Synthesis Centers as Critical Research Infrastructure

Authors: Jill S. Baron[1*], Alison Specht[2,3], Eric Garnier[2,4], Pamela Bishop[5,6], C. Andrew Campbell[7], Frank W. Davis[8,9], Bruno Fady[2,10], Dawn Field[11], Louis J. Gross[5], Siddeswara M. Guru[12], Benjamin S. Halpern[8,9], Stephanie E. Hampton[13], Peter R. Leavitt[14], Thomas R. Meagher[15], Jean Ometto[16], John N. Parker[17], Richard Price[18], Casey H. Rawson[19], Allen Rodrigo[20], Laura A. Sheble[21], Marten Winter[22]

Affiliations:

[1]U.S. Geological Survey, John Wesley Powell Center for Ecological Analysis and Synthesis, Fort Collins CO 80526-8118, USA.

[2]CEntre for the Synthesis and Analysis of Biodiversity, Batiment Henri Poincaré, Technopôle Petit Arbois, 13100 Aix-en-Provence, France

[3]School of Geography, Planning and Environmental Management, the University of Queensland, St Lucia QLD 4072, Australia

[4]CNRS (CEFE, UMR 5175), 1919 route de Mende, 34293 Montpellier Cedex 5, France.

[5]National Institute for Mathematical and Biological Synthesis, University of Tennessee, Knoxville TN 37996-3410, USA.

[6]National Institute for STEM Evaluation and Research, University of Tennessee, Knoxville TN 37996-3410, USA.

[7]Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin 0909, Australia.

[8]National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, Santa Barbara CA 93101-3351, USA.

[9]Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, 93106, USA.

[10]Institut National de la Recherche Agronomique (INRA), UR629 - Ecology of Mediterranean Forests (URFM), Avignon, France.

[11]Department of Marine Sciences, Göteborg University, Box 463, Göteborg, Sweden SE-405 30

[12]Terrestrial Ecosystem Research Network, the University of Queensland, St Lucia, Queensland 4072, Australia.

[13]Center for Environmental Research, Education and Outreach, Washington State University, Pullman WA 99164-6525, USA.

[14]Canadian Institute of Ecology and Evolution (CIEE), University of Regina, Regina, Saskatchewan S4S 0A2 Canada

[15]Centre for Biological Diversity, School of Biology, University of St Andrews, St Andrews, Fife KY16 9[TH], United Kingdom

[16]National Institute for Space Research (INPE), Av dos Astronautas, 1758, 12227-010 - São José dos Campos, SP, Brazil

[17]Barrett, The Honors College, Arizona State University, Tempe AZ 85287, USA.

[18]Australian National University, Fenner School of Environment and Society, Australia.

[19]School of Information & Library Science, University of North Carolina, Chapel Hill, NC 27599-3360, USA.

[20]The Research School of Biology, The Australian National University, Acton, ACT 2601, Australia.

[21]Duke Network Analysis Center, Duke University, Durham, NC, 27708-9976, USA.

[22]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Synthesis Centre for Biodiversity Sciences – sDiv, 04103 Leipzig, Germany.

*Correspondence to: Jill S. Baron, jill_baron@usgs.gov.

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Abstract:

Synthesis centers offer a unique amalgam of culture, infrastructure, leadership, and support that facilitates creative discovery on issues critical to science and society. The combination of logistical support, post-doctoral or senior fellowships, complex data management, informatics and computing capability/expertise, and most of all, opportunity for group discussion and reflection lowers the 'activation energy' necessary to promote creativity and cross-fertilization of ideas. Synthesis centers are explicitly created and operated as community-oriented infrastructure, with scholarly directions driven by ever-changing interests and needs of an open and inclusive scientific community. The last decade has seen a rise in the number of synthesis centers globally, but also the end of core federal funding for several, challenging sustainability of the infrastructure for this key research strategy. Here we present the history and rationale for supporting synthesis centers, integrate insights arising from two decades of experience, and explore the challenges and opportunities for long-term sustainability.

Main text:

Demand for the opportunity to participate in a synthesis center activity has increased in the years since the US National Science Foundation (NSF) funded National Center for Ecological Analysis and Synthesis (NCEAS) opened its doors in 1995, and as more scientists across a diversity of scientific disciplines have become aware of what synthesis centers provide. NSF has funded four synthesis centers and more than a dozen new synthesis centers have been established around the world, some following the NSF model and others following different models suited to their national funding environment (http://synthesis-consortium.org/).

