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Main Article:

Collaborative Research on Sustainability: Myths and Conundrums of Interdisciplinary Departments

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Abstract

Establishing interdisciplinary academic departments has been a common response to the challenge of addressing complex problems. However, the assumptions that guide the formation of such departments are rarely questioned. Additionally, the designers and managers of interdisciplinary academic departments in any field of endeavour struggle to set an organisational climate appropriate to the diversity of their members. This article presents a preliminary analysis of collaborative dynamics within two interdisciplinary university departments in Australia focused on sustainability. Social network diagrams and metrics of coauthorship and cosupervision are analysed qualitatively. A "vicarious interdisciplinarity" was identified among key academics working narrowly in order to earn the resources that allow them to support others working interdisciplinarily. Those supported in this way appear to benefit from the esteem and nonredundant collaborative connections their mentors provide via this strategy, but they experience uncertainty about their own career opportunities in similar settings. This article thus unearths a conundrum of succession for interdisciplinary academic environments, and suggests that simple colocation of diverse academic stars is an inadequate strategy to achieve effective intradepartmental collaboration.

Keywords: sustainability science; social networks; collaboration; research training; coauthorship; cosupervision

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1. Introduction

Sustainable development is a goal that challenges the ethic of economic growth and the associated inequalities of modern life (Dovers, 2005a). It is most commonly defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 43). There remains considerable debate about the concept in academic literature (e.g., Robinson, 2004), but applied researchers have redirected their focus to the processes that could enable a transition to *sustainability* (taken here as equivalent to sustainable development). The goal of sustainability is multidimensional, involving the following key "pillars": economic viability, environmental responsibility, social justice, and cultural vitality (Hawkes, 2001). Increasingly diverse parts of universities are involved in research aimed at contributing to these various aspects of sustainability. Dedicated academic departments have also been formed at many universities to

undertake more integrative studies. Sustainability departments typically colocate experts from a range of relevant disciplines, in the hope that they collaborate on research questions that cannot be tackled from within any one field. As will be discussed in more detail later, this assumption is not always correct.

The discipline of geography, with its multiscaled dedication to the human-environment project, most resembles the scope of sustainability, but has somehow missed the opportunity to be a leader (Liverman, 1999; Wilbanks, 1994). Instead, a nascent field called *sustainability science* seeks to advance the transition to sustainability as defined above. It is essentially an amalgam of social and natural sciences united by an aspiration to be applied and policy relevant. In lieu of a common method, it has an organising framework (Millenium Ecosystem Assessment, 2003) and a unifying concept in "resilience" (Ludwig, Walker, & Holling, 1997). Kates et al. (2001) describe the challenges inherent in the scope of sustainability science, as it must:

> (1) Span the range of spatial scales between diverse phenomena as economic globalization and local farming practices, (2) account for both the temporal inertia and urgency of processes like ozone depletion, (3) deal with functional complexity such as is evident in recent analyses of environmental degradation resulting from multiple stresses, and (4) recognize the wide range of outlooks regarding what makes knowledge usable within both science and society. (p. 641)

Sustainability science must not only span many disciplines but transcend them, as well as transcending the boundaries of the university itself. This last goal is a feature of "transdisciplinary research," which involves the integration of stakeholders deeply into the research process (Tress, Tress, van der Valk, & Fry, 2003). In tracking collaboration only within universities, this article is more concerned with interdisciplinary collaboration, which describes the integration of multiple theories and methods to form a common research approach. Interdisciplinarity is assumed to be more integrated in day-to-day activities than multidisciplinary activities, in which multiple disciplines apply themselves to a common problem simultaneously, but often without mutual engagement. Research on sustainability topics is becoming increasingly mainstream, with the Australian federal government, for instance, listing environmental sustainability as one of the four national research priorities in 2002 (Department of Education Science and Training [DEST], 2002), but interdisciplinarity still faces many challenges (Metcalfe, Riedlinger, Pisarski, & Gardner, 2006).

Social networks are used here to visualise patterns of collaboration around academic publication and research training in sustainability. This work was inspired by a previous analysis of research collaboration throughout two Australian universities (Sherren, 2006). On sustainability topics, departments in both universities looked outside their walls for research collaborators but inside for cosupervisors to support research students. That earlier work was blind to the patterns of interactions within the departments. The analysis presented here explores the academic interactions between individual academics and research students in the key interdisciplinary, sustainability-focused department at those same universities. This preliminary analysis suggests that: (a) the pro-

collaboration rhetoric that justifies the founding of interdisciplinary, problem-based departments on cross-cutting topics like sustainability has limited applicability and (b) the assumption that colocation necessarily breeds collaboration needs reconsideration. While this current analysis is itself preliminary and country-specific, it sets the stage for a research agenda on the design of such interdisciplinary units, while they are multiplying worldwide.

This article will first provide a background to the challenges of interdisciplinary collaboration and introduce the methods and theories adapted here to investigate it. The two cases are briefly outlined and followed by a range of custom metrics, visualisations, and qualitative analyses that we used to glean common patterns. Finally, a thought experiment is used to play these patterns forward to understand their impacts on individual careers, university structures, and sustainability science per se.

2. Background

Analysing research networks in interdisciplinary departments calls for understanding the characteristics of academic life that drive collaborative choices and finding an appropriate methodological approach.

2.1. Drivers of Academic Collaboration

Sustainability research covers a vast territory. Dovers (2005a, p. 9) captures the daunting scale of sustainability with a list covering “resource depletion and degradation,” “pollution and wastes,” “fundamental ecological life support services,” and “society and the human condition.” Sustainability work in universities thus spans such disparate fields as biology, economics, and philosophy, and is vulnerable to academic fragmentation. This fractious nature is caused in part by the competing and overlapping pressures of disciplines, career goals, and administrative units acting all at once on individual academics.

The main academic cultures are often identified as science (natural and social) and the humanities (Snow, 1959), which differ fundamentally in pattern of research, research training, and education (Becher, 1989; Moses, 1990). Natural science emphasises cumulative knowledge development through measuring and calculating; the humanities build knowledge iteratively and with frequent revisitation of past work with new lenses. Social science combines the characteristics of the other two (Donald, 1986; Lattuca & Stark, 1995). These broad “sectors” are reputedly the most difficult boundaries to cross academically (Poole, 1994), although numerous “interdisciplines” like ecological economics and human ecology have sprung up in the interstices (Dovers, 2005b). Interdisciplinary areas such as sustainability that touch on all three struggle to combine cultures. For instance, Fujigaki (2002) found that environmental science demonstrated little integration, its subdomains instead resembling the traditional disciplines from which they originated.

Disciplinary identity and peer-determined disciplinary status are strong motivators for the

collaborative choices made by many academics. Such positional characteristics also dictate their collaborative style and their collaborative opportunities. These opportunities may differ dramatically depending on whether the disciplinary identity is a "cohesive" one or a "diffuse" one, as defined by Whitley (1984). Cohesive disciplines have the collective focus to allow for long-range planning and the division of labour among researchers, whether colocated or not (Adams, Black, Clemmons, & Stephen, 2005). They also typically share methods, making outcomes easily anticipated and described, facilitating successful grant writing, and the overall pace of progress (Considine, 2006; Russell, 2005). Cohesive fields have a clearer social utility and their leaders are often better resourced. In contrast, the approach to be taken to solve sustainability problems is often unclear, the relevant peers and publications may vary throughout the research, and the outcomes are more difficult to anticipate. Fragmentation frequently occurs around methods, with individual actors seeking publication and prestige in different places. Rigour is harder to enforce as peer review cannot happen without appropriate peers (Laudel, 2006b). Even compiling comprehensive literature reviews is challenging, let alone undertaking new research. Diffuse scientific paradigms such as this can be a hurdle to success in winning grants, which can negatively affect disciplinary development and personal success (Long & Fox, 1995). If funding is won, too much team diversity can be detrimental to research progress (Barjak, 2006; Melin, 2000).

Social identity theory suggests that humans seek group membership in order to reduce uncertainty in goals, status, and roles (Hogg & Terry, 2000). Social identity is measured relatively, via constant comparison with representative group member archetypes; a person's degree of match with such characteristics determines how they fit in a group. Those at the edges may withdraw, or simply go "unpreferred" as "self-interest[ed] researchers . . . link together in search of rewards, reputation, and resources" (Wagner & Leydesdorff, 2005, p. 1610). As a result, those working in disciplinary interstices often feel the pressure to become "disciplined" in order to gain credibility, clarity of purpose, and a share in academic rewards. This process includes developing common research goals, defining central concepts and methods, narrowing research tasks, and working on the reproduction of the field through the training of research students (White, 1999). The risk is that such "bounding" activities will make it as blind to new ideas as the disciplines it earlier rejected. This is the tug-of-war that any sustainability department must face, as much as the academics within it (Wasson & Dovers, 2005).

