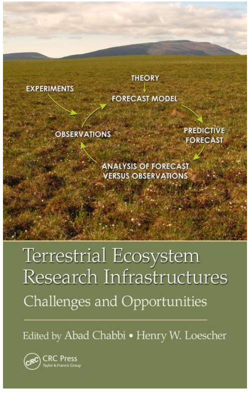

Terrestrial Ecosystem Research Infrastructures Challenges and Opportunities

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Synthesis Centres

Publication details
https://www.routledgehandbooks.com/doi/10.1201/9781315368252-19
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Published online on: 22 Feb 2017

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Synthesis Centres: Their Relevance to and Importance in the Anthropocene

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CONTENTS

Abstract

In a world where there is increasing demand for solutions to urgent and complex ecological questions requiring multidisciplinary participation and transdisciplinary insight, but where the abundance of information has become overwhelming, the analysis and synthesis centre has emerged recently as an effective and arguably indispensible tool. Using staff with multidimensional skills and considerable experience, the synthesis centre provides a supportive environment for groups of people with diverse disciplinary, organisational, cultural and geographical origins to work together using existing data to address big science questions. It fills a niche in time-pressed and discipline-centred lives, enabling wisdom to be drawn from a heterogeneous mass of data.

The successful performance of synthesis centres depends on a unique marriage of knowledge of learning, collaboration and teamwork behaviours, data management expertise (including legal aspects) and scientific understanding, coupled with the knowledge of national and international scientific and organisational landscapes.

The synthesis centre approach, described in this chapter, has proved to be remarkably successful, with high publication output and citation rates, and the delivery of many data packages for future use. Participation in a synthesis centre provides users with a uniquely stimulating experience and enables them to forge new and strong professional relationships. Without such centres, transdisciplinary insights will continue to be limited to existing partnerships and short-term goals and will lack the probity that original work on data and information can provide.

Keywords: Analysis and synthesis centre, Data deluge, Collaboration, Working group, Data reuse, Data delivery

18.1 Introduction

The technological changes experienced in our daily lives over the last 50 years as a result of the explosion in computational power are unprecedented (Marx 2013). They have led us into the era of 'big data' and to the emergence of fields such as genomics and spatial and sensor sciences, but they have also presented us with many challenges. Never before have we had the ability to compile and access such a wide range of data in order to solve complex problems, but as expressed by Wilson (1998), 'We are drowning in information while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely'. This highlights the need for specialised expertise, dedicated space and time to deal with the challenging aspects of the 'data deluge' (Science Staff 2011, Thessen and Patterson 2011). Lack of sufficient and supported time for appropriate analysis and reflection has been blamed for a decline in confidence in the scientific enterprise and in its inability to handle the superabundance of information (Siebert et al. 2015).

The explosion in computational power and capacity has also been accompanied by, or indeed resulted in, an unparalleled rise in awareness of a range of complex, interconnected global social and environmental problems that need urgent attention. Understanding complex systems is itself challenging (Hmelo-Silver and Azevedo 2006), and solving today's complex problems rests not only on the availability of suitable data and our technical ability to deal with it but also in our ability to collaborate effectively across the necessary disciplinary and organisational boundaries (Crowston et al. 2015). Despite increased connectivity through social media, the discovery and development of working relationships with colleagues, especially those from other disciplines and across sectoral and geographical boundaries, requires directed effort (Cheruvelil et al. 2014, Specht et al. 2015a). Several challenges present themselves: (1) how to find the time to gather together the necessary information and to analyse and synthesise it in order to gain new understanding and insight; (2) how best to make sense of this information when we need to converse with each other across disciplinary, organisational and geographical boundaries; and (3) how to respond when our training systems are slow to react and careers are governed by disciplinary rewards.

The great explorations of the sixteenth and seventeenth centuries presented similar challenges. Explorers returning to the 'old world' with a deluge of information from the 'new world' challenged understanding of the meaning of civilisation. These discoveries, driven in large part by the acquisition of territory and wealth, drove the hunger of the community for exotica, the development of science and the systematisation of knowledge. As the bourgeoisie grew, with their aspirations, there was a demand for wider participation in discourse, something previously limited to the aristocracy (Chartier 1991, Kale 2002). The creation of egalitarian, often constructed, fora such as the Salons of France and greater Europe in the eighteenth century (Konczacki 1986, Vincent 2014), which continued until the early twentieth century (Kale 2002), was a societal response to create opportunities to assimilate, analyse and make sense of the plethora of new information and the accompanying cultural and social changes. Significantly for the purposes of this chapter, salons were described, *inter alia*, as 'civil working spaces of the project of the Enlightenment*' (Goodman 1994, p. 53) lying 'outside rule-bound institutions and established cultural bodies' (Chartier 1991 cited in Goodman 1994, p. 69). Their continuation beyond the Enlightenment attested to their popular utility, providing a protected space in which matters of concern of the day could be debated and discussed (Kale 2002). These 'salons' and their ilk were somewhat passive, however, compared with the demands and goals of the ecological/environmentally based *analysis and synthesis centre*, which has emerged arguably as a response to two pressures: the challenges of dealing with the 'information age' in an effective manner and the increasing pressure to answer global problems requiring critical analysis and integration of transdisciplinary information.