Scientific synthesis integrates diverse data and knowledge to increase the scope and applicability of results and yield novel insights or explanations, within and across disciplines (Pickett *et al.* 2007; Carpenter *et al.* 2009). The demand for synthesis comes from the pressing societal need to address grand challenges related to global change and other issues that cut across multiple societal sectors and disciplines, and recognition that substantial added scientific value can be achieved through synthesis-based analysis of existing data. Demand also comes from groups of scientists who see exciting opportunities to generate new knowledge from interdisciplinary and transdisciplinary collaboration, often capitalizing on the increasingly large volume and variety of available data (Kelling *et al*. 2009; Bishop *et al.* 2014; Specht *et al.* 2015b). The ever-changing nature of societal challenges and availability of data with which to address them suggest there will be an expanding need for synthesis.

Yet we are now entering a phase where government support for some existing synthesis centers has ended or will be ending soon, forcing those centers to close or develop new operational models, approaches and funding streams. We argue here that synthesis centers play such a unique role in science that continued federal investment to maximize benefits to science and society is justified. In particular, we argue that synthesis centers represent community infrastructure more akin to research vessels than to term-funded centers of science and technology (e.g. NSF STCs). Through our experience running synthesis centers, and in some cases developing post-federal funding models, we offer our perspective on the purpose and value of synthesis centers. We present case studies of different outcomes of transition plans, and argue for a fundamental shift in the conception of synthesis science, and the strategic funding of the centers by government funding agencies.

A brief overview of synthesis centers

The first synthesis center, NCEAS, arose in response to evolving scientific knowledge and research technologies, growing need for interdisciplinary and transdisciplinary explanations, and increasing requests by practitioners to connect science to applications (Hackett *et al.* 2008). Recognizing these changes, the Ecological Society of America (ESA), the Association of Ecological Research Centers (AERC), and O.J. Reichman at the US NSF, called for establishment of a place to undertake “multidisciplinary analysis of complex environmental problems.” The enabling language stated ‘‘Synthesis is needed to advance basic science, organize ecological information for decision makers concerned with pressing national issues, and make cost-effective use of the nation’s extant and accumulating database” (as reported in Hackett *et al.* 2008). While the specific themes may differ among today’s newer synthesis centers, these three tenets form the foundation for all of them to this day. As the pioneering centers such as NCEAS and NESCent, the National Evolutionary Synthesis Center, matured, they, along with newer centers, developed a science infrastructure for catalyzing new ideas that can and are used for scientific advance and public benefit.

Synthesis centers share many commonalities (Lynch *et al.* 2015). The fundamental unit of most synthesis centers is the working group; some synthesis centers also support other activities, including workshops, short courses, and catalysis meetings. These are one-time meetings of up to about thirty scientists to focus on grand challenges and high-risk, high-reward initiatives. In contrast, working groups are teams of up to twenty people that come together for intensive collaboration for several days at a time, often across a series of meetings housed within the center and supported by an integrated research staff. Teams are designed to be collaborative and convergent, often combining experts with different backgrounds, expertise, and perspectives to approach a common question or topic. Existing data from multiple researchers that may span space and time scales across multiple disciplines are analyzed. All synthesis centers provide some degree of computational support, data management, and informatics expertise (Box 1; What is a synthesis center?).

Synthesis centers often function as effective boundary organizations linking science, management, and governance (Box 2). Formal and informal partnerships develop when people from different organizations come together around mutually important topics, increasing the role of science in decision-making. One example of this is the Science for Nature and People Partnership (www.snap.is) between NCEAS, The Nature Conservancy (www.tnc.org) and the Wildlife Conservation Society (www.wcs.org) that brings interdisciplinary and transdisciplinary science to bear on the nexus of biodiversity conservation and human development (Stokstad 2011). Policy makers and managers were active participants in examining the impacts of land use and hydrological intensification in Australia (Davis *et al.* 2015). SESYNC, the Socio-Environmental Synthesis Center (US), opened its doors in 2012 with the specific goal of accelerating synthesis for the advancement of actionable science. By 2015, SESYNC had supported over 50 synthesis teams, and 25% of the participants in those were from government, NGOs, or businesses with a strong interest in the relevance of the science to decision-making (Palmer et al. 2016). By involving decision-making organizations and practitioners at the synthesis stage of science discovery, results are more likely to be rapidly transformed into actionable science and implemented (Stokstad 2014).