Career development is a clear motivator for collaborative activities. For academic careers, there are a range of contexts within which to position oneself and a matching range of constituencies to please. Besides one's disciplinary or interdisciplinary identity, the organisational structure of the university is also a dimension that affects career opportunities. Responsibilities around research training and teaching often align with organisational budget units (Klein, 1999). Local cost and infrastructure issues dictate day-to-day issues such as contact hours with students, supervisory responsibilities, available resources for research or networking with disciplinary peers (e.g., conference travel), administrative burdens, the capacity to experiment with pedagogy, and expectations regarding community outreach (whether for public good or university marketing).

Finally, academic careers are influenced by fluctuating government priorities in research and education. A university under external pressure, say, to improve research output quantity, will often echo the same stimuli in their internal career incentives (Gläser & Laudel, 2005), even if this encourages quantity over quality (Butler, 2003). Internal performance management processes may thus not advance individual aspirations, scholarly progress, national esteem, organisational harmony, or policy relevance.

Interdisciplinary university departments are a special case within the academic context described above. Many interdisciplinary research centres have arisen globally on environment and sustainability since the early 1970s (Klein, 1999). Such problem-based departments are typically staffed by academics from a wide range of disciplines, often with little duplication. For example, one economist, one historian, one biologist, and so on, may be on the permanent academic payroll; research students, field staff, or visiting collaborators are then recruited to create critical mass.

It is a common assumption that colocation improves collaboration in academic or other research settings (Adams et al., 2005; Katz, 1994; Rhoten, 2004; Younglove-Webb, Gray, Abdalla, & Thurow, 1999). Having offices close to one another or sharing a common room (e.g., tea room or lounge) does increase the likelihood of felicitous informal meetings. Such interaction has been noted to result in conversations and group learning that occasionally ignite research collaborations, even among colleagues from differing disciplinary traditions (Lattuca, 2002; Laudel, 2001; Melin, 2000). Fragmentation, however, may simply be “an intractable aspect” of institutions grappling with broad issues like sustainability (Rydin, 2006, p. 214). Rhoten (2004) notes that centres staffed “nominally”--to fill a disciplinary niche rather than undertake a specific role--tend to suffer from a lack of common direction and waste the benefits of colocation. Social reasoning (including previous collaboration or mentorship) is responsible for 32 per cent of collaborative choices (Melin, 2000). Academics exercise the right to choose any collaborators they need, as they cannot choose their coworkers.

Ambiguity in organisational expectations presents many opportunities for drift in the direction of prevailing pressures like those already discussed. Rhoten (2004) argued that interdisciplinary centres fail less because of a lack of intrinsic motivation by academics or students, or a dearth of support by funding agencies or other external pressures, than by mal-adaptation at the level of management and leadership. University structures and incentives have “tended to approach interdisciplinarity as a trend rather than a real transition” (Rhoten, 2004, p. 6) and have failed to establish systemic support for the undertaking. Abbott (2001) suggests that the sign that a new field has become established is when academic departments tackling the subject hire their own or each other’s graduates. As this analysis will show, such is not always the case with the field of sustainability research.

2.2. Dynamics of Academic Collaboration

Interdisciplinary researchers in universities are subject to a range of pressures, such as departmental duties, priorities of external funding agencies, and the attractions of working within disciplines. Methods of visualising collaborative networks can help to reveal which pressures shape collaboration. Theories for describing positions in such networks can help to explore the ramifications of those collaborative decisions, individually and for the institution.

Sociologists have spent considerable time looking at academia and the production of knowledge in traditional science (Bourdieu, 1984/1988; Cole, 1983; de Solla Price, 1965; Kuhn, 1962/1970; Latour, 1987). Sociometric methods like social network analysis (SNA) are commonly used. SNA explores connections between individuals or organisations, and how patterns of linkage can affect information flows or aggregate behaviour (Borgatti & Everett, 2003; Klovdahl, 1997; Wellman, 1983). Interdisciplinary sociometric research has been largely limited to narrow and clearly defined areas that involve the sharing of expensive research infrastructure such as neuroscience and experimental physics (Braun, Glänzel, & Schubert, 2001; Chompalov, Genuth, & Shrum, 2002; Laudel, 2006a). The applied, context-driven, and interdisciplinary "Mode II" research (Gibbons, Limoges, Nowotny, Schwartzmann, Scott, & Trow, 1994; Nowotny, Scott, & Gibbons, 2001) typical of sustainability science involves many players and disciplines and could also be a candidate for sociometric analysis.

Many different interactions can be used to build pictures of social networks, but some, like e-mail exchanges or corridor conversations, are difficult to capture (Frank, 1996; Price, 2003; Tichy, Tushman, & Fombrun, 1979). To understand research collaboration, bibliometric evidence of influence is a natural choice and easy to document. Evidence of influence, but not necessarily interaction, includes citation (Crane, 1969) and cocitation (van Raan, 1990). Coauthorship and cosupervision of research students demonstrate influence as well as interaction, and both are used here as a proxy measure for collaboration (Laudel, 2002; Newman, 2004). These data can be mapped visually with sociograms, which are maps of agents and linkages formed by collaboration between them (Barabási, Jeong, Neda, Ravasz, Schubert, & Vicsek, 2002; Newman, 2001).

Collaboration is a common element of contemporary academic life, although "eagerness and need to collaborate" differs by discipline (Melin, 2000, p. 38; also Qin, Lancaster, & Allen, 1997). Collaboration builds and draws on social capital. In an academic setting, social capital comprises "the sum of researchers' professional networks and their technical skills and resources" (Bozeman & Corley, 2004, p. 599). A lack of such capital is an impediment to collective action in academe as elsewhere (Porac, Wade, Fischer, Brown, Kanfer, & Bowker, 2004; Rydin, 2006). Mentoring can transfer social capital between generations. Collaboration harnesses academic capital from a range of sources to solve a problem, and such networks can be small or large, locally situated or dispersed, dense or sparse, homogenous or heterogeneous, depending on need, inclination, and opportunity.

Dense networks bring numerous rewards. Dense and relatively homogenous networks make it

easiest for individuals to coordinate with each other to help one another (Borgatti & Everett, 2003; also Coleman, 1990). This supports the strategy of selecting a supervisory panel from within a single department or discipline, where a student is more likely to receive face-to-face assistance based on a consistent set of norms. Such clarity and support is reassuring for a student tackling a complex field like sustainability. Homogeneity among supervisors and mentors, however, increases the risk of "groupthink" or intellectual stagnation in the long term (Beaver, 2001; Hogg & Hains, 1998). This is especially so for interdisciplinary areas that need to refresh constantly and draw on new research from other disciplines (Rinia, van Leeuwen, Bruins, van Vuren, & van Raan, 2002).

A dense network is not the best way to advance knowledge among the mentors themselves. The first links added to an unconnected set of agents drastically improve connectivity, but the improvements become smaller as more are added (illustrated using graph theory in Chartrand, 1985). Simply put, close neighbours often come with redundant knowledge and opportunities. Each linkage requires equivalent effort to maintain, even if it brings little reward, so dense networks make for an inefficient system. Sparse networks are possibly more efficient means of transferring social capital and information to address complex problems, particularly among advanced researchers (Burt, 1992; Granovetter, 1973; Mehra, Kilduff, & Brass, 2001). The combination of dense internal cosupervision networks and sparse internal coauthorship networks found in the case studies reported here suggests a strategy of *vicarious interdisciplinarity* amongst key academics. These researchers reach outside the department in coauthorship with disciplinary peers to acquire esteem and rewards, and inside to cosupervise research students working interdisciplinarily with departmental peers.

Of course, real-world networks are rarely uniformly sparse or dense, but are clustered to varying degrees. The position of a node within such a heterogeneous network may reveal much about the real-world status, attractiveness, and importance of the individual it represents. Accordingly, different roles have been recognised within scientific communities. In one typology, "continuants" are those who are productive in the years preceding and following an analysis (Braun, Glänzel, & Schubert, 2001). Continuants often mediate communications between others, including via publication, appearing in sociograms as coauthorship hubs (Stokes & Hartley, 1989). This reinforces their attractiveness for "preferential attachment based on reputations and rewards" (Wagner & Leydesdorff, 2005, p. 1611). Such rewards mean continuants are often able to turn collaborators into colleagues, thus reducing the uncertainty, transaction costs, and cognitive tasks often involved in arranging the division of labour vertically and allocating resources and credit (Beaver, 2001; Landry & Amara, 1998; Laudel, 2001). Despite their large networks, the career path for such players is quite rigid, focused on developing the disciplinary excellence and consistent track record needed to acquire yet more funding (Lattuca, 2002; Laudel, 2006a; Rhoten, 2004). In a classification of specifically interdisciplinary centres, these players were defined as "stars," in comparison to the "connectors" who linked disciplines (Rhoten, 2004). In our analysis they are simply called key players (see Table 1 to map our terminology with that of others used

here).