18.2 Analysis and Synthesis Centres

The well-established research workflow follows a classical pathway, from review of the literature (with particular focus on gap analysis), hypothesis setting, experimentation or observation, analysis of the results and

* The Enlightenment, *Siècle des lumières*, and *Aufklärung inter alia* are retrospective definitions of a phase of European history in the eighteenth century in which there was a growth in advocacy of rationalist thought (Lough 1985).

communication of the findings through the literature. Historically, this is largely an individual endeavour, certainly so for PhD students, the fundamental training for all scientists. Rarely do scientists 'synthesise material from linking facts and fact-based theory across disciplines to create a common groundwork for explanation' (Wilson 1998). Scientists by themselves generally do not have the time, collaboration skills, networking knowledge, resources or professional incentives to bring together the components required to build a broader understanding of ecosystems or to manage human interactions with them more effectively (Costanza 2003).

Scientific synthesis generally relates to an inductive process of integrating disparate elements (i.e. concepts, data, methods, analytical results) from one or more disciplines to develop a novel integrative insight or model as a primary outcome (Sidlauskas et al. 2010). Synthesis can be systematic and tied to particular methodologies that are quantitative or qualitative (Cooper and Hedges 2009). In its simplest form, 'synthesis' is a creative activity in which the aim is to produce new insights or outcomes that are greater and more meaningful than the constituent parts.

The National Center for Ecological Analysis and Synthesis (NCEAS) was established in the United States in 1995 in response to the recognition in the ecological community that the activity of synthesis was both essential and vastly under-supported (Costanza 2003), although 'synthesis centres' servicing data repositories had emerged previously (e.g. the synthesis centre attached to the Chinese Ecosystem Research Network [CERN] in 1988). NCEAS was designed to facilitate data analysis and synthesis around topics of concern (Rodrigo et al. 2013). NCEAS has been enormously successful in facilitating the production of many very highly cited papers, identifying and fostering many new frontiers in ecology, establishing the value of analysis and synthesis of existing data, initiating the development of the data management workflow and stimulating the development of many similar centres around the world (Table 18.1).

Each of these centres has interpreted the analysis and synthesis centre approach differently, dependent on their organisational structures and circumstances of how they come about. The Australian Centre for Ecological Analysis and Synthesis (ACEAS, established in 2010), for example, was designed to be inclusive of scientists, managers and policymakers. The intention was to fast-track the assembly of information around big science questions, enabling new insights and knowledge to guide long-term research and monitoring: the challenge of Lindenmayer and Likens (2010, p. 108). As stated in the funding application for ACEAS, it would '… support the integration and synthesis of ecosystem data and information across the many relevant disciplines and institutions in Australia… thereby enhancing and accelerating our knowledge and understanding of science particularly to improve our policy and management decision-making. ACEAS [will] achieve this by the sponsorship of integrative activity, mainly through working groups and workshops, in which groups of scientists and managers amalgamate

TABLE 18.1

Vital Statistics of Ecological (in the Broad Sense) Synthesis Centres Arranged from the Oldest Centre to the Newest Centre

Centre (Acronym)	Dates	Location	Linkage with Data Infrastructure
Chinese Ecosystem Research Network (CERN)	1988	China	Integral component of the CERN—observatory network
National Center for Ecological Analysis and Synthesis (NCEAS)	1995	USA	Created the Knowledge Network for Biodiversity, a major partner in DataONE
National Evolutionary Synthesis Center (NESCent)	2004–2015	USA	Supported the development of Dryad, a partner in DataONE
Biodiversity Synthesis Center (BioSync)	2007–2013	USA	No direct link
National Institute for Mathematical and Biological Synthesis (NIMBioS)	2008	USA	No direct link
Canadian Institute of Ecology and Evolution (CIEE/ICEE)	2008	Canada	No direct link
John Wesley Powell Center for Analysis and Synthesis	2009	USA	Associated with the USGS data repositories
Australian Centre for Ecological Analysis and Synthesis (ACEAS)	2010–2014	Australia	A component of the Terrestrial Ecosystem Research Network
Centre for the Synthesis and Analysis of Biodiversity (CESAB)	2010	France	A component of the Foundation for Research on Biodiversity (FRB), which has a fledgling data repository, ECOSCOPE
National Socio-Environmental Synthesis Center (SESYNC)	2011	USA	No direct link
Environmental 'Omics Synthesis Centre (EOS)	2012	UK	Linked with the Centre for Ecology and Hydrology and their infrastructure
Synthesis Centre for Biodiversity Sciences (sDiv)	2012	Germany	Linked with iDiv and through that TRY and other initiatives
Tansley Working Groups	2013	UK	No direct link

Note: More information and links to centre web sites can be found on www.synthesis-consortium.org.

unpublished and published data to develop a new understanding of an ecosystem problem'.

