellectual Property rights belong to USM. To promote open access, we will stipulate that for USM employees receiving direct or indirect funding from EnSynC, that the USM waives its rights asserted under Articles V and VI, and, instead, authorizes the open distribution of all inventions and creations produced by these employees. All USM employees whose activities at the Center are subsidized, either directly by EnSynC funds or indirectly through USM cost-sharing in support of EnSynC, will be required to sign a statement of agreement with this open access principle. This does not constrain the rights of employees to publish results from their Center activities. Published material will be maintained on Center websites directly when this is legal, or through links to authors' web pages, where appropriate. EnSynC will request that similar guidelines, including signatures on statements agreeing to open access, be followed by Center participants who are not USM employees. These guidelines will be recommendations, however, not requirements, because we recognize that such individuals may be constrained by policies of their own employers.

We will also establish a maintenance and archiving policy for data (broadly defined to include facts, statistics, computer codes, publications, model descriptions, etc.) resulting from EnSynC activities. We will archive or arrange to have data and metadata archived in a public metadata registry and/or data repository. Archives will be maintained in two separate locations with daily backups to provide redundancy. The Auditing Control Environment (Song and JaJa 2007), used by a number of digital preservation efforts associated with the Library of Congress, will be employed to monitor and ensure the long-term integrity of the data. EnSynC-sponsored data and metadata will be made available in a

timely manner, generally no later than one year after the conclusion of an EnSynC award to a center investigator/participant, or immediately upon publication of an associated article, whichever comes earlier. There will be no restrictions on use and dissemination. We will also develop standard agreements for managing datasets over their lifetimes. Any data updates will need to be documented using appropriate standards and conventions approved by the Cyberinfrastructure director, to include appropriate acknowledgment and attribution of data from other sources, as required by the copyright, license or terms of use of such data.

Cyberinfrastructure Director JaJa has extensive experience managing large datasets and associated metadata from his research. Federal geospatial metadata standards (e.g., FGDC) are not designed to deal with complex output from models, but new metadata approaches used by other NSF Synthesis Centers (e.g., NIMBioS) will allow us to deal with complex spatio-temporal data arising from models. The center will incorporate metadata standards in its databases, consistent with federal ones. They will be appropriate for the diversity of data and products to be built at the center, using prior expertise as well as that arising from projects, such as the USGS National Biological Information Infrastructure, the Ecological Metadata Language developed at NCEAS, and the NSF-supported SEEK project.

Data or datasets, software, published books, and scholarly articles generated or created by an EnSynC fellow or through a project or meeting funded by EnSynC must appropriately and conspicuously acknowledge EnSynC and the National Science Foundation.

Section 8. Facilities and Capabilities of the Institution to Host and Manage the Center

The EnSynC facility will be located in historic Annapolis, Maryland, on the western shore of the Chesapeake Bay. It is a central location offering easy access to Washington, DC (33 miles away), Baltimore (30 miles), College Park (27 miles), three major airports (Baltimore-Washington [BWI], Ronald Reagan Washington National, Washington Dulles International) and many restaurants, coffee shops hotels and B&Bs. Annapolis, the state capital, is a major tourist destination with rich cultural offerings. UMCES has existing facilities in downtown Annapolis that can accommodate EnSynC's initial needs. These are currently used primarily by UMCES' Integration & Application Network (IAN) as a synthesis center for science translation and communication. Within the first 6-to-8 months, we will move to a larger facility (~9000 ft^2) located close to the IAN office. Leasing is the best option because the University does not own space in Annapolis and there are abundant offerings available. The going rate of commercial leases is \$25-\$32 per ft^2, depending on whether the space is waterfront and if the building is newer. Should small groups wish to assemble in a scenic rural locale, it is only about 50 miles from Annapolis to either the Horn Point or Chesapeake Biological Labs of UMCES, both on the water and with dorms and conference facilities. In Washington, DC, RFF will provide conference facilities and office space for EnSynC scholars, Mission Meetings and Policy Briefings. RFF is just blocks from the White House and key government agencies. Finally, the Helmholtz Centre-UFZ, our partner in Leipzig, Germany, will make their excellent facilities available for EnSynC activities and visitors; WSU-V in Washington State will do the same.

8.1 Fiscal Administration and Accountability. Fiscal reporting responsibility for EnSynC will reside at UMCP, which has many quasi-autonomous research centers, including the NSF-funded Materials Research Science and Engineering Center, the NOAA-funded Cooperative Institute for Climate Studies, and the NASA-funded Earth System Science Interdisciplinary Center and Global Land Cover Facility. Consequently, UMCP has extensive experience meeting the budgetary, auditing, intellectual property, and other challenges of hosting major research initiatives. Director Palmer will report fiscally to the Dean of Chemical and Life Sciences.