Interdisciplinary connectors are attracted to disciplinary fringes and they facilitate integration. They are usually not subject to the same pressures to maintain large research programmes as stars. We call them secondary players, but another typology calls them "newcomers" (those at the beginning of their career, like postdoctoral fellows), or "terminants" (those at the end, like visiting fellows or emeritus professors) (Braun, Glänzel, & Schubert, 2001). They are "driven to the edges of their fields by a shift in their epistemological values and intellectual interests" (Rhoten, 2004, p. 8-9), despite the recognised risks (particularly to young academics) of doing so (Rhoten & Parker, 2004). Although not included in our definition of secondary players, a last set of interdisciplinary connectors are "transients", who publish only once in an area and may be from another field entirely (Braun, Glänzel, & Schubert, 2001). In interdisciplinary departments, transients are likely to be PhD students, but as will be seen, they do play an important linking role in creating departmental cohesion.

Table 1. *Academic Positions and Classifications of Scientific Network Roles*

Academic Position	***Braun, Glänzel, and Schubert (2001)***	***Rhoten (2004)***	***In this article***
Post-doctoral researchers or junior academics	*Newcomers*	*Connectors*	*Secondary*
Continuing senior appointments	*Continuants*	*Stars*	*Key*
Emeritus professors or late-career academic visitors	*Terminants*	*Connectors*	*Secondary*
Research students and other visitors	*Transients*	*Connectors*	*Periphery*

3. Cases and Methods

Sustainability departments at two universities were studied and compared. University A is a postwar, research-intensive urban university with a high ranking nationally and internationally, active in sustainability research since the founding of its research-only environmental department in 1973. This interdisciplinary department was launched specifically to encourage collaboration on complex environment--and now sustainability--issues. It has a small number of ongoing positions earmarked for disciplines contributing to the sustainability pillars (see Figure 1a); temporary roles like PhD students, postdoctoral fellows and visitors make up the rest of the actors, and money for them must be found externally.

University B is a regional, multicampus university formed by the amalgamation of several

vocational institutions in the late 1980s. It houses a department with an emphasis on rural society and natural resource management (see Figure 1b). It is staffed to undertake research and to provide teaching programs at undergraduate and graduate levels on those topics, and is thus not so beholden to external funds to maintain a full complement of staff.

Both the focal departments dominate sustainability research at their respective institutions, and also form the nuclei of variously formalised university-wide peer-networks on sustainability that connect individuals across the university with similar interests. They differ in their disciplinary content as befits their respective histories and goals. This analysis sought to explore how interdisciplinary departments collaborate to contribute to research progress in diffuse fields like sustainability, and what collaborative choices say about prevailing pressures.

3.1. Data Sources

Academic collaboration in the departments was mapped using records of research student cosupervision and scholarly coauthorship from 2000 to 2004. These two activities--supervision and publication--are essential to the progress of research in any academic department. Tracking collaboration on grant-writing was also considered, but only successful grants would be released by centralised offices, and it was assumed that these would already be reflected in coauthorships. No filtering was done on either of these data sets, a decision analogous to the common bibliometric assumption that the content in a journal classified by the Institute for Scientific Information (ISI) as "interdisciplinary" *is* interdisciplinary. During the 5-year period chosen for study, the first author spent at least a year working in each university, allowing for an embedded interpretation of the metrics and visualisations developed here. It also covered a period of little change in the key staff of both departments. Finally, this period allowed comparability with a previous, wider-scoped but coarser-grained analysis of sustainability research at the same institutions (Sherren, 2006).

Coauthorship was derived from the internal databases kept by universities since the Australian Government Department of Education, Science and Training (DEST, now the Department of Education, Training and Workplace Relations) introduced transfer payments to universities on the basis of the number of peer-reviewed publications produced annually by their staff or students meeting certain criteria. Eligible publications included scholarly books (edited volumes and textbooks were excluded from this definition), book chapters, refereed conference articles and journal publications. All outputs were worth one so-called "DEST point," hereafter called "performance point," save scholarly books, which were worth five.

The quality of these internal databases admittedly varied but they still provide a valuable snapshot of academic activity. University A's database returned only 84 per cent of the eligible publications due to a temporary reporting error, but that was twice the scholarly output that the ISI indexed in the same period. ISI does not systematically index book chapters, creative works, or the grey literature, and applied science, social science, and humanities citations are under-represented

(Butler & Visser, 2006). University B's database was complete but required refinement because of inconsistent input standards.

Cosupervisory panel information came from annual reports and internal records from each sustainability department, because centralised data sources captured only research Masters and Doctorates. These data included the topics and supervision panels of Honours theses (1-year full-time) and coursework Masters sub-theses (a half-year) that take up a significant amount of supervision time. Only students enrolled at each of the sustainability departments for their higher study were included, not those enrolled in another department whose panel included someone from the sustainability department. Such arrangements are common, as each university encourages panels instead of individual supervisors, requiring that only one supervisor is affiliated with the department at which the student is enrolled.

3.2. Modelling Approach

This analysis involved the use of Analytic Technologies' *UCINET* (Borgatti, Everett, & Freeman, 2002) and *NetDraw* (Borgatti, 2002) for creating sociograms. Each dataset provided department-level affiliations; the topical or disciplinary orientations shown in Figures 1 and 2 were determined by looking at article titles. Coauthorship networks were mapped by the pairwise linking of all authors from the university in question that were listed on each article. Some postprocessing was then done to ensure that each publication's collaborative links got fractional *weights* that summed to the output's performance point value, rather than a simple integer count, the latter of which would have created a bias towards outputs with a large number of authors (Moses, 1990; Najman & Hewitt, 2003). This step helped to balance those who publish books or monographs infrequently with those who constantly publish smaller units.

Unlike the coauthorship analysis, cosupervision was not mapped at the level of individual. Individualised data were not consistently available because one university did not consider supervisory teams a matter for the public record. One author of this article who was privileged to internal data for the department in question gained permission to map supervisory panels in a way that could be presented anonymously. Supervisory panel chairs were thus linked to other cosupervisors on the panel, and both were aggregated to the research clusters to which the individuals were identified as belonging in the coauthorship sociograms.

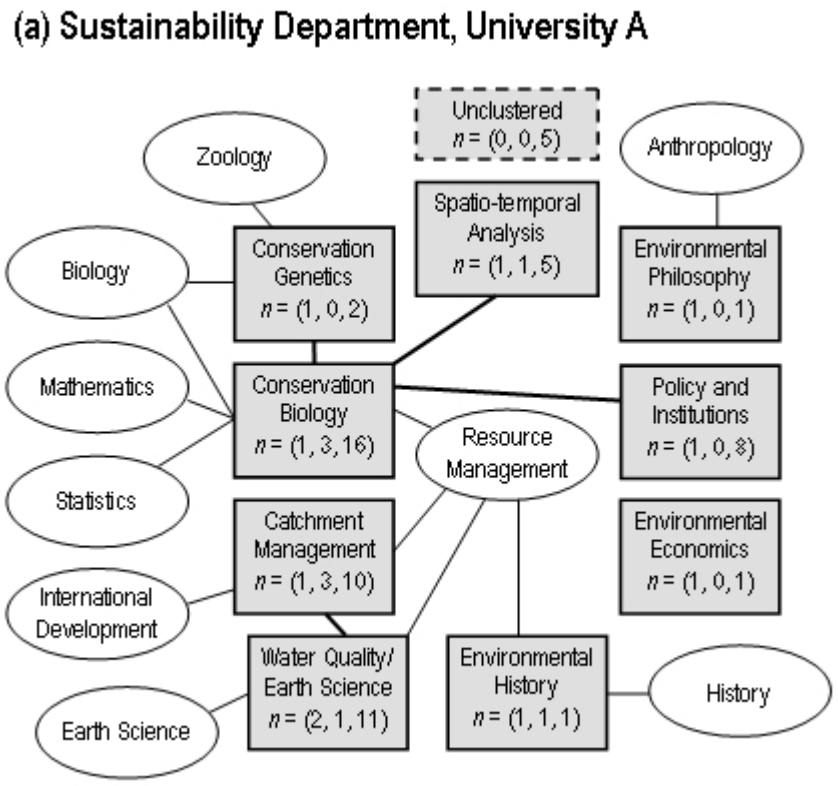
The analysis undertaken of the coauthorship and cosupervison networks was largely interpretive and exploratory, based on custom metrics and visualisations relevant to each case. The only standard SNA statistic used to compare the two cases was *density*, the number of links present (regardless of their weights) divided by the number of links possible, given the number of nodes involved. These sociograms and metrics were interpreted by the first author based on her experience within each case, with iterative feedback from the others (who comprised her supervisory panel).