Participation in synthesis center research fosters lasting increases in collaborative behavior among the participants who pass through them (Hampton and Parker 2011; Lynch et *al.* 2015, Specht *et al*. 2015a). A wealth of studies and essays show the relationship between in-person interdisciplinary collaboration and knowledge creation (Rhoten *et al.* 2009; Parker and Hackett 2012; Alberts 2013). Lifting terms from the ecological vocabulary, Parker and Hackett (2012) note that having focused time at locations isolated from outside distraction lead to 'hot spots and hot moments' – bursts of unusually high creativity that enable potentially transformative science. These elements are the distinguishing ingredients of synthesis centers and evidence show the benefits persist and the culture of collaboration spreads outward from group members. At NIMBioS, transdisciplinary collaborations were actively nurtured between mathematics and many other disciplines over its first five years of activity (Figure 3). The collegiality lasts well beyond the synthesis center activity; subsequent publication author lists after participation in NCEAS activities showed a significant increase in collaboration and more than a six-fold greater rate of increase in co-authorship on papers than a random subsample from ecological journals (Hampton and Parker 2011). Interdisciplinary collaboration and number of coauthors increase research productivity and impact, although the effect may take more than a decade to become evident (Hampton and Parker 2011; Van Noorden 2015). With hundreds of new participants hosted at each center yearly, collectively these results suggest a lasting influence on scientific culture and conduct.

Insights from 20 years of synthesis

While the NCEAS model was the blueprint for the modern synthesis center, additional insights have come from the modern family of centers that have increased their effectiveness in producing transformative knowledge. Through experimentation, common sense and adaptive management, all synthesis centers have improved their ability to nurture innovative science, highly productive groups, and opportunities for expanding the collaborative culture among scientists. Synthesis centers now interact with each other and share best practices. Further, the methods of practice and the lessons learned are portable and the impact magnified if adopted by other institutions. Below, we describe some of the lessons learned that make synthesis centers successful today. In general, there are six critical ingredients, presented in no particular order, for a successful synthesis center:

1. active management of social dynamics and intellectual space for teams by synthesis center staff;
2. cutting edge computing, data management and informatics support;
3. organizational flexibility to accommodate the scientific and intellectual needs of working groups;
4. support for students, post-doctoral, and sabbatical fellows;
5. diversity of working group participants; and
6. offering the time and environment for group associative thinking.

<u>Active management</u> - Synthesis centers are not passive entities; their staff members manage working groups to achieve success. The more diverse the collaborations, the more challenging, but many scholars are actively working to develop strategies to achieve synergy and form cohesive teams (Lyall and Fletcher 2013, NRC 2015). To help accelerate interdisciplinary and transdisciplinary team progress, SESYNC provides an array of services including training in new methods and communication skills, assistance with co-development frameworks or activities and direct facilitation of synthesis team meetings (Palmer et al. 2016).

Active management begins with a rigorous selection process. Proposals are solicited and evaluated not only for their scientific breakthrough potential and significance, but also for group composition. We look for teams where each person has an essential role. We also look for teams that include complementary combinations of disciplines and expertise, and a range of career stage, gender, and ethnic perspectives. It is not uncommon for synthesis center staff to suggest changes to group composition. Synthesis center staff members work with working group leaders to orchestrate productive meetings and progress toward goals before and after meetings. Indeed the meetings are regarded as an essential component of a much longer association with the center and the working group. Working groups often use virtual meetings and common document sites months prior to arriving on-site to allow the group to get to know each other and to share papers, data, and models. This allows face-time while at the synthesis center to be as productive as possible. Synthesis center staff help develop meeting agendas and goals that move projects forward. Structured talks and rigid agendas are kept to a minimum, while spontaneous or organized discussions and breakout groups are encouraged to pursue promising new directions or ideas. While facilitators may help groups who do not know each other well, care must be taken to avoid poor or formulaic facilitation that can impede creative association and breakthroughs.

Ongoing evaluation of the success or failure of specific activities in promoting collaboration across disciplines, training young scholars, or producing new information is a key component of active management. There are a variety of metrics available for assessment of activities (Bishop et al., 2014). The metrics can provide feedback for managing ongoing working groups, or for organizing future activities. Evaluation also measures the extent to which synthesis centers are reaching their intended goals, and provides funding agencies with much-needed information about the impacts resulting from their investment in the center.

