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The role of geospatial industrial diversity in the facilitation of regional industrial symbiosis

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ABSTRACT

This paper explores geospatial industrial diversity and its influence on the brokerage of industrial symbiosis working agreements (otherwise known as synergies). Research conducted in 2011 concluded that within third-party brokered resource exchanges between two or more normally unrelated companies, the industrial diversity of a given geographic area was the primary driver behind how far a material travels from its point of origin to its point of reuse. This conclusion was largely derived from intuition and the elimination of other widely discussed drivers or limitations to symbiotic resource movement (e.g., mental distances, resource value and/or the physical characteristics of a resource). The presented article sets out to empirically test this suggestion by mapping the geospatial industrial diversity of England and comparing it to the movement of resources within synergies facilitated by the National Industrial Symbiosis Programme (NISP). Among other results, it was established that there are correlations between geospatial industrial diversity and the distance materials move in addition to the number of synergy types and the replication of synergies facilitated within a given area. It was found that 76% of synergies were facilitated within areas of high (upper 10% of values) contiguous diversity, areas of high 'species' richness possessed a greater variety of synergies, and areas of high synergy replication were areas of high 'species' population evenness. Based on a sensitivity analysis of diversity indices and diversity mapping techniques, it was concluded that high 'species' richness provided the greatest opportunities for realising local industrial symbiosis.

1. Introduction

It has been argued that industrial ecologists should empirically explore the development of what are seen to be 'desirable' and increasingly needed aspects of nature, such as resource recycling, productive efficiency, and/or system resilience, before attempting to prescribe or 'mimic' them in the design and development of industrial ecosystems (see Jensen et al., 2011a). One particular observation of nature which has drawn much attention within industrial ecology is the concept of diversity and the many beneficial effects of its presence within a given locale. In orthodox ecology it has been argued that increased diversity has positive effects on system production (e.g., Tilman et al., 2001; Hooper et al., 2005; Flombaum and Sala, 2008); whilst suggestions that a diversity of system actors can promote resource efficiency and system resilience have existed within ecological research circles for many years[1]. As such, it is readily apparent why diversity should be a concept of interest within industrial ecology research. Indeed, the subject of diversity within industrial ecosystems has already been afforded dedicated examination by several authors (e.g., Korhonen, 2005; Wells and Darby, 2006; Wright et al., 2009); whilst the concept is given more than a passing consideration within many further industrial ecology focussed articles (e.g., Korhonen, 2001; Nielsen, 2007; Mayer, 2008; Ashton, 2009; Jensen et al., 2011a). Many of these articles are largely conceptual in nature and approach the subject of diversity and its potential for promoting the development of sustainable and resourceful industrial systems from a theoretical and assumptive position. Keeping in

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[1] Though see Yue et al. (2005) for an overview of the many debates on the relationships between diversity and ecosystem functioning and see Hooper et al. (2005) for a "consensus of current knowledge" on the subject of biodiversity and ecosystem functioning.

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mind that industrial ecology is still a nascent discipline, there is nothing intrinsically wrong with this form of analysis and each article, in its own way, provides a stepping stone towards the greater depth of understanding required to elevate industrial ecology to a position where it can deliver tangible eco-industrial development. However, as stated by Wright et al. (2009), ecology is largely a quantitative science. Indeed, orthodox ecology is a science based upon observation, analysis, and interpretation into sound context-specific scientific principle. Thus, the actual role that diversity plays within the development and functioning of an industrial ecosystem must be ascertained through empirical observation and analysis before it is promoted as a desirable aspect of sustainable or resource efficient industrial development.

This paper continues by further exploring the concept of diversity and its effects on system functioning. The specific context of this discussion is that of understanding the role industrial diversity plays in providing opportunities for resource efficiency. Using a geographic information system (GIS) and novel industry type sampling techniques, an empirical study was conducted into the geospatial industrial diversity of England and the role it played in the facilitation of industrial symbiosis working agreements (brokered by the United Kingdom's National Industrial Symbiosis Programme [NISP]). Correlations between the presence of resource synergies and the industrial diversity surrounding the resource partners were tested. The results of this study, which is unique in the context of industrial ecology, are presented and discussed in relation to understanding how geospatial industrial diversity affects resource movement, how diversity affects industrial ecosystem productivity, and how study findings can be employed in proactive attempts to implement eco-industrial development. By way of conclusion, the article provides options for developing the diversity mapping methodology in addition to suggesting avenues for further essential research into the development of functional diversity and niche based diversity indices.