4. Collaboration Within Sustainability Departments

What kind of research and research training takes place within sustainability departments? Is it interdisciplinary work that draws together the collected skills in a way that would be difficult in a traditional department? Alternatively, are these departments internally fragmented resulting in collaboration aimed toward disciplinary peers? With this preliminary analysis, a start is made towards answering these questions.

4.1. Coauthorship: Patterns of Isolation and Clustering

Sociograms of coauthorship in both sustainability departments suggest well-worn paths of collaboration that were rarely breached. These activity clusters or solitary nodes, depending on disciplinary tradition, were surrounded by rich external networks leading to other departments (see Figure 1) and outside of the university.



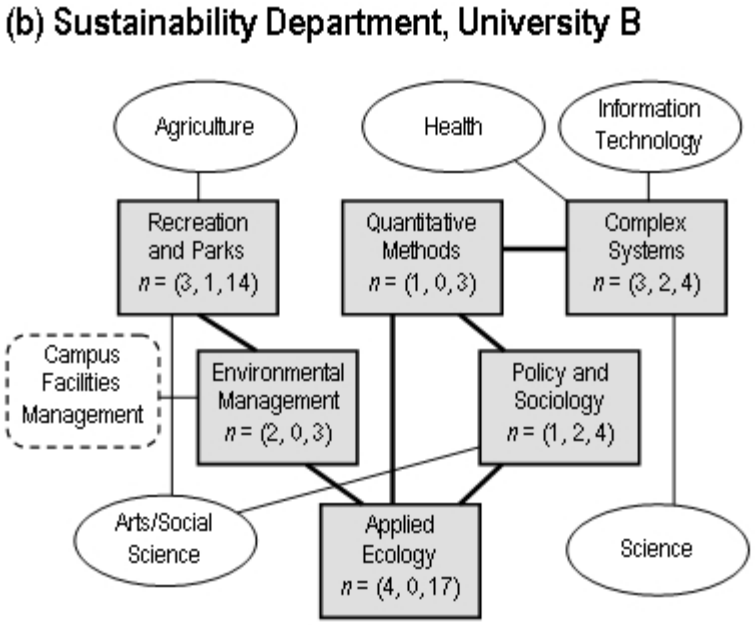


Figure 1. University-wide coauthorship networks during 2000-2004, using case department research clusters as the unit of analysis (shown here as squares, with other departments as ovals). The numbers in the shaded squares denote the number (*n*) of actors of three types: key, secondary, and periphery.

In university A's sustainability department no single discipline had a "critical mass" of permanent staff. Nine clusters covering the humanities, social sciences, and natural sciences emerged from the coauthorship network (Figure 2), although individuals may not be clustered within their original field of study. Individuals in these clusters appeared to follow the different publication and collaboration traditions of these large sectors, rather than any particularly interdisciplinary model. Solo or joint publication was common in the first two academic areas--humanities and social science--and teams (large or small) in the third, natural science.

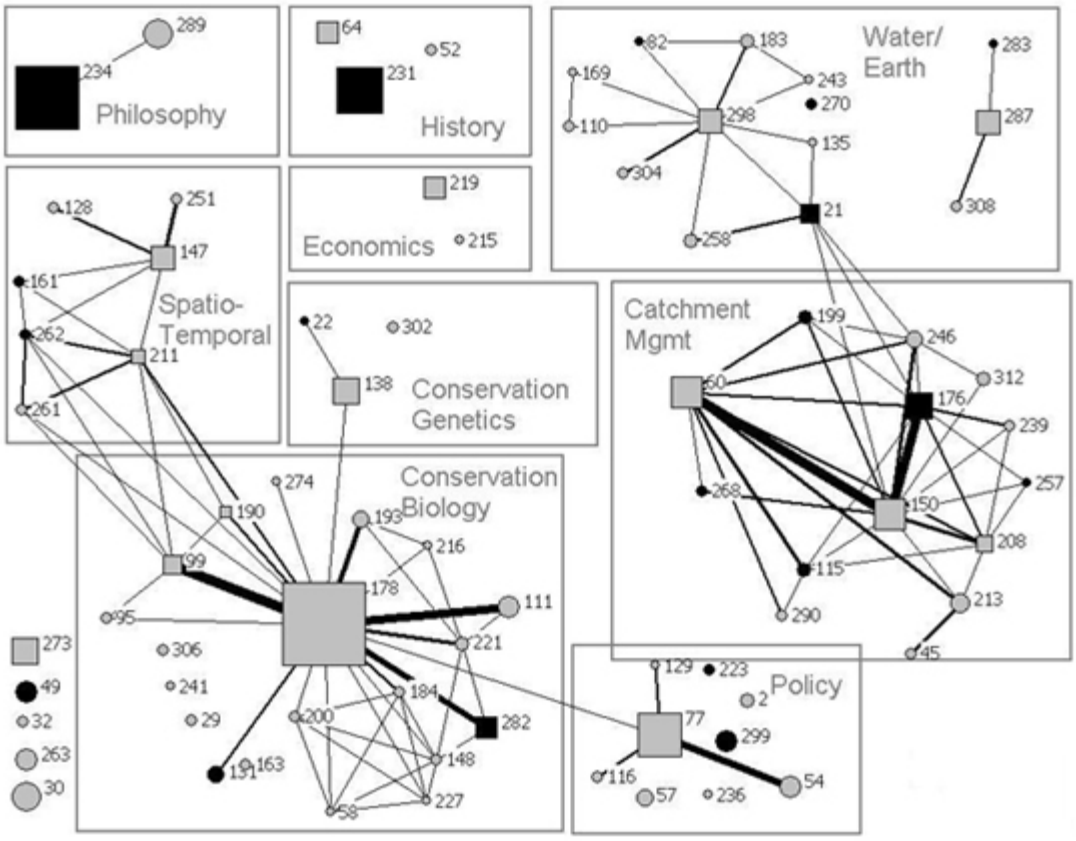


Figure 2. Research clusters within the sustainability department at University A, as identified from coauthorship collaborations during 2000-2004. Shading is by sex (men are grey, women black); squares identify key and secondary nodes; size indicates the share of performance points produced by the author; links are weighted by the proportion of work shared by the nodes.

Only ten key individuals appeared in all of the 5 years under study and had continuing appointments. A further ten secondary nodes were visible in most years or played interesting structural roles via their more temporary positions like postdoctoral research fellow, academic visitor, or emeritus faculty. These 20 key and secondary nodes, identifiable as the square nodes in Figure 2, form the core of the research activity at the department. The periphery is comprised of the circular nodes in Figure 2 (n = 59), many of whom were undertaking a PhD at the department at the time. Only 3.6 per cent of the possible linkages between those 79 nodes were actually represented in coauthorship activities.

Figure 2 shows that the sparse network of individuals at the sustainability department of University A did not consist of evenly dispersed links, but isolated clusters around key players. In the one cluster that possessed two key players and a collaborative disciplinary tradition--water quality/earth science--the key players did not coauthor any scholarly work in the 5 year span. Key players instead coauthored with visitors they had attracted, their PhD students and postdoctoral researchers (the latter usually former PhD students of the key player), and disciplinary peers from outside the department. Formation of such cliques may be exacerbated by the fact that the department did not offer a degree program that would require collaboration for curriculum design

and assessment.

Little boundary spanning was apparent, whether done directly between clusters, or via outsiders. Within the sustainability department of University A, only a few research outputs bridged clusters during this period, and such connections were as likely to be caused by protégés as they were by key nodes. As shown in Figure 2, early career researcher (ECR) 21 had worked with the water quality/earth science group and the catchment management cluster, for example. Conservation biology ECRs 99 and 190 also used and helped to refine the software programs developed by the spatio-temporal group. When more than one individual from the department engaged with the same outside department, it was rarely with the same person. Of the 57 external but intrauniversity individuals named on publications produced by the department, only two had links to more than one of the research clusters.

University B's key coauthorship clusters during the years of interest aligned closely with its degree programs in environmental management, recreation and heritage, and information technology (Figure 3). In addition, the clusters that overlapped with the degree programs had more key players because of the burden of teaching.

Although a critical mass of key players existed within most clusters at University B, the coauthorship pattern was similar to that of University A: sparse, with 3.2 per cent of potential connections existing between the 63 unique authors. The activity was also highly clustered, usually radiating from one of the key players, defined for this department as those present in a majority of the 5 years in question and enjoying above-average productivity. In two of the biggest fields, applied ecology and recreation, key players often did not publish together and had few links elsewhere in the university. Fields where key players did coauthor included complex systems and policy/sociology, and the smaller group of environmental management. The first of these was most active elsewhere in the university, having linked to the widest number and diversity of other departments as they sought new problems to tackle with their computational techniques (see Figure 1). The internal methods group was the most connected within the department, possibly for similar reasons.