Computing and informatics capabilities –Synthesis centers play a strong role in promoting open science, including collaboration and free access to data and results. NCEAS and NESCent were early developers of tools for data management and publication that are today expected of all scientists. An eco-informatics pioneer, NCEAS played a major role in advancing metadata standards and tools, data registries, online data archives and automated workflow systems (Jones *et al.* 2006). Similarly, NESCent incubated the widely used Dryad data repository (http://www.bioone.org/doi/abs/10.1525/bio.2010.60.5.2), and ACEAS, the Australian Centre for Ecological Analysis and Synthesis, spearheaded the formal link between DataONE (https://www.dataone.org) and TERN, the Australian Terrestrial Ecosystem Research Network. Many of the synthesis centers offer "open science" style workshops to provide software and data science training to promote collaboration, improve the synthesis process, and promote sharing of data and tools. These tools and partnerships provide opportunities for participants to discover, re-use and re-purpose data to extract new and significant knowledge and to deliver synthesized data in a sophisticated manner.

Most working groups are comprised of a range of specialists, and they learn from each other and synthesis center staff members in the process of their activity (Specht *et al.* 2015b). For some participants, the data and informatics education acquired may be skills rarely required in other parts of their working life, and an important outcome of participation. Few working groups have team members with real data science or informatics backgrounds, and members may be unaware of relevant innovative methods, techniques, and technologies that can either be employed or augmented by the working groups. Synthesis center data management specialists help with working groups before, during, and after meetings to acquire and organize data, compile databases and models, and offer the opportunity to make the most out of the data with which they work. Synthesis center staff members also assist in the publication of the synthesized data, thus continuing the cycle.

Flexibility is fundamental to giving working groups the tools and the time needed to produce the best results. Specifically, we refer to maintaining flexibility with respect to topic, length of working group activities, scheduling, and especially in meeting structure (Bishop *et al.* 2014). The ability to recognize and accommodate individual and group needs can make all the difference when it comes to attracting the right student, post-doctoral, or sabbatical fellow, making sure the right people can attend working groups, and encouraging the intellectual dynamics of different types of people. When surveyed, participants of both NIMBios and ACEAS activities identified flexibility as important to achieving their goals (Bishop *et al.* 2014; Lynch et al., 2015).

Student and Fellow Support - The template for student, post-doctoral, or senior fellows differs among centers. At NSF-funded centers and sDIV, fellows work at the center where they interact productively with each other. There are other models, such as at the USGS-supported Powell Center, and in the UK, France and Canada, where fellows are independent and geographically distributed among investigators engaged in synthesis-based research. All fellows are dedicated to the working group for one to three years, and often compile data, develop and run models, write manuscripts, and maintain connectivity among participants. For working groups, the benefit of having a dedicated postdoc or fellow is substantial, particularly in terms of overall productivity (Hampton and Parker 2011). The benefits to fellows and working groups alike persist through time, fostering collaborative behavior, multi-authored papers, and competitiveness for jobs (Hampton and Parker 2011).

Diversity - There are direct intellectual benefits to teams that are diverse in gender, age structure, career stage, ethnicity, and discipline beyond the laudable goal of developing a scientific workforce that mirrors the national population. The overall performance of groups, termed "collective intelligence" by Woolley *et al.* (2010), increases with higher average social sensitivity of group members, and is correlated with the proportion of women (Bear and Woolley 2011). Entire fields such as global health and sustainability science have arisen from interdisciplinary and transdisciplinary cross-fertilization of ideas, where methods or concepts from one discipline serve to spark new ideas in others (Whitfield 2008; Uzzi *et al.* 2013). Often called convergence, integrative thinking and analysis foster emergence of new scientific principles and solution to complex vexing problems (Sharp and Langer 2011).

The value of unstructured time - Personal interactions are vital to collaborative efforts to inspire new ideas, in part because face-to-face meetings stimulate the "random collision of ideas and approaches" in ways that remote meetings do not (Alberts 2013). Stein and Stirling (2015) identified three aspects of group dynamics that not only ensure "civil' debate, but go beyond to foster the relationships that lead to emergent understanding. Unstructured group time outside the meeting room was built into every working group meeting. Unstructured activities foster friendship and trust rather than confrontation, and help free the mind from the logical thought patterns that are the trademark of scientists (Scheffer 2014; Stein and Stirling 2015). Ground rules were set for involvement: participants would be allowed to argue passionately for their personal views, but must also then identify and acknowledge the weaknesses of their approach. Finally, group discussions around the table were egalitarian; no one person was in control.