The focus of ACEAS was largely on transdisciplinary* integration of biophysical science and linked social science through environmental policy

* Transdisciplinary research is defined to mean research involving multiple scientific disciplines in collaboration with policy and management (not solely citizen or community engagement) (Lynch et al. 2015). This contrasts with interdisciplinary research which is defined here as research between academic disciplines in a nonadditive or non-transformational way, and multidisciplinary research as research between academic disciplines in an additive manner.

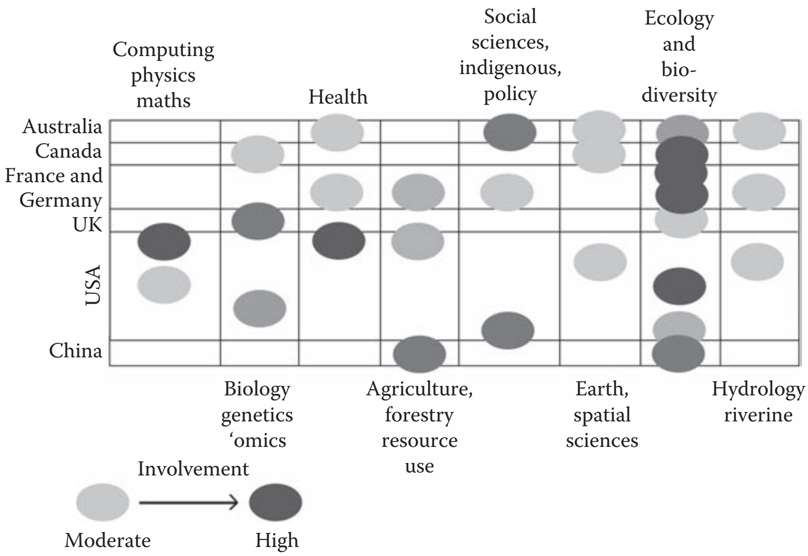

FIGURE 18.1
Diagram to illustrate disciplinary coverage of ecological and biodiversity synthesis centres.

and management. While NCEAS continued to have a broad non-engineered platform, centres in Europe (sDiv and CESAB) have focused on biodiversity, NESCent and EOS on evolutionary genomics and SESYNC (established in 2011) on the interface between ecology and society (Figure 18.1). Most have followed the NCEAS model of operation to a greater or lesser extent.

18.2.1 Function of Analysis and Synthesis Centres

The salons of the 1700s and 1800s brought together discussants, who would normally not meet, within an egalitarian social structure, which was revolutionary at the time. Synthesis centres do the same and have some other common programmatic elements. All centres provide funding for groups of people (working groups) to address complex questions using existing data. The groups are usually self-identified and submit proposals through annual funding rounds. Some centres provide merit-based or professional development funding for postdoctoral students, either separately (EOS) or in association with working groups, either directly linked (e.g. CESAB and sDiv) or independent (e.g. NCEAS and NESCent). There is no funding provided to gather new data, the centre proposition being that there are plenty of data in the world unused or unrealised, and analysis of these is the aim.

Together with the analysis of existing data, all centres have as central aims the analysis and synthesis of complex information (data) across normally unbridged disciplinary, organisational and geographical boundaries. Most follow a collaborative crowd-sourced working group model, where groups of people from different sectors who have some input to bear on the solution of a question propose that they can provide a new insight into an important problem if given the opportunity to work together. These 'sectors' are generally disciplinary but may also be organisational and geographical, as required by the question at hand.

The element of 'work' is critical to the function of the synthesis centre: these groups of people have to demonstrate the existence of data, qualitative or quantitative, with which to work. Synthesis centre participation is not a process of presentation (active) and critique (passive), or debate and conversation, although at various times these might occur. Active collaboration to analyse and synthesise real data causes many participants to work with people whom they may not have met before the working group was established (in ACEAS only half the group members knew each other personally before joining the group, and early analyses of CESAB participants indicate the same proportion) and with people from other disciplines and organisations. This can present communication challenges, as gulfs between disciplinary and organisational paradigms and norms have to be discovered and bridged. It is through the work process that trust is established between parties, critical to the success of the working group (Specht et al. 2015b).