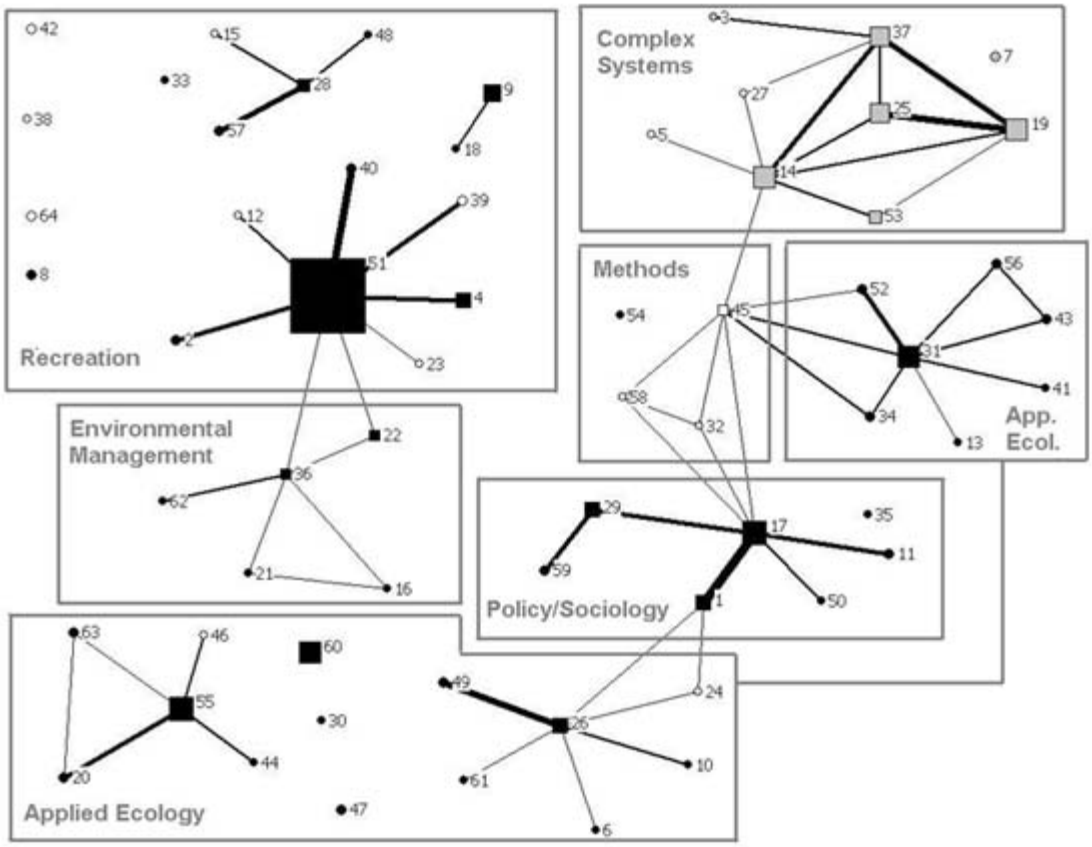


Figure 3. Research clusters within the sustainability department at University B, as identified from coauthorship collaborations during 2000-2004. Shading is by affiliation in formalised peer-networks (sustainability is black, complex systems grey, and those without affiliation are white); squares identify key and secondary nodes; size indicates the share of performance points produced by the author; links are weighted by the proportion of work shared by the nodes.

4.2. Cosupervision: Pattern of Integration

Vicarious interdisciplinarity does appear to be a dominant strategy for supervisors, whether it is conscious or not. While the sparse internal copublication networks rarely spanned disciplinary clusters, many of the isolated individuals frequently collaborated on the panels of research students enrolled locally, although departmental regulations do not require it (see Figures 4a and 4b). For drawing the network graphs shown in these figures, authorship was mapped symmetrically, with all authors connected, using all reward-eligible publications produced by each department during 2000-2004. Supervision was mapped directionally from the panel head to other supervisors and advisors. The types of theses involved differ: at University A, theses begun during 2000-2004 were mapped; at University B, theses completed in that time period were used.

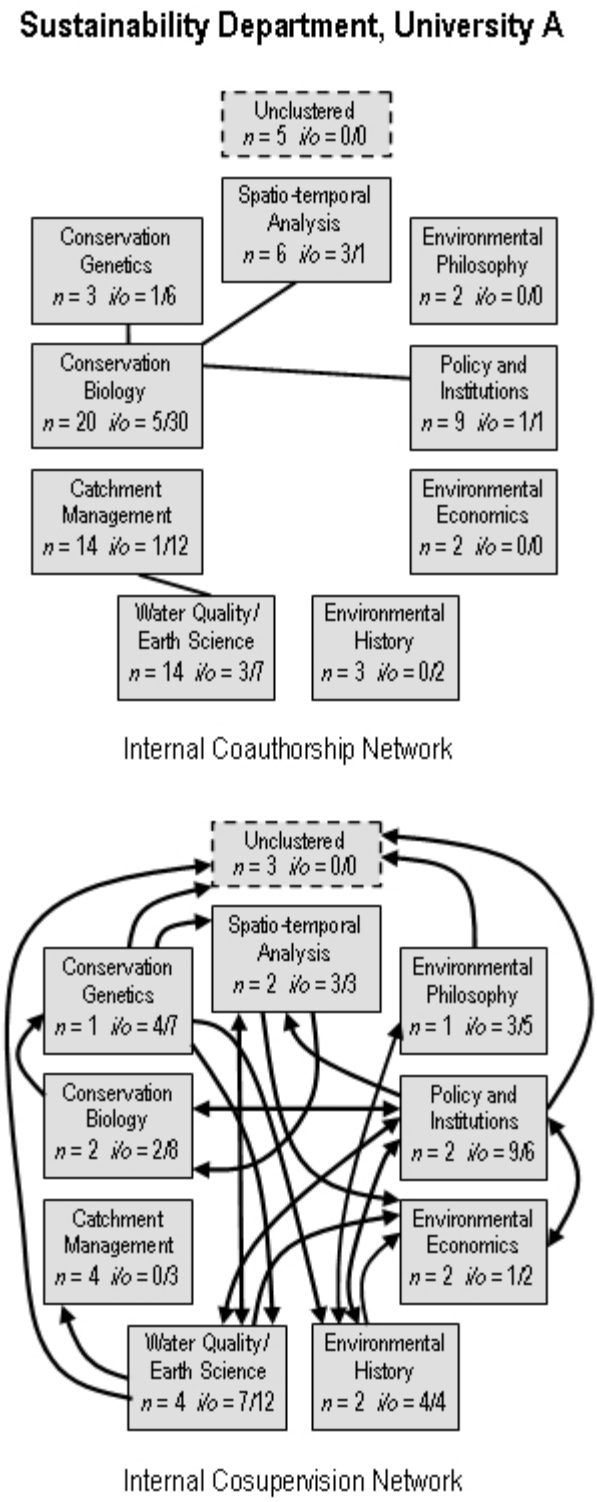


Figure 4a. Coauthorship and cosupervision networks for the sustainability department at University A using research clusters as the unit of analysis. The number of authors or supervisors within each cluster is given by *n*, the number of coauthors or cosupervisors from other clusters by *i*, and the number from other departments as *o*.

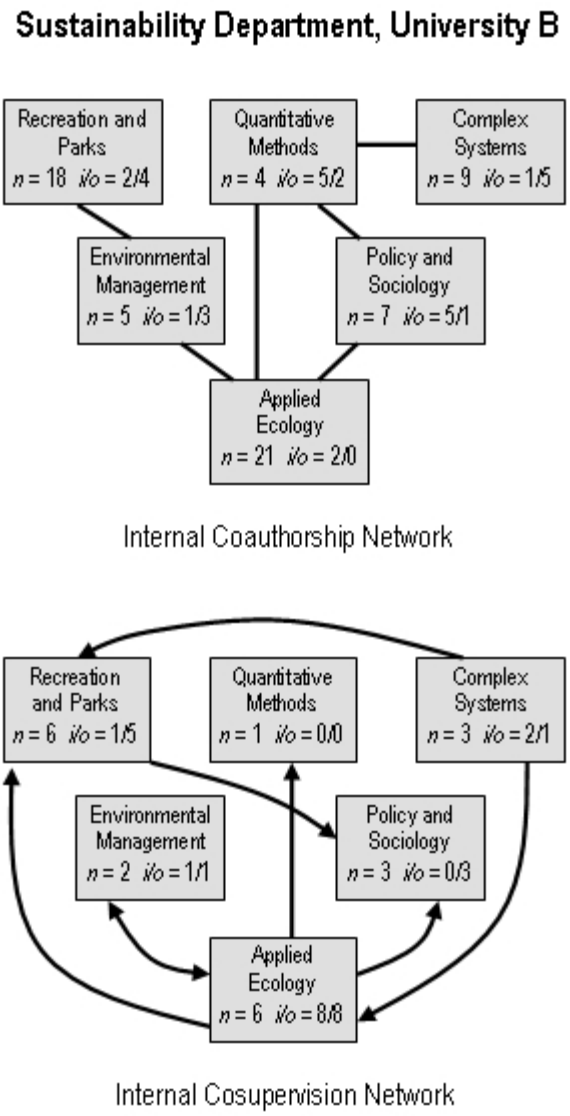


Figure 4b. Coauthorship and cosupervision networks for the sustainability department at University B using research clusters as the unit of analysis. The number of authors or supervisors within each cluster is given by *n*, the number of coauthors or cosupervisors from other clusters by *i*, and the number from other departments as *o*.