This latter idea, of letting the brain roam creatively among different ideas, methods, and thoughts, is termed associative thinking by psychologists. Associative thinking is linked to creativity, and opportunities to foster it among groups of knowledgeable scientists are provided by synthesis centers. Scheffer writes: “The best science seems to come from a balanced mix of rationality and adventurous association.” Synthesis centers do not have a lock on stimulating group encounters that lead to breakthroughs, but it is one of the signature opportunities provided by these facilities. In fact, it might be one of the most important values of synthesis centers: this brew/mixture/special sauce of time for creative unstructured thought and discussion fueled by good coffee, food, beer and pleasant surroundings (Hackett *et al*. 2008; Scheffer 2014).

Sustaining Synthesis Centers

The need for scientific synthesis is certain to increase in an ever more connected and environmentally challenged world with growing awareness of common societal challenges. Exceptional prior investment (up to $34 million USD/center), combined with a unique culture of collaboration, integration and achievement, provide synthesis centers the capability to address future challenges to the benefit of society and governments in a highly cost-effective manner. As noted above, successful synthesis is as much a cultural transformation as it is a set of tools. Growth of this culture is difficult and expensive. To maximize the return on government investment in science we should, therefore, consider the long-term benefits of continued federal support.

Financial security poses the greatest challenge for long-term sustainability for any center, especially for supporting infrastructure, defined as not only the physical space and associated computational resources, but also informed and expert staff that enable a center to function. Synthesis centers also face the challenge of finding support for basic science missions and projects, generally only the purview of government funding. While successful transitions from centralized federal funding demonstrate the importance of investment in specialized personnel and infrastructure, they often also result in a narrowing of focus.

Although aspects of scientific synthesis can happen without the existence and support of centers, two highly successful and impactful attributes are particularly challenged in the absence of dedicated infrastructure: the working group approach to synthesis; and the nurturing of collaborative and interdisciplinary behaviors, particularly among younger scientists and fellows. Important as these are in the developed world, interdisciplinary collaboration can be catalytic for scientists from developing and transitional countries. There are a number of viable options for overcoming these challenges, although none are simple. Five case studies of transition or closure provide insight into the challenges and opportunities for sustainability.

- NSF funding for NCEAS ended in 2010. Several key changes to the mission and funding strategy have allowed NCEAS to continue and thrive. A diverse funding portfolio has been built around a stronger emphasis on applied questions, including partnerships with Science for Nature and People Partnerships (SNAPP) and the State of Alaska Salmon and People (SASAP) funded by private philanthropy and foundations, and project-based science supported by an array of funders (including NSF).

- NSF funding for NESCent ended in 2015, but the infrastructure was repurposed to become TriCEM, a smaller center with a different mission (evolutionary medicine; http://tricem.dreamhosters.com/) that focuses on engaging local scientists associated with the consortium of universities that now provide its funding.

- NIMBioS is two years from the end of its NSF funding and has begun to explore sustainability options. Their strategy is to establish “centers of excellence” under the existing NIMBioS infrastructure. The first of these centers, The National Institute for STEM Evaluation and Research (NISER) has recently been launched, capitalizing on the evaluation experience of NIMBioS to offer external evaluation services to the STEM research and education community. Other centers of excellence are in development, with the hope they will generate the necessary revenue to support a continuing mission of high quality interdisciplinary education and synthesis-focused research.

- The Canadian Institute of Ecology and Evolution (CIEE) arose in 2008 as a consortium of universities and academic research societies dedicated to synthesis using a geographically distributed funding and operational model. Member organizations pay annual fees to support working groups and training activities across Canada, a process that favors flexibility and regional participation, but sacrifices long-term computational and post-doctoral student support. Challenges to this system include lower annual budget, slower development of the ‘culture of synthesis’, and vulnerability to membership turnover or donor fatigue.

- ACEAS, the Australian Centre for Ecological Analysis and Synthesis, was established as a component of an ecological observatory network supported by government science infrastructure funding. It closed its doors permanently in 2014 after four years successfully fostering synthesis activities. ACEAS was a victim of declining funding where priority for scarce resources was given to primary research.