8.2 Scientific Capabilities. The three lead institutions collectively house >100 senior researchers with expertise directly relevant to EnSynC. UMCP environmental science and policy researchers come primarily from the Colleges/Schools of Chemical & Life Sciences; Computer, Math, & Physical Sciences; Behavioral and Social Sciences; Agriculture; Engineering; and Public Policy. They also

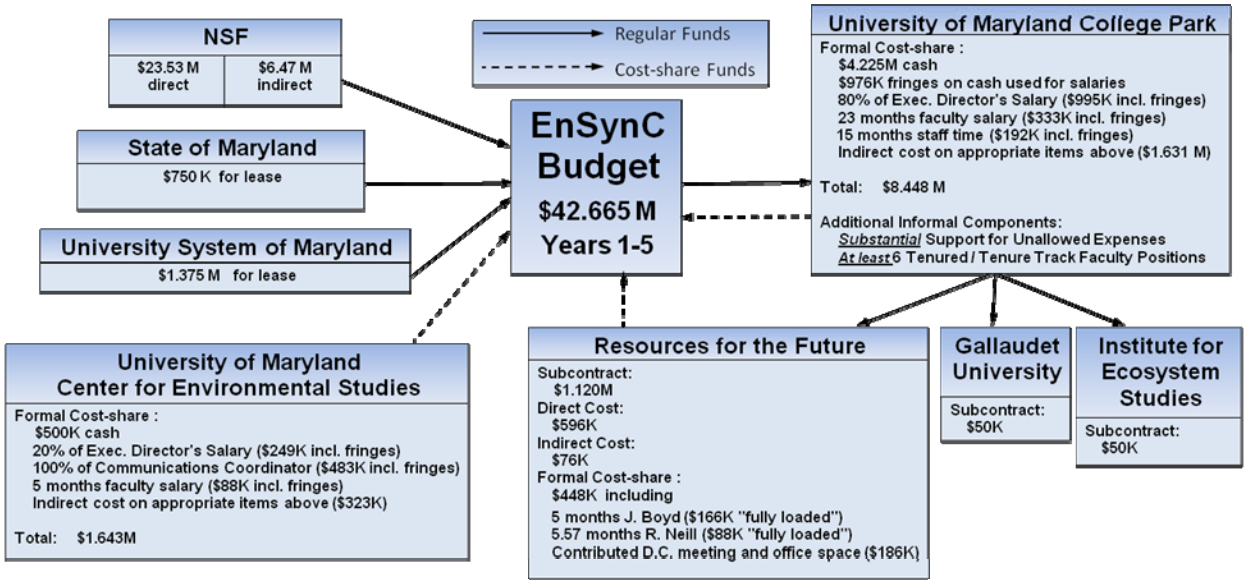
are in Centers, such as Bioinformatics and Computational Biology; Environmental Energy Engineering; Smart Growth Research and Education; Earth System Science Interdisciplinary Center; Graphics & Visual Informatics Laboratory; Harry R. Hughes Center for Agro-Ecology, and others.

UMCES has 87 full-time, mostly tenure-track faculty who reside at the Chesapeake Biological Lab, Horn Point Lab, or Appalachian Lab, all of which have large basic and applied, externally funded research programs linked by a strong graduate program.

RFF has one of the largest environmental social science research staffs in the world. For 60 years, RFF has excelled in research and policy collaborations, policy innovation, research dissemination and public engagement among the diverse influential institutions in Washington, DC. Among its achievements, RFF researchers were the first to 1) apply the principles of resource economics to the world's fishing stocks, thereby calling attention to the risk of overfishing and motivating innovative policies, such as tradable quotas, and 2) delineate the "three pillars of resource economics" (i.e., the existence value of wilderness area, the option value of preservation and the irreversible nature of some economic development). RFF recently received the Italian FEEM 20th Anniversary Prize in Environmental Economics.

8.3 Educational, Policy and NGO Resources. The Annapolis-Baltimore-Washington area is home to five major research universities (UMCP, Johns Hopkins, Georgetown, UMCES, George Washington) and a host of universities and colleges dedicated to balancing strong education programs with various levels of research (e.g., Gallaudet, Howard, Towson, UM-Baltimore County). Washington, DC, hosts numerous think tanks and NGO headquarters (e.g., TNC; World Wildlife Fund; Forest Trends; World Resources Institute; Conservation International; the H. John Heinz III Center for Science, Economics and the Environment, National Council for Science and the Environment), as well as associations (Ecological Society of America, Association of Environmental and Resource Economists, American Geophysical Union, etc.).

8.4 Institutional Commitments. Maryland brings significant commitments to recruit NSF's Environmental Science Synthesis Center to our state. The Lead Institutions for this proposal have agreed to institutional commitments totaling $12.665 million, which are summarized here and detailed in the Budget Justification.



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Addendum to NSF Synthesis Center Proposal

By leadership team

Re: Discussion with Site Team Review Panel

Preface: The site visit team "unanimously agreed that the education/outreach, the management and organization plan, the cyberinfrastructure, and the assessment and strategic planning components were very strong. The disciplinary breadth represented by the three consortium institutions and their partners is very broad, encompassing a wide ethnic, socio-economic, and language diversity". They concluded that the Maryland team "will produce high-quality, socio-environmental research." There was considerable discussion about the complex epistemological issues and the difficulties associated with bridging interdisciplinary divides among the social, natural, and computational sciences. Conceptual models of environmental synthesis are appropriately quite diverse and SESYNC leadership is committed to using an adaptive process for managing the center and responding to community needs which will change over time. Our goal is to foster evolution of environmental synthesis in response to the science and policy communities over the next decade. Here we provide some of the SESYNC leadership's views and additional comments on our process; we look forward to input on this issue from the broad community that the center will serve.