At the sustainability department of University A, 23 supervisors were involved in 33 instances of internal boundary crossing in the supervisory teams of the 51 research students (mostly Doctoral, but some research Masters) that began study between 2000 and 2004 in that department. This suggests that research students in such a group may be supported in undertaking integrated research projects within the department, even if their supervisors do not undertake such projects. Different disciplinary traditions were demonstrated in cosupervision as well as coauthorship. Supervisors in the social sciences (environmental history, economics, and policy and institutions) were recruited most frequently by other areas in the department, and the last of these called on the most other clusters in turn. The water quality/earth science cluster recruited the most external supervisors (as well as frequently calling on others within the department). The conservation clusters (conservation biology and conservation genetics) also aimed outward. Catchment management was the most insular or self-sufficient. Spatio-temporal analysis and environmental

philosophy were the least connected, consistent with the more solitary mathematics and humanities traditions of those that comprise them.

At the sustainability department of University B, denser networks also existed between fewer players in the cosupervision of research theses than in coauthorship, but the pattern is not as marked. Between 2000 and 2004, 21 internal staff members chaired or sat on the panels of the 53 students completing Honours, Doctorates, or Masters, and 10 per cent of the possible links between the supervisors existed. The apparent density is lower than University A primarily because of the high proportion of Honours theses involved (three-fifths); they typically have smaller panels. Cosupervision linked together previously disconnected key nodes; only six of the 21 cosupervisory linkages were reflected in coauthorship. The applied ecology cluster reached out to other clusters quite frequently for cosupervisors, whereas those studying recreation and parks heritage and complex systems were more inward-looking. The two smaller groups of environmental management and policy/sociology were also quite closed. The methods cluster was largely just a “service” field to applied ecology in terms of cosupervisory teams.

4.3. The Conundrum of Succession

The two sustainability departments studied were very different in history, organisational niche, and structure, so the degree of similarity that emerged between their networks is surprising. Individuals in each department earned a similar number of performance points over the 5-year period, on average (see Table 2). The coauthorship networks were similarly sparse and clustered, with comparable numbers of nodes presenting as core (i.e., key and secondary) and periphery. Although the theses were selected using different criteria (thesis starts at University A, and completions at University B), they were similar in number, and involved the same number of intradepartmental supervisors (unsurprisingly, mostly those with continuing appointments). Cosupervision served to link the core nodes who rarely published together during the same period.

The networks present a pattern that--played out over time--suggests a conundrum of succession lurking on the horizon for such departments. In coauthorship, postdoctoral fellows and junior or contract academics were often the ones integrating the departments, and this integrative tendency was often fostered by having completed Doctorates in the same department. Perhaps those who are mentored by a diverse panel drawn locally, are more likely to pursue that type of research when they graduate. But are permanent positions open such “integrators” when departmental viability depends so much on research esteem and external research funds?

Consider the following thought experiment. If the young interdisciplinarians cannot rise to permanent positions in the departments in which they are trained by researching the way they were trained to, the departments send a negative message about the utility of their graduates. What is more, the research area of sustainability may be rendered permanently immature, its departments full of disciplinary scholars who are drawn together to reinvent means of collaborating, while the

collaborative interdisciplinarians they have fostered are rejected. If the interdisciplinary graduates *are* hired, they may be likely to continue to work interdisciplinarily in their own research and encourage the same of their own students, but their peer networks may not open up as much opportunity, nor their track records attract the same resources.

Table 2. *Collaborative Relationships Inside Sustainability Departments: Comparison Between Two Universities*

Metrics of Collaboration	***University A***	***University B***
NUMBER OF NODES		
• *Core*	20	19
• *Periphery*	59	45
COAUTHORSHIP		
• *Performance Points*	175.7*	160.2
• *Unique Authors*	79	64
• *Network Density (%)*	3.6	3.2
COSUPERVISION		
• *Number of Theses***	51	53
• *Unique Supervisors*	23	21
• *Network Density (%)*	n/a***	10

* The database provided by University A did not include all of the 208.15 points reported to DEST.

** University A includes theses started between 2000 and 2004 (mostly PhDs), while University B includes those completed during those years, primarily Honours.

*** University A cosupervisory data were aggregated to clusters, rather than persons, so density cannot be calculated.

Some differences did exist between the two sustainability departments. It was suggested earlier that individuals in interdisciplinary units tend to follow the traditions of the outside disciplinary community if a specifically interdisciplinary culture is not actively fostered. This appeared to be the case in University A, where the sustainability department was comprised largely of pure disciplines or environmental subdisciplines, operating independently. The coauthorship clusters at the sustainability department of University B were more problem-based or applied and its individual members more interconnected, perhaps as a result of cohesion around the teaching programs they deliver together. Teaching programs also require more than one permanent staff member per field of study, ideally able to teach in many areas, and research graduates of the department *were* hired into ongoing positions at University B. The interdisciplinary perspective of individuals so trained is perhaps more highly valued for teaching roles than for research. Undergraduate teaching may be relevant to researchers as more than just a source of good Honours students, but as a means to build relationships with local peers. Nonetheless, the limited amount of

time academics have available to spend sustaining collaborative relationships may still be best spent on linking to those otherwise disconnected, for the reasons listed earlier.

Of the few fields that were present in both the universities, an interesting difference suggested that personality and operational context were stronger indicators of collaborative behaviour than disciplinary tradition. Applied ecology was quite an isolated cluster in University B's publication network, but it showed the highest level of engagement with other clusters on its research students' supervisory panels. At University A, the conservation biology group was responsible for most of the cross-cluster publication collaborations, but was insular in its supervision. Similarly, the policy cluster at University B had a handful of external linkages, but recruited no one from other clusters in its supervision, while the corresponding cluster at University A drew on the most other clusters. While personality and chosen discipline are likely to be closely correlated, the former is perhaps a stronger predictor of collaborative choices. Certainly, no conclusions can be drawn from this about which fields are best colocated in such organisational settings.

An overarching reality is the fact that the two departments differ widely in their access to potential research colleagues and end users. One is a regional university with far-flung sister campuses, still building its research capacity; the other is a capital city institution with high research productivity and local access to peers throughout the many teaching and research, disciplinary and problem-based, departments on the same campus. Such a context clearly influences collaborative choices and opportunities.

5. Conclusions and Speculations

Acceleration in global environmental and social change issues is inspiring an increasing number of sustainability research initiatives worldwide. Much of this problem-based investigation is taking place in universities, organised as temporary clusters, formal departments, or dispersed networks. Interdisciplinary departments are a common option for undertaking environmental or sustainability research and teaching. Our research suggests that colocation may not be the panacea to disciplinary fragmentation that it is often thought to be. Rather, pressures and rewards flowing from disciplines, career planning, and government policies may have a confounding effect on integration within such departments. There is a disjoint between the rhetoric and reality in such settings that is a particular problem for those trained interdisciplinarily for research careers within them. Their qualifications may not be valued by disciplinary departments and new continuing appointments, in these interdisciplinary departments at least, have been rather limited.

The key staff members, typically those with ongoing appointments, are the primary publication nuclei visible in the two departments studied here, both staffed to comprise disciplinary diversity. Some are also individual interdisciplinarians, largely working alone. Researchers from collaborative traditions form dense and isolated coauthorship webs with those they have attracted into the department (doctoral students, visiting fellows, and postdoctoral fellows). The rest of their efforts are directed to peers and colleagues outside the department, as they build the networks

which provide esteem, credibility, and financial rewards. With the social capital amassed from proven and repeated success in a relatively narrow set of activities, these key individuals are able to foster interdisciplinary research students vicariously. Without exercising such focus in their personal research, the key individuals' careers may suffer, the pace of research progress may be slower, and the rewards with which they are able to enrich their environment may be fewer.