Most centres advocate a flat organisational structure where, however senior or eminent an individual member may be, all participants are regarded as of equal importance for the achievement of the goal, that is, the product of a working group. Deliberations within the group are expected to range freely but confidentially; the synthesis centre provides a safe place to test ideas and interpretations, trial models, and argue semantics, without fear or favour. Some centres have ethics policies to ensure participants are reminded of, and commit themselves to, standards of collaborative behaviour.

Emphasis is usually placed on ensuring that group composition is appropriate, both for the successful functioning of the groups and for the wider benefit of the activity. Disciplinary expertise is usually fairly effectively determined by proponents, although assistance is often required to find individuals with appropriate expertise. Consideration of sociological elements is encouraged, such as ensuring wide representation across ages, gender, geographies, personality types and organisations (Figure 18.2). This advice is informed by educational and managerial team theory, as creation of a functional team from a mere assemblage of people is fundamental to success (Bammer 2013, Belbin 1993, Carpenter et al. 2009, Cooperstein and Kocevar-Weidinger 2004, Mutch 1998). Many of these considerations (age ranges, organisational and cultural diversity, gender diversity) not only promote effective team function but result in outcomes that are for the common good ('The range of skills/expertise/disciplines was very stimulating' KEIWS205*; 'we benefitted from the expertise of members using different approaches (modelling,

* Comments from ACEAS and CESAB feedback surveys.

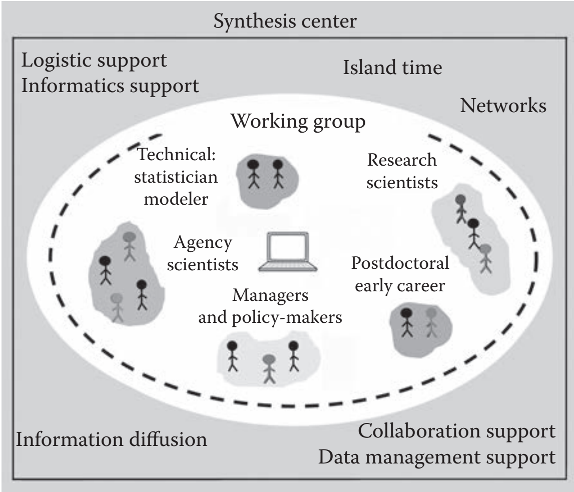

FIGURE 18.2
Synthesis centre structure showing elements of group composition and the main components of scaffolding provided by the centre. The indicated group composition shows different broad types of participants, different intensities indicating different aspects of relevant represented diversity (e.g. age, gender, discipline and geographical origin).

fieldwork, experimental virology) in different contexts which led to fruitful discussions and collaborative work'. BIO604). The benefit to a group participant has been shown to not only be an improved publication record (a well-known outcome of synthesis centre activity) but the effect of participation on subsequent practices in his or her workplace. This largely results from new techniques learnt, different insights and approaches experienced, and new relationships developed through the working group experience ('Great collaboration and learning as well as sharing knowledge. It was also a very good networking opportunity' SPEWS111).

For these reasons and more, it is recognised by all centres that sponsor working groups that the process of collaboration around the analysis and synthesis of existing data is not short term. The activity itself is part time for most participants, additional to their normal workplace commitments. Time is therefore often one of the most critical factors in the success of the process: limitations in time and a need for time. Time is required to develop communication languages, to develop trust, to obtain and clean data, and to analyse and test the result, to be in the 'zone'. Each interaction takes time, and there need to be rewards for participating.

Face-to-face meetings are fundamental to the development of relationships and trust, and depending on the question and the nature of the group, centres usually sponsor several such meetings. Face-to-face meetings have been found to be important for team productivity (Hall et al. 2012, Stokols et al. 2010). These meetings usually last from 3 to 8 days (although some are longer), and centres place importance on using meeting venues that separate participants from their day-to-day distractions. Several key criteria for suitable locations have been identified, which balance isolation and connectivity ('The perfect environment for stimulating productive teamwork'. DAVWS102).

When the following conditions are in place—collaborative intellectual stimulation and the combination of location and 'stolen' time (often called 'island' time; Figure 18.2)—a highly creative environment ensues, which aids the development of team identity, and also intellectual production (the 'hot moments' described by Parker and Hackett 2012).