One solution is to adopt a long-term funding model for synthesis centers based on the provision of communal infrastructure. Examples of long-term, sustained funding include the USGS-supported Powell Center, the NSF LTER program, and the ‘national capability’ initiatives of the United Kingdom (e.g., EOS, http://environmentalomics.org/omics-synthesis-centre/). Provision of consistent federal funding supports the infrastructure essential to data-intensive, culturally diverse analyses at the nexus of the synthesis approach. Such support is further justified because synthesis centers serve a large community within and among disciplines (e.g., 500-800 unique participants each year). As well, synthesis centers are basic scientific infrastructure, like telescopes for astronomy or ocean vessels for oceanography, which enable advancements beyond the fiscal capabilities of individual research organizations. This infrastructure will evolve and adapt to scientific and social requirements, but must exist first for innovation to happen. In particular, with the near exponential growth of scientists and products (data, analytical systems, publications), the need to extract value from existing data to the benefit of society will continue to grow. Synthesis centers represent the essential cultural transformation needed to allow scientists to exploit this opportunity.

Summary

When we think of research infrastructure, most people imagine complex equipment such as particle accelerators, radio telescopes, sophisticated imaging and sensing equipment, research vessels, super computers and other ‘hard’ objects. Rightly so — these are all important tools that aid scientific discovery within disciplines. However, science is increasingly being asked to help address important and enduring global change, societal and human health challenges that cut across multiple sectors of society and disciplines and that may require us to make sense of existing large-scale and heterogeneous data. Places and processes that accelerate the rate by which information from different sources and perspectives is transformed via synthesis into knowledge that can be applied toward solving problems are desperately needed (Wilson 1998; Carpenter *et al.* 2009). Synthesis centers serve this role. They will be needed more than ever going forward. As infrastructure, synthesis centers may not be as tangible as a telescope, but technology alone cannot match the brain power of a diverse group of experts who are committed to focusing their combined insights, experience, tools and networks on a shared problem in a collegial environment.

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Box 1: What is a synthesis center?

While synthesis is accomplished by individuals or groups and in settings as diverse as university departments and boardrooms, synthesis centers are specifically designed to catalyze collaboration leading to breakthrough ideas (Gray 2008; Schmidt and Moyer 2008). Among the ways they do this is by taking an active role in structuring group size, composition and interactions, managing operational and logistical details, and providing computing and informatics capabilities. In short, synthesis centers lower the activation energy needed to generate emergent ideas by providing an environment that encourages cross-fertilization of ideas, creative thinking, and associative thinking (Rodrigo *et al.* 2013; Scheffer 2014). Synthesis centers offer something rare: distraction-free time and space for a group to immerse themselves in a question (Hampton and Parker 2011; Lynch *et al.* 2015).

We distinguish synthesis centers from primary research institutions such as universities, and also from other interdisciplinary research centers primarily because the topics addressed at synthesis centers respond to the evolving questions of the scientific community and because existing data, often from many different sources, are repurposed (Rodrigo *et al.* 2013; Bishop et al. 2014). Small, often interdisciplinary or transdisciplinary, teams from geographically distributed locations come together for intense multi-day meetings at synthesis centers to work with existing data, theories, and ideas. These meetings repeat over several years against a background of supported virtual collaboration. Ecological and Earth system synthesis centers represented by the authors are listed in Table 1.

Synthesis Center	**Topics of synthesis**	**Location**	**Funding source**	**Dates of operation**
ACEAS, the Australian Center for Ecological Analysis and Synthesis	Ecosystems	Working groups took place throughout Australia	Australian Government through the National Collaborative Research Infrastructure Strategy	2010-2014
CESAB, the CEntre for the Synthesis and Analysis of Biodiversity	Biodiversity	Aix-en-Provence, France	multiple funding sources through the Foundation for Research on Biodiversity	2010-present
CIEE, the Canadian Institute for Ecology and Evolution	Ecology and Evolution	Headquartered at University of Regina, working groups distributed	Seven member institutions cover operating costs	2008-present

		across member universities		
EOS, the Environmental Omics Synthesis Centre	Environmental 'omics, (e.g. genomics, metabolomics) and including bioinformatics	St. Andrews University, UK	NERC, UK	2011-present
NESCent, National Evolutionary Synthesis Center	Cross-disciplinary research in evolution	Durham, NC, USA	National Science Foundation	2004-2015
➔TriCEM, Triangle Center for Evolutionary Medicine	improve understanding of human, animal and plant health through application of evolutionary and ecological principles	Durham NC, USA	Non-profit incubator, funding from universities	2014-present

NIMBios, the National Institute for Mathematical and Biological Synthesis ➔ NIMBios Centers of Excellence	cross-disciplinary research at the interface of mathematics and biology The National Institute for STEM Evaluation and Research (NISER)	Knoxville TN, USA Knoxville TN, USA	National Science Foundation NSF and contracts	2009-2018 2016-present
NCEAS, the National Center for Ecological Analysis and Synthesis ➔ NCEAS	Ecological knowledge Applied ecological knowledge	Santa Barbara, CA, USA Santa Barbara, CA, USA	National Science Foundation and State of California Various sources, including foundations, NSF, and the State of California	1995-2010 2010-present