The research students in the two departments studied have been shown to have diverse supervisory panels, however. This is where interdisciplinary departments do coalesce. If a student needs the expertise of an economist, for instance, the one down the corridor is more likely to be consulted than one elsewhere. This is good for students, as the supervisors are thus accessible and operating under the same administrative norms and expectations. This benefit may be even more compelling for students experiencing the discomfort of interdisciplinary graduate work, which is likely to be extending them into unfamiliar areas of study. Each supervisor also brings a wide set of resources, intellectual and financial, that are likely to be novel within the department as a result of the coauthorship isolation described. But there are disadvantages, too. By the diversity of the panels, interdisciplinarity appears to be actively encouraged, even if there is a scarcity of local models for research success via an interdisciplinary pathway. Another difficulty comes in postdoctoral career planning. Is there an academic home for such graduates or are they fated for careers outside the academy?

Although such conclusions are beyond the scope of this preliminary analysis, the authors hypothesise that:

(a) The progress of research and teaching around sustainability does not necessarily suffer by such vicarious interdisciplinarity. As already discussed, research progress comes faster in areas which are narrow, with strong paradigmatic development, or in groups without too much diversity. Sustainability problems may actually be addressed more effectively through the action of numerous focused efforts rather than fewer diffuse ones.

(b) Interdisciplinarity gets more institutionalised and presents less of a career risk in teaching departments. Interdisciplinary teachers are able to teach a range of topics, and can make the cross-disciplinary connections that help build comprehensive pictures for students. (In fact, several permanent academics at the sustainability department of University B had completed Doctorates in the same school, unlike at the sustainability department of University A, which lacked a teaching program.)

The debate between cohesion and outreach has been playing out in interdisciplinary departments for years, without any resolution (Wasson & Dovers, 2005). Total connectivity is not only impossible, but undesirable and unsustainable under current university working conditions. It cannot be a choice between inside only or outside only, so why not encourage their combination in such a way as this analysis suggests seems to happen naturally? Although further research is

necessary to explore some of these themes, there may be a message here for those undertaking research in sustainability departments, and for those leading them.

Progress in sustainability requires focus and clarity, just as in any other field or problem-based area. Vicarious interdisciplinarity in research training may represent an optimum investment for the students and staff of sustainability departments. Establishing this or some other clear strategy around interdisciplinarity could clarify departmental identity, internal communications, and expectations. For instance, it may be futile to encourage redundant collaboration between the forcibly affiliated or colocated, or even to colocate at all in such a rigid fashion. Fluctuating project clusters or problem-based networks may well be more efficient structures for inspiring new combinations of information to be explored, (for alternatives, see Stokols, Misra, Moser, Hall, & Taylor, 2008; Syme, 2005; van Kerkhoff, 2005). Such arrangements should not mimic typical grant-based structures, where emerging opportunities and paths often cannot be pursued if not already locked to a promised deliverable. If research training and undergraduate education are agreed to be the locus of departmental integration, this decision, and the associated risks and opportunities, can be clearly presented to those concerned. An overarching interdisciplinary strategy could also help to optimise recruitment and clearly convey working conditions to candidates. Finally, such transparency of purpose might help address the conundrum of succession caused by fostering interdisciplinary students in a context that they may be unable or unwilling to replicate. Their expectations can be managed, and a suitable destination carved for these integrators. Additional research into interdisciplinary organisational design, scholarly progress, staff succession, and student destinations is needed to explore these possibilities further.

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References

Abbott, A. (2001). *Chaos of disciplines*. Chicago: University of Chicago Press.

Adams, J. D., Black, G. D., Clemmons, J. R., & Stephen, P. E. (2005). Scientific teams and institutional collaborations: Evidence from U. S. universities, 1981-1999. *Research Policy*, *34*, 259-285.

Barabási, A. L., Jeong, H., Neda, Z., Ravasz, E., Schubert, A., & Vicsek, T. (2002). Evolution of the social network of scientific collaborations. *Physica A*, *311*, 590-614.

Barjak, F. (2006). *Team diversity and research collaboration in life sciences teams: Does a combination of research cultures pay off*? Olten, Switzerland: University of Applied Sciences.

Beaver, D. d. (2001). Reflections on scientific collaboration (and its study): Past, present, and future. *Scientometrics*, *52*(3), 365-377.

Becher, T. (1989). *Academic tribes and territories: Intellectual enquiry and the cultures of disciplines*. Milton Keynes, UK: The Society for Research into Higher Education and Open University Press.

Borgatti, S. P. (2002). *NetDraw: Graph visualization software*. Harvard, MA: Analytic Technologies.

Borgatti, S. P., & Everett, M. G. (2003). The network paradigm in organizational research: A review and typology. *Journal of Management*, *6*(1), 991-1013

Borgatti, S. P., Everett, M. G., & Freeman, L. C. (2002). *UCINET for Windows: Software for social network analysis*. Harvard, MA: Analytic Technologies.

Bourdieu, P. (1988). *Homo academicus* (P. Collier, Trans.). Stanford, CA: Stanford University Press. (Original work published in 1984)

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy*, *33*, 599-616.

Braun, T., Glänzel, W., & Schubert, A. (2001). Publication and cooperation patterns of the authors of neuroscience journals. *Scientometrics*, *51*(3), 499-510.

Burt, R. S. (1992). *Structural holes*. Cambridge, MA: Harvard University Press.

Butler, L. (2003). Academic reactions: Modifying publication practices in response to funding formulas. *Research Evaluation*, *12*(1), 39-46.

Butler, L., & Visser, M. S. (2006). Extending citation analysis to non-source items. *Scientometrics*, *66*(2), 327-343.

Chartrand, G. (1985). *Introductory graph theory*. New York: Dover.

Chompalov, I., Genuth, J., & Shrum, W. (2002). The organization of scientific collaborations.

Research Policy, *31*, 749-767.

Cole, S. (1983). The hierarchy of the sciences? *American Journal of Sociology*, *89*(1), 111-139.

Coleman, J. S. (1990). *Foundations of social theory*. Cambridge, MA: Harvard University Press.

Considine, M. (2006). Theorizing the university as a cultural system: Distinctions, identities, emergencies. *Educational Theory*, *56*(3), 255-270.

Crane, D. (1969). Social structure in a group of scientists: A test of the 'Invisible College' hypothesis. *American Sociological Review*, *34*(3), 335-352.

de Solla Price, D. (1965). Little science, big science. NY: Columbia University Press.

Department of Education, Science and Training. (2002). *National research priorities*. Canberra, Australia: Government of Australia. Retrieved March 21, 2009, from http://www.dest.gov.au/sectors/research_sector/policies_issues_reviews/key_issues/national_research_priorities

Donald, J. G. (1986). Knowledge and the university curriculum. *Higher Education*, *15*, 267-282.

Dovers, S. (2005a). *Environment and sustainability policy: Creation, implementation and evaluation*. Sydney, Australia: Federation.

Dovers, S. (2005b). Clarifying the imperative of integration research for sustainable environmental management. *Journal of Research Practice*, *1*(2), Article M1. Retrieved March 21, 2009, from http://jrp.icaap.org/index.php/jrp/article/view/11/22

Frank, K. A. (1996). Mapping interactions within and between cohesive subgroups. *Social Networks*, *18*, 93-119.

Fujigaki, Y. (2002). Analysis on dynamics of research sub-domains in interdisciplinary fields: Analysis using personal distribution versus papers. *Scientometrics*, *54*(1), 63-74.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzmann, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. London: Sage.

Gläser, J., & Laudel, G. (2005). The impact of evaluations on the content of Australian university research. In R. Julian, R. Rottier, & R. White (Eds). *TASA 2005 conference proceedings* (Section 11: Open Session). Hawthorn, Australia: The Sociological Association of Australia (TASA). Retrieved March 21, 2009, from http://www.tasa.org.au/conferencepapers05/papers%20(pdf)/open_glaser.pdf

Granovetter, M. S. (1973). The strength of weak ties. *American Journal of Sociology, 78*(6), 1360-1380.

Hawkes, J. (2001). *The fourth pillar of sustainability: Culture's essential role in public planning*. Melbourne, Australia: Common Ground and The Cultural Development Network.

Hogg, M. A., & Hains, S. C. (1998). Friendship and group identification: A new look at the role of cohesiveness in groupthink. *European Journal of Social Psychology, 28*, 323-341.

Hogg, M. A., & Terry, D. J. (2000). Social identity and self-categorization processes in organizational contexts. *Academy of Management Review*, *25*(1), 121-140.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., et al. (2001). Sustainability science. *Science*, *292*, 641-642.

Katz, J. S. (1994). Geographical proximity and scientific collaboration. *Scientometrics*, *31*(1), 31-43.

Klein, J. T. (1999). *Mapping interdisciplinary studies*. Washington, DC: Association of American Colleges and Universities.

Klovdahl, A. S. (1997). Social network analysis. In J. P. Keeves (Ed.), *Educational research, methodology and measurement: An international handbook* (2nd ed., pp. 684-695). Cambridge, UK: Pergamon/Cambridge University Press.