Face-to-face meetings are by no means the only component of synthesis centre working group activity. Work must continue between formalised meeting times at the very least to prepare for the next. The between-meeting phases can be more or less effective, depending on the technological competence and commitment of the group and the support of the centre. Centres that have dedicated postdoctoral scholars (or staff) for each group depend greatly on their skills in maintaining the continuity of the group's work. Without this, much time can be lost. Regardless of the presence or otherwise of postdoctoral scholars, most centres engage in several strategies to maintain continuity, including (from Crowston et al. 2015)

- Making working group members aware that discontinuities are likely to arise but that they can be addressed with focused attention and a willingness to address them by creating continuities
- Establishing shared communication practices that facilitate the creation of continuities
- Allowing sufficient time for continuities to develop
- Ensuring the active participation of bridge builders such as librarians who know how to ask questions about disciplines other than their own

As may be clear from these strategies, centres provide a scaffolding* for their working groups, consistent with the type of support required for effective problem-based learning in higher education (Cooperstein and Kocevar-Weidinger 2004, Dickey 2006, Hmelo-Silver and Azevedo 2006) and other fields (Smith et al. 2007). This scaffolding (Figure 18.2) ranges from the clearly evident, such as logistic support—the aim of most centres is to make travel, accommodation and most meal arrangements effortless

* Scaffolding is support tailored to the needs of the client with the intention of helping them achieve his/her goals (paraphrase of Sawyer 2006).

for the participants—but also support for effective face-to-face and remote collaboration (e.g. through the provision of private wiki spaces), support of connectivity through networks (e.g. is there someone else in the world working on this problem, and can they help us?), informatics support (making sure that the Internet works, computing power is suitable and digital storage is available and secure), data management support and advice (diversification of data sources and assured access) and extension (information diffusion) support (including data delivery and often visualisation, support for scientific publications, conference presentations, web and social media presence).

18.3 Data Management

For an individual scientist, it can be a challenge to manage one's own data, let alone to discover, manipulate and manage the data produced by others. The disciplinary experts at a synthesis centre are primarily focused on the analysis phase of the research data life cycle (Specht et al. 2015b) and regard the management of data as a marginal activity in which they are little experienced (Volk et al. 2014). Scientists generally lack the competence or skills to publish their data for future reuse (Costello 2009) and lack confidence in using the data of others. Debate has emerged recently in an attempt to 'strike a balance' between the growing requirement to share data and restrictive factors relating to the willingness of owners to share, conditions on sharing (e.g. open data policies), protection of key datasets (e.g. propriety periods) and acknowledgement of data (e.g. Mauthner and Parry 2013, Mills et al. 2015, 2016, Tenopir et al. 2015, Whitlock et al. 2016). Few publications discuss the actual experience of data reuse and data management. The synthesis centre is arguably a microcosm of the wider community, as the entire data workflow from acquisition to publication of data is experienced (Figure 18.3), so it provides an invaluable insight for the participant and for the data management community (Specht et al. 2015b).

Data management specialists are generally obligatory members of the synthesis centre working groups (Figure 18.2). They can assist, but their competence varies widely and indeed their understanding of the scientific workflow is often limited being specialists themselves, thus making communication and workflows doubly difficult. The synthesis centre staff with their accumulated experience in all aspects of the data management and workflow with the disciplinary experts play an important role in facilitating, supporting and educating both the scientist and the data specialist in the practice of scientific, inter- and transdisciplinary data management.

Four components of the data workflow are relevant to the work of a synthesis centre. These are (Figure 18.3)

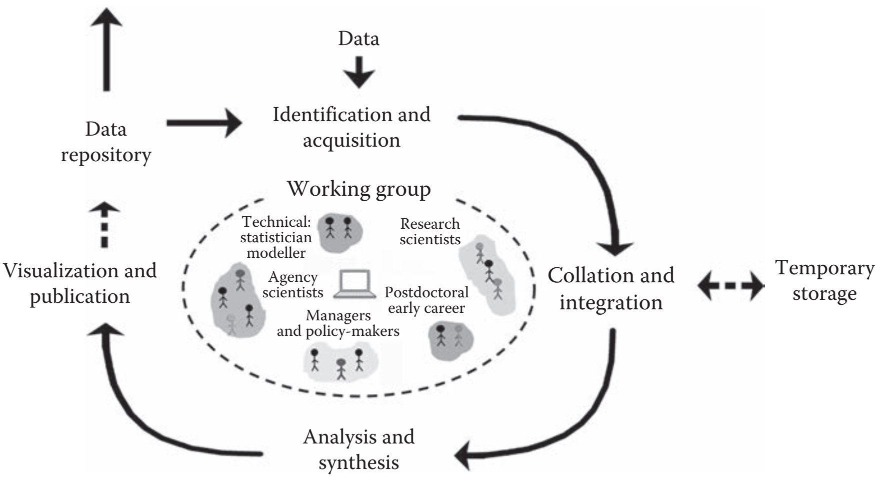

FIGURE 18.3
The modified synthesis centre data life cycle. (Adapted from Specht, A. et al., *Sci. Total Environ.*, 534, 144, 2015b.)