Powell Center, the John Wesley Powell Center for Analysis and Synthesis	Earth system sciences	Fort Collins CO, USA	U.S. Geological Survey	2009-present
sDIV, Synthesis Centre for Biodiversity Research	Biodiversity	Leipzig, Germany	iDIV, German Centre for Integrative Biodiversity Research	2013-present
SESYNC, the National Socio-Environmental Synthesis Center	Socio-environmental synthesis	Annapolis, MD, USA	National Science Foundation	2012-present

End of Box 1

Box 2: Examples of policy impacts of synthesis center research

Perhaps the greatest role of synthesis centers now and moving into the future is their influence on management and policy (Specht *et al*. 2015a). A few examples of where synthesis results have led to actions are listed below.

One of the most cited papers of all time, Costanza et al. (1997) was generated by an NCEAS working group. This foundational paper, with nearly 16,000 citations, established the principle of ecosystem services with international impact leading to the Millennium Ecosystem Assessment, the establishment of the formal discipline of ecological economics.

Another particularly influential NCEAS working group concerned with theory to support the design and establishment of marine reserves convened in the 1990s (Figure 1; Allison *et al.* 2003). The group amassed evidence of the positive influence of no-take reserves on fish stock diversity, biomass, body size and fecundity and associated spillover effects. This evidence contributed the establishment of a Marine Protected Area network in California's Channel Islands and ultimately to the development of the California Marine Life Protection Act of 1999 (http://www.dfg.ca.gov/marine/mpa/intro.asp).

The North American monarch butterfly population has plunged from 1 billion to less than 60 million over the past 20 years, possibly from loss of critical habitat (Figure 2). The Monarch Conservation Science Partnership convened four times over 24 months at the Powell Center to develop robust estimates of extinction risk, regional conservation priorities, priority threats, and specific restoration scenarios. Their report informed the development of a national strategy to promote the health of honeybees and other pollinators (Pollinator Health Task Force 2015). Plans for conservation have been expanded to include habitat in Canada and Mexico through the Trilateral Committee for Wildlife and Ecosystem Conservation and Management.

Pollen incidence across time and space and its relationship to respiratory illness was the topic of an ACEAS Working Group. Their results, described in Davies et al. (2015), provided the platform from which to establish a national pollen monitoring system, the AusPollen network (http://pollenforecast.com.au/index.php). The network provides the basis to implement and evaluate the utility of current local pollen data for improved self- and clinician-management of patients with allergic respiratory diseases such as hay fever and asthma triggered by airborne pollens. The program precipitated ongoing partnerships between public, private and academic partners. The AusPollen Partnership established web-based and smart phone technology to support the development of patient and clinical education resources through partnership with the Australasian Society of Clinical Immunology and Allergy, and Asthma Australia.

Many governmental entities are beginning to adopt an ecosystem services framework for decision-making. In the US federal agencies have mostly relied on ecological assessments as indicators of services yet ecological features and processes are not the same as ecosystem services unless there is a direct societal benefit that is valued. SESYNC hosted a workshop and conversations with federal agencies that resulted in recommendations for best practices in integrating ecosystem services in federal decision-making (Olander et al. 2015). They outlined how to use measurable indicators that go beyond narrative description by using well-defined measurement scales that are compatible with valuation and decision analysis methods.

Community deliberation facilitated by EOS, the UK Environmental Omics Synthesis Centre, supported establishment of a funded Natural Environment Research Council Highlight topic: eDNA: a tool for 21st century ecology (http://www.nerc.ac.uk/latest/news/nerc/highlight-topic/).

End of Box 2

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Figure captions:

Fig. 1. The Channel Islands National Marine Sanctuary, which was established, in part, due to evidence amassed on the value of marine protected areas as a result of a synthesis center

working group. Image courtesy of Julie Bursek, NOAA Channel Islands National Marine Sanctuary.