Kuhn, T. S. (1970). *The structure of scientific revolutions*. Chicago: The University of Chicago Press. (Original work published in 1962)

Landry, R., & Amara, N. (1998). The impact of transaction costs on the institutional structuration of collaborative academic research. *Research Policy*, *27*, 901-913.

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Milton Keynes, UK: Open University Press.

Lattuca, L. R. (2002). Learning interdisciplinarity: Sociocultural perspectives on academic work. *The Journal of Higher Education*, *73*(6), 711-739.

Lattuca, L. R., & Stark, J. S. (1995). Modifying the major: Discretionary thoughts from ten disciplines. *Review of Higher Education*, *18*(3), 315-344.

Laudel, G. (2001). Collaboration, creativity and rewards: Why and how scientists collaborate. *International Journal of Technology Management*, *22*(7/8), 762-781.

Laudel, G. (2002). What do we measure by co-authorships? *Research Evaluation*, *11*(1), 3-15.

Laudel, G. (2006a). The art of getting funded: How scientists adapt to their funding conditions. *Science and Public Policy*, *33*(7), 489-504.

Laudel, G. (2006b). Conclave in the Tower of Babel: How peers review interdisciplinary research proposals. *Research Evaluation*, *15*(1), 57-68.

Liverman, D. M. (1999). Geography and the global environment. *Annals of the Association of American Geographers*, *89*(1), 107-120.

Long, J. S., & Fox, M. F. (1995). Scientific careers: Universalism and particularism. *Annual Review of Sociology*, *21*, 45-71.

Ludwig, D., Walker, B., & Holling, C. S. (1997). Sustainability, stability and resilience. *Conservation Ecology*, *1*(1), 7.

Mehra, A., Kilduff, M., & Brass, D. J. (2001). The social networks of high and low self-monitors: Implications for workplace performance. *Administrative Science Quarterly*, *46*(1), 121-146.

Melin, G. (2000). Pragmatism and self-organisation: Research collaboration on the individual level. *Research Policy*, *29*, 31-40.

Metcalfe, J., Riedlinger, M., Pisarski, A., & Gardner, M. J. (2006). *Collaborating across the sectors: The relationship between the humanities, arts and social sciences (HASS) and science, technology, engineering and medicine (STEM) sectors* [CHASS occasional paper no. 3]. Canberra, Australia: Council for Humanities, Arts and Social Sciences.

Millenium Ecosystem Assessment. (2003). *Ecosystems and human well-being: A framework for assessment*. Washington, DC: Island.

Moses, I. (1990). Teaching, research and scholarship in different disciplines. *Higher Education*, *19*, 351-375.

Najman, J. M., & Hewitt, B. (2003). The validity of publication and citation counts for sociology and other selected disciplines. *Journal of Sociology*, *39*(1), 62-80.

Newman, M. E. J. (2001). The structure of scientific collaboration networks. *PNAS: Proceedings of the National Academy of Sciences of the United States of America*, *98*(2), 404-409. Retrieved March 21, 2009, from http://www.pnas.org/content/98/2/404.full.pdf+html

Newman, M. E. J. (2004). Coauthorship networks and patterns of scientific collaboration. *PNAS: Proceedings of the National Academy of Sciences of the United States of America*, *101*(April

supplement 1), 5200-5205. Retrieved March 21, 2009, from http://www.pnas.org/content/101/suppl.1/5200.full.pdf+html

Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-thinking science: Knowledge and the public in an age of uncertainty*. Cambridge, UK: Polity.

Poole, M. E. (1994). Melting 'snow' and shifting 'cultures': The strategic repositioning of Australian universities' research and development. *Higher Education Research and Development*, *13*(2), 143-155.

Porac, J. F., Wade, J. B., Fischer, H. M., Brown, J., Kanfer, A., & Bowker, G. (2004). Human capital heterogeneity, collaborative relationships, and publication patterns in a multidisciplinary scientific alliance: A comparative case study of two scientific teams. *Research Policy*, *33*, 661-678.

Price, R. J. (2003). Identifying social spaces in the Sustainable Grazing Systems program. *Australian Journal of Experimental Agriculture*, *43*, 1041-1059.

Qin, J., Lancaster, F. W., & Allen, B. (1997). Types and levels of collaboration in interdisciplinary research in the sciences. *Journal of the American Society for Information Science*, *48*(10), 893-916.

Rhoten, D. (2004). Interdisciplinary research: Trend or transition. *Items & Issues*, *5*(1-2), 6-11. Retrieved March 21, 2009, from http://publications.ssrc.org/items/items_5.1-2/interdisciplinary_research.pdf

Rhoten, D., & Parker, A. (2004). Risks and rewards of an interdisciplinary research path. *Science*, *306*(December 17), 2046.

Rinia, E. J., van Leeuwen, T. N., Bruins, E. E. W., van Vuren, H. G., & van Raan, A. F. J. (2002). Measuring knowledge transfer between fields of science. *Scientometrics*, *54*(3), 347-362.

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*, 369-384.

Russell, A. W. (2005). No academic borders? Transdisciplinarity in university teaching and research. *Australian Universities Review*, *48*(1), 35-41.

Rydin, Y. (2006). Conclusions. In Y. Rydin & E. Falleth (Eds), *Networks and institutions in natural resource management* (pp. 201-216). Cheltenham, UK: Edward Elgar.

Sherren, K. (2006). Mapping an interdiscipline: Research collaboration around sustainability in

the tertiary sector. In V. Colic-Peisker, F. Tilbury, & B. McNamara (Eds), *TASA 2006 conference proceedings* (Section 2: Education, work, stratification and class). Hawthorn, Australia: The Sociological Association of Australia (TASA). Retrieved March 21, 2009, from http://www.tasa.org.au/conferencepapers06/papers/Education,%20Work,%20Stratification%20and%20Class/sherren.pdf

Snow, C. P. (1959). *The two cultures and the scientific revolution*. Cambridge, UK: Cambridge University Press.

Stokes, T. D., & Hartley, J. A. (1989). Coauthorship, social structure and influence within specialties. *Social Studies of Science*, *19*(1), 101-125.

Stokols, D., Misra, S., Moser, R. P., Hall, K. L., & Taylor, B. K. (2008). The ecology of team science: Understanding contextual influences on transdisciplinary collaboration. *American Journal of Preventive Medicine*, *35*(2S), S96-S115.

Syme, G. (2005). Integration initiatives at CSIRO: Reflections of an insider. *Journal of Research Practice*, *1*(2), Article M3. Retrieved March 21, 2009, from http://jrp.icaap.org/index.php/jrp/article/view/17/26

Tichy, N. M., Tushman, M. L., & Fombrun, C. (1979). Social network analysis for organizations. *Academy of Management Review*, *4*(4), 507-519.

Tress, B., Tress, G., van der Valk, A., & Fry, G. (Eds). (2003). *Interdisciplinary and transdisciplinary landscape Studies: Potential and limitations*. Wageningen, The Netherlands: Delta Program, Alterra Green World Research, Landscape Centre. Retrieved March 21, 2009, from http://www.tress.cc/delta/series2.html

van Kerkhoff, L. (2005). Strategic integration: The practical politics of integrated research in context. *Journal of Research Practice*, *1*(2), Article M5. Retrieved March 21, 2009, from http://jrp.icaap.org/index.php/jrp/article/view/14/24

van Raan, A. F. J. (1990). Fractal dimension of co-citations. *Nature*, *347*(October 18), 626.

Wagner, C. S., & Leydesdorff, L. (2005). Network structure, self-organization and the growth of international collaboration in science. *Research Policy*, *34*, 1608-1618.

Wasson, R. J., & Dovers, S. (2005). Integrative research in the university context: Centre for Resource and Environmental Studies, The Australian National University. *Journal of Research Practice*, *1*(2), Article M4. Retrieved March 21, 2009, from http://jrp.icaap.org/index.php/jrp/article/view/13/23

Wellman, B. (1983). Network analysis: Some basic principles. *Sociological Theory*, *1*, 155-200.

White, W. J. (1999). Academic topographies: A network analysis of disciplinarity among communication faculty. *Human Communication Research*, *25*(4), 604-617.

Whitley, R. (1984). *The intellectual and social organisation of the sciences*. Oxford, UK: Clarendon.

Wilbanks, T. J. (1994). “Sustainable development” in geographic perspective [Presidential address]. *Annals of the Association of American Geographers*, *84*(4), 541-556.

World Commission on Environment and Development. (1987). *Our common future* [The Brundtland Report]. New York: Oxford University Press.

Younglove-Webb, J., Gray, B., Abdalla, C. W., & Thurow, A. P. (1999). The dynamics of multidisciplinary research teams in academia. *The Review of Higher Education*, *22*(4), 425-440.

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