1. Identification and acquisition (discover)
2. Collation and integration
3. Analysis and synthesis
4. Publication and visualisation (deposition)

One common attribute of synthetic research is to compile data points that have been reported at various places in the literature into a single dataset that is amenable to comparative analysis or meta-analysis (Vision and Cranston 2015). Although most data will be identified prior to funding (a condition of funding for most centres), working groups usually have to physically obtain the data soon after they start and usually discover more in the process. Lack of metadata, and hence inability to assess the suitability of available data, is a common problem for data reuse experienced by working groups (Specht et al. 2015b). Once data are discovered, permission may be required to obtain them; then further time and skill is expended to ascertain their quality. The synthesis centre staff typically assist working group members in this phase by exploring data sources unknown to the participants, writing letters of support, talking to data providers and determining the conditions that would allow the working group's access and reviewing the data suitability with the working group participants. It is common that

- Researchers holding suitable data are reluctant to share their data due to concerns about reuse
- Reuse of data is challenging due to the question-specific context of the original studies

- Metadata is inadequate in many cases to be confident in reuse and the authors are often unable to provide information if contacted
- Difficulties occur in data discovery in open access repositories due to lack of awareness of repositories and lack of knowledge about how to interrogate the repositories

Once working groups identify and acquire their data, it has to be assembled and transformed into a suitable format so that it is fit for purpose and analyses can be conducted. Integrating datasets to allow for analysis can be very challenging. The main barriers are

- Blending data of dissimilar scales to the full, desired, geographic or temporal representation
- Time-consuming formatting required to correct data mismatches
- Correcting for different research purposes in data collection
- Adjusting to account for different data collection methods

Synthesis centres commonly provide support at this stage by assisting in the reorganisation of disparate datasets so they can be combined together for analysis. The magnitude of this task and the discipline required for organised data assembly is usually underestimated, but when done well, with good metadata and provenance description, the next steps are easier.

When significant challenges of the first two steps of the data workflow are overcome, working groups can begin to analyse their collated data. These collaborative activities often break new ground due to the amount of data used for analyses (supra-individual) and the high degree of multi-disciplinarity involved. However, establishing a consistent, standardised analysis technique is a major hurdle, and the group may find they do not have the suitable technical skills to accomplish their analyses, for example, write the code required, utilisation of cloud-based resources, interfaces with other large-scale relational databases or their associated applications. Frequently, groups develop their own approaches to deal with the data workflow challenges in partnership with synthesis centre staff.

Challenges also extend to the publication and visualisation of synthesised data, the least familiar of the steps in the data workflow for participants. There can be strong reluctance to publically release primary data from a technological and cultural viewpoint, for example (Specht et al. 2015b, Swauger and Vision 2015):

- Many journals won't publish articles if the data have already been released for open access.
- Some journals require *a priori* open access of all data and associated provenance and attribution.
- Some journals require *a priori* data management plans.

- Empowering a competitor or commercial partner prior to publication of articles based on the data.
- Insecurity about the quality of data (should it be released at all).
- Lack of knowledge of and trust in data repositories.

The importance of the establishment of data ownership and usage conditions in the acquisition phase often emerge at this stage, as, even though the data have been modified and transformed, the provenance needs to be acknowledged appropriately. Publication can be prevented if a data contributor cannot be contacted to obtain permission for data release; there is unknown ownership of a contributing dataset; there is uncertainty about institutional data publication policies; there are data licensing restrictions on some of the data (but perhaps not all); or there is confusion with respect to the correct attribution of the original data providers. All these matters can hinder data delivery, even of synthesised (and hence transformed) data. To solve them requires anticipation and planning and experience and knowledge of legal requirements and data licensing policies. The synthesis centre staff are vital at this stage enabling, quite often, rare and valuable 'long-tailed' data (*sensu* Heidorn 2008) to be delivered, 'cleaned' and enhanced by blending with other datasets.

18.3.1 Pioneering Tools for Data Management and Open Science

All centres, in partnership with their scientific communities, continue to create and promote standards and best practices for making data discoverable and accessible. Although many synthesis centre working groups develop new tools and models (e.g. release of r-scripts, controlled vocabularies, the SPEDDEXes group of ACEAS; www.emast.org.au/models/speddexes/), the close interaction between the informatics specialists in the centres and the energetic, highly qualified, innovative scientists has stimulated the production of new tools by centre staff which have wide applicability.

NCEAS changed the state of the art for data management in the ecological sciences. They recognised that synthesis has much to do with the development of semi-automated sharing, developed management tools (such as Morpho* and Metacat†) and analysis tools (Kepler‡), and built the web data repository Knowledge Network for Biocomplexity (KNB§), now

* Morpho Data Management Software allows the creation and management of data and enables sharing.