What is Environmental Synthesis? Environmental synthesis is fundamentally about bringing together diverse forms of knowledge in ways that generate useful new insights: producing new knowledge, anticipating future conditions, producing new solutions to problems, or opening up new ways to think about a particular problem. Importantly, the problems and discoveries at issue require synthesis of diverse forms of knowledge. By knowledge, we mean: theories, methodologies (e.g., quantitative and qualitative), data, and ideas. Any one of these can be a catalyst for synthesis that calls on many forms of expertise. While we must be able to facilitate the merger and management of diverse and large quantitative data sets, synthesis is not limited to combining numbers, parameters, or quantitative models, and it is not limited to a particular scale or analytic mode.

We anticipate that some of the most significant accomplishments in synthesis science will come from the co-development of environmental synthesis theory with an open, evolving array of policy-relevant intellectual Pursuits: novel combinations of different research traditions and epistemological perspectives. SESYNC will nurture the production of novel methodological frameworks and theoretical approaches. It will do so, first, by engaging the broad scientific community in discussions of the wide array of potentially productive approaches to environmental synthesis, and second, by analyzing those approaches from the perspective of the goal of synthesis.

In our proposal, we discussed "Horizontal Synthesis" which is growth of the environmental synthesis process over the life of the center through a variety of structured mechanisms including: 1) syntheses across Pursuits and Themes; 2) studies and assessments of the synthesis process "in action" at the center (i.e., by participants/visitors); and 3) evaluations of Center functioning and leadership. Horizontal synthesis requires "looping back" constantly to synthesize at even higher levels (i.e., across different projects or even Themes) than has traditionally been done. It also enables"looping back" to learn from Center projects and grow successful synthesis processes.

Will all funded projects (Pursuits) include transdisciplinary teams? We will emphasize transdisciplinary synthesis because that is what is needed for environmental discoveries and solutions to emerge. We expect many or most individual projects ("Pursuit" or "Venture" in SESYNC terms) will be transdisciplinary in some capacity; however, we will also focus on transdisciplinarity at the level of the 'portfolio' of funded projects. Projects will be carefully co-selected by teams of social and natural scientists to best address a particular environmental issue, or "Theme," each of which will have been carefully co-defined by a broad group of social and natural scientists. SESYNC funds can be used by individuals, small or large groups, and even among people who never meet face to face. We anticipate synthesis occurring within a Pursuit, across Pursuits within a Theme, and across Themes. Synthesis can also occur outside the center's basic Themes, because our Ventures program leaves the door open for any highly creative idea to be funded.

How will Themes and Pursuits be chosen? SECYNC's founding plan requires mutual engagement of social and natural scientists in a facilitated process, implemented through the Synthesis Council and leading to the joint refinement of synthesis projects as well as the collaborative framing of policy-relevant questions that transcend disciplinary boundaries. The process of "co-defining and co-developing," involves a structured and iterative facilitation process in which the broad community (often including policy makers) identifies research needs associated with actionable science. We will begin with the development of a Strategic Plan and the mechanisms to engage the community will include: 1) web-based input including idea management tools; 2) Mission Meetings which engage a broad array of scientists and policy-makers to discuss research needs, what constitutes actionable science, and prioritizing themes; and 3) Workshops at the center and at national society conferences. The External Advisory Board (EAB) will play a critical role in the process of final theme selection. This board will be broad and will include representatives from the research and policy community.

Once a theme is agreed upon, we will undertake an iterative, facilitated process to co-define the goals and central questions of the Theme. This process will include Theme leaders from the external community, leaders of various Pursuits within a Theme, the Synthesis Council and key stakeholders (i.e., policymakers and others). This may include a charrette process to establish a scientific foundation (i.e., common understanding of approaches, technical needs, common data sources, models and visualization demands) for the Theme.

Scholarly Basis of the Center Approach From the beginning, SESYNC will employ current knowledge of synthesis processes, organizational behavior and cognitive theory relating to epistemological divides, group dynamics, and goal-oriented mutual engagement (Paolisso 2002, 2007; Eigenbrode et al. 2007; Miller et al. 2008; Jerneck et al. 2010; Osbeck and Nersessian 2010). SESYNC's organizational model is meant to facilitate group "visioning and framing … to break out of past mind-sets and open up the content of new agendas" (Gray 2008).

The overarching basis for our approach is to combine the most current scholarly knowledge of synthesis process, from many disciplinary and practice sectors with planful adaptive learning. We will plan Center projects to make their synthesis processes accessible to review for discovery of characteristics that contribute to success in science, transdisciplinarity, and policy relevance. SESYNC's

processes will adapt with growing synthesis knowledge, which the Center will rapidly disseminate for community use.

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