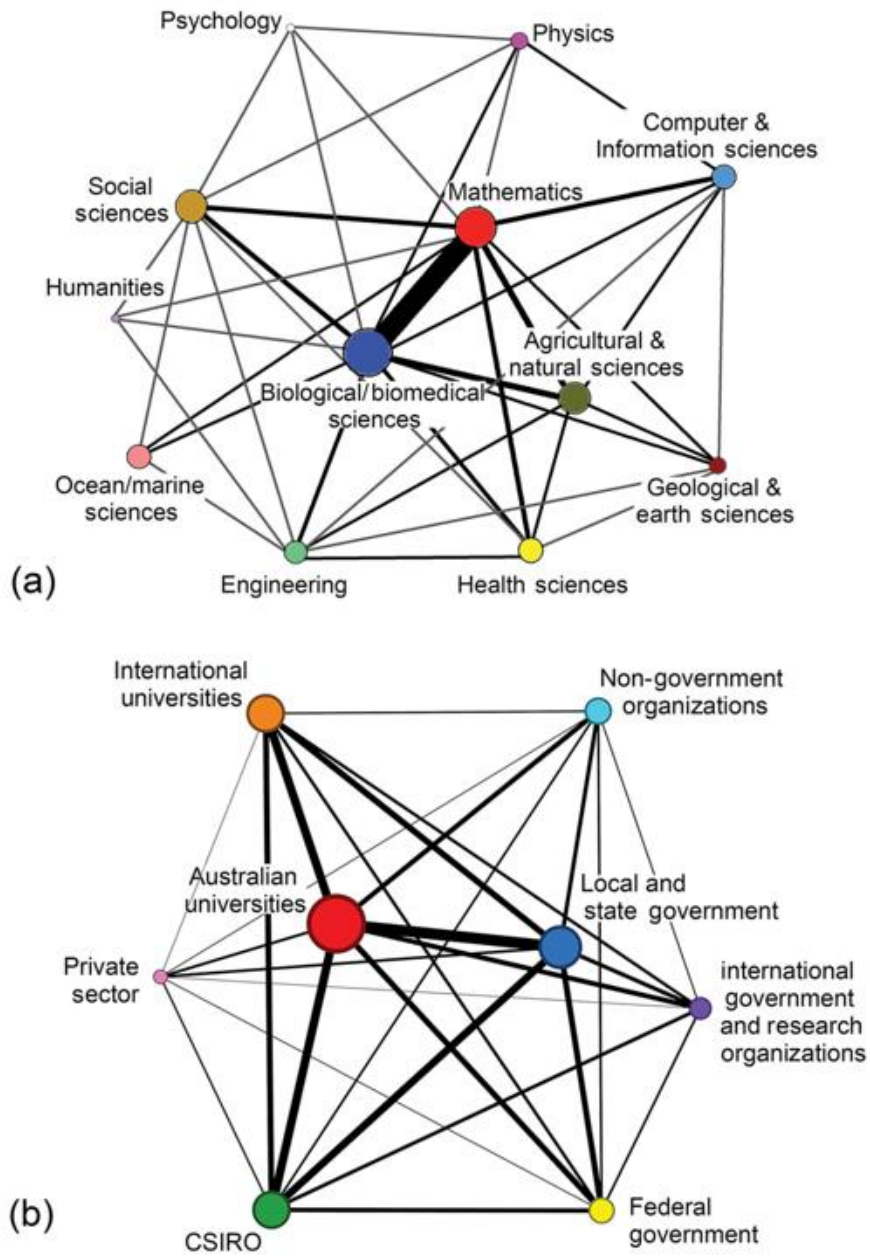
Fig. 2. Monarch butterfly. Photo courtesy of Jacqueline Pohl, Iowa State University

Fig. 3 a) Interdisciplinary connections fostered by NIMBioS, the National Institute for Mathematical and Biological Synthesis, for working group participants in 2008-2012, and; b) Organizational linkages that ACEAS, the Australian Centre for Ecological Analysis and Synthesis, supported over the period 2010-2014. Node size represents number of working group participants in a given research or organizational area, where the node radius is the log number of participants. Line size represents the number of collaborations between research areas or organizations within working groups. The largest lines represent 25(a) or 29(b) connections, and the smallest lines represent one (a) or four (b) connections. Line width is log scaled.

Figure 1

Figure 2

Figure 3


Psychology
Physics
Computer &
Information sciences
Social
sciences
Mathematics
Humanities
Agricultural &
natural sciences
Biological/biomedical
sciences
Ocean/marine
sciences
Geological &
earth sciences
Engineering
Health sciences
(a)
International
universities
Non-government
organizations
Australian
universities
Local and
state government
Private
sector
international
government
and research
organizations
(b)
CSIRO
Federal
government