† Metacat is an open-source metadata catalogue and data repository that targets scientific data, particularly from ecology and environmental science.

‡ Kepler (https://kepler-project.org) is an open-source scientific workflow application designed to help scientists, analysts and computer programmers create, execute and share models and analyses across a broad range of scientific and engineering disciplines.

§ KNB is a data repository intended to facilitate ecological and environmental research: https://knb.ecoinformatics.org/.

a core partner of DataONE, a distributed discovery network for environmental data (Jones et al. 2006, Michener et al. 2012). The NCEAS staff also developed, with the Ecological Society of America, the Ecological Metadata Language (EML*), providing a mechanism for describing ecological information. This has become one of the standards for metadata description of ecological data.

Younger centres have responded similarly to the stimulating, problem-solving, environment of the synthesis centre. NESCent supported the development of the Dryad data repository (datadryad.org), while several centres have used geospatial visualisation methods for deposited data (www.aceas.org.au: 'products and outcomes' and www.betsi.cesab.org). The visualisations developed for ACEAS working groups fell into two categories: (1) those linked to metadata only and (2) those that provided a gateway to the raw data. Two ACEAS working groups felt that spatial delivery of their bibliographic collations was vital for understanding, prioritisation of effort and future conservation planning and worthy of spatial visualisation (Campbell et al. 2015, Pert et al. 2015). Other groups determined spatially coherent subsets of their synthesised data (from sub- to supra-continental scale) linking each zone to the raw data to provide evidence for their determinations (e.g. Bryan et al. 2013, McAlpine et al. 2015, Murphy et al. 2013, Thomson et al. 2015).

The wide variety of terminologies used in the ecological sciences is an impediment to effective communication and our ability to benefit from available data and information (Herrando-Perez et al. 2014, Jones et al. 2006). This is highlighted in the synthesis centre where combining data from different sources, across difference scales and from different domains is core business. The NCEAS staff and postdoctorates have been closely involved in the development of ontologies and thesauri (e.g. Bowers et al. 2010, Laporte et al. 2012, Madin et al. 2008) and the CESAB staff are participating with several groups in Europe, including the National Centre for Scientific Research (CNRS; www.cnrs.fr) to develop thesauri for reliable and explicit description of objects and measurements (e.g. t-sita.cesab.org; Pey et al. 2014a,b).

Organisation of the data from acquisition through to delivery also requires planning, and alongside encouraging the use of data management plans, CESAB is developing a decision support tool to assist biologists and ecologists create their databases. The National Institute for Mathematical and Biological Synthesis (NIMBioS) has developed evaluation approaches to quantify the value and benefit of publication (Bishop et al. 2014), and the

* EML is a metadata specification to document ecological data and a standard under ISO-19115-2. It is used by the Atlas of Living Australia (ALA; www.ala.org.au), DataONE (www.dataone.org), ECOSCOPE (www.fondationbiodiversite.fr/en/research/frb-programmes/ecoscope.html), Global Biodiversity Information Facility (GBIF; www.gbif.org) and the Terrestrial Ecosystem Research Network (TERN; www.tern.org.au), among others.

SESYNC is applying innovative approaches to enable effective collaboration across socioecological fields that will inevitably have a profound effect on the way science is practised.

18.4 Discussion

At the beginning of this chapter, some challenges were presented that we face today as we struggle to create the necessary wisdom to advance ecological thought to guide us into an ecologically sustainable future, despite being deluged with a superabundance of information. I have considered the first two challenges: (1) how to find the time to gather together the necessary information and to analyse and synthesise it in order to gain new understanding and insight and (2) how best to make sense of this information when we need to converse with each other across disciplinary, organisational, geographical and geopolitical boundaries. The collaborative working environment of the synthesis centre approach is demonstrably a very effective way for time-poor specialists to access valuable time for analysis and synthesis of a complex wealth of available information, in a manner that allows them to converse successfully across disciplinary, organisational and geographical boundaries.

It remains to consider the third challenge, 'how to respond when our training systems are slow to react and careers are governed by disciplinary rewards'. Through the collaborative and trusting environment and the support provided by the synthesis centre, participants not only analyse and synthesise data to answer their questions, but they learn new techniques and develop strong relationships that enable them to perform better in their own workplaces (Lynch et al. 2015). In other words, the synthesis centre experience for working group participants is a learning exercise and should be regarded as vital professional development. It provides many with an enriching experience that they have not felt since they were postgraduates: competing to be the last person to leave the laboratory, testing ideas, sharing coffee, successes and failures, learning about a new program/technique/model, helping on field trips, monitoring experiments, sorting that programming question and kicking that proverbial ecological can down the road. Learning from peers at that time was important, and the synthesis centre provides an opportunity for that to occur again, overcoming the professional isolation felt by many when they are embedded in their workplaces ('sharing thinking on a topic always helps me to distill and organise my own thoughts by drawing on other peoples' perspectives' BALWS112).

The results of the synthesis centres feed into established media and performance metrics. Publication rates from synthesis centres are high, and impact factors are also high (Baron et al. subm., Hampton and Parker 2011). A high proportion of all publications resulting from the activities of synthesis centres are published in leading multidisciplinary journals and are cited highly compared with other research institutions (NESCent 2011). Similar success factors are evident for data deposition, with the KNB data repository now reaching, at the time of writing, 21,174 data packages deposited as a result of NCEAS activity (knb.ecoinformatics.org/#data/page/0).

The typical workflow processes occurring in a synthesis centre shown are based on the operation of two synthesis centres (ACEAS and CESAB; Figure 18.4), and establishing the International Synthesis Consortium (www.synthesis-consortium.org), and close interaction with DataONE, the Terrestrial Ecosystem Research Network, and the Atlas of Living Australia. Figure 18.4 illustrates the attributes of the people, data and processes characteristic of the synthesis centre. The operation of the centre is rarely exposed beyond being a place where 'things happen' (the 'condensor' model of the diagram). As mentioned, the synthesis centre provides intelligent support (scaffolding) for the participants to enable them to achieve their goals. The people involved in providing this support are usually multitaskers and polymaths, and their role in the synthesis centre enhances those attributes. The expertise developed by the staff, through their exposure to the vast array of topics and people that pass through the centres, biased according to the focus of the

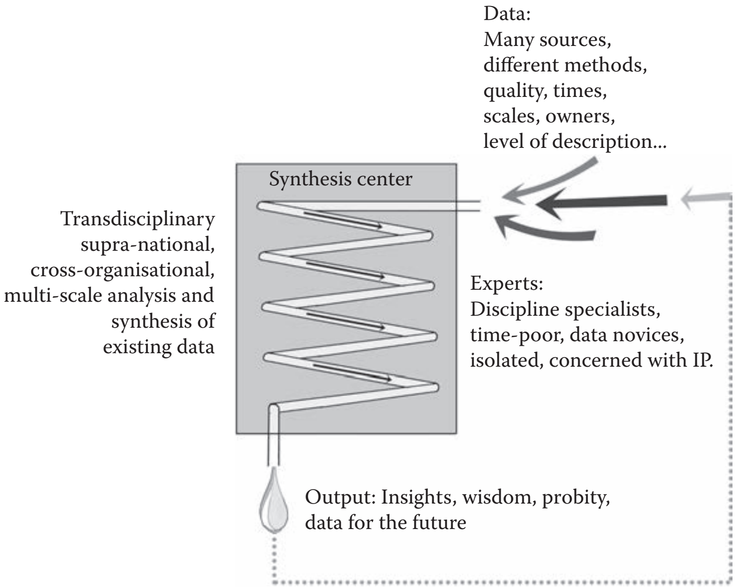

FIGURE 18.4
The function of the synthesis centre in facilitating the 'getting of wisdom' by scientists, policy-makers and managers, beginning with the reuse of multiple, heterogeneous data and producing new insights and cleaned and synthesised data which can be made available for reuse.

centres (Figure 18.1), becomes a resource in its own right. This has resulted, for example, in the development of the tools mentioned in this chapter but also in a deep understanding of the breadth of topics, the interrelationships between disciplines and technologies and the characteristics of the people in the respective communities of practice. The idea of the synthesis consortium capitalises on this, as together, through sharing the particular skills and knowledge acquired in each centre, we can enhance the effectiveness of each and potentially create a new 'super' centre well suited to tackling global environmental questions beyond geographical and geopolitical boundaries.

Pivotal to the synthesis centre, of course, is the analysis and synthesis of existing data and information. They are places where existing data are given new life, legacy data are brought into the light and existing data are quality assured and value added in new ways. Centres are a place to test new ideas and analysis techniques outside normal institutional and funding structures and are thus in the fortunate position of being at the cutting edge of intellectual experimentation. This benefits not only the participants but also the centre staff and data providers. The synthesis centre concept is commended to scientists, policymakers and managers who are faced with complex ecosystem science questions and who wish to make the most of the emergent 'big data' world.

Acknowledgements

The author thanks the staff and participants of both ACEAS and CESAB and the members of the International Synthesis Consortium for many challenging discussions, support and collaboration. The author also thanks Drs. M. Schildhauer and M. Jones for his initiation into the world of data analysis in synthesis centres.

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