2. 'Diversity' and its evolution

Diversity is a highly relative concept and its effects in a given ecosystem are invariably idiosyncratic (Jensen et al., 2011a). Due to the many semantic, conceptual and technical problems involved in the study of diversity it can, in some contexts, be deemed to be a 'non-concept' (Hurlbert, 1971). As such, what does diversity mean and what is meant by its effects in a given system? Diversity, at its most basic, is the richness of species within a sampled area (e.g., the number of distinctly different individuals)[2]. This meaning of diversity is further developed when considered in relation to the equability, or evenness, of the total population of each sampled species. For instance, a sampled geographic area which possesses 30 individuals, consisting of three species with equal populations of 10 individuals, is ordinarily deemed to be more diverse than a sampled area that possesses a population of 28 individuals of one species and one each of two further species. Although both sampled areas contain 30 organisms and three distinct species, the former area is more equitable in terms of the populations that compose the area's community than that of the latter area's community which is dominated by one species. To assess community evenness in a more sophisticated manner, and make measurements of evenness diversity comparable to other communities, indices (or indexes) have been devised which allow comparison between sampled areas by measuring evenness on normalised scales (e.g., Simpson, 1949). Whether, however, these basic definitions of diversity and the many (further) ways it can be measured and compared are meaningful or useful has, within orthodox ecology, been a debate in its own right (e.g., Hurlbert, 1971; Jost, 2006).

Indeed, it is essential to note that all species are not equal in their effects on ecosystem functioning (Mouchet et al., 2010); and some are more competitive or simply more fecund than others. As a consequence of these facts, some of the key discussion points within ecological research revolve around understanding the specific role a given species plays within an ecosystem and duly the concepts of functional and redundant diversity (and, paradoxically, functional-redundancy). In very simple terms, functional diversity refers to a species or a collection of species that perform a function within a given community which directly supports other species or a process that is essential to the ongoing functioning of the ecosystem (these species are sometimes termed 'keystone' species). Redundant diversity, meanwhile, postulates that some species fill the same or similar roles within an ecosystem and consequently the loss of one of these species would have little or no immediate impact on their community and wider system functioning[3]. These two forms of diversity, and how they intrinsically affect how we latterly conceptualise diversity and the ostensibly positive ecosystem properties that they help to generate, are extremely important. For the level of analyses presented in this paper, however, the simple definition and distinction between functional and redundant diversity, provided above, are adequate (for a more detailed elucidation of these points, however, see Hooper et al., 2005; Begon et al., 2006).

The apparent effects of system 'diversity' that, from an anthropogenic viewpoint, are deemed to be desirable (e.g., increased recycling, productivity and system resilience), largely emerge from the processes which also promote the evolution of ecosystem diversity. Effectively, greater localised diversity is a result of increased local resource availability and usage pathways, both in a spatial and temporal sense. The increase in resource availability and pathways for reuse and recycling of resources derive from the processes of niche construction, facilitation and realisation (as promoted by, among other processes, system succession). For example, pioneer species that colonise and proliferate in seemingly bare earth create, by their very appearance, niches for further species of biota to eventually colonise a given area. This continual (action-reaction *or* cause-effect) process of system evolution leads to feedback controls and processes which shape an ecosystem and its constituent elements. As an ecosystem develops and fundamental niches are realised by a given species[4], or a species evolves to fill a niche, complementarity, competition and niche partitioning amongst species develops and resource efficiency and recycling invariably increases along with system productivity (see Odum, 1969 for a general background to ecosystem succession). This process of ecosystem diversification and the evolution of each species' fundamental and specific niches are arguably applicable to any form of system, including industrial systems. Agglomeration economies and other theories relating to industrial clustering which derive from the field of economic geography, largely translate as basic niche construction and realisation theory within biological ecology's understanding of the evolution of mutually beneficial (and competitive) interactions (see Renner, 1947; Nielsen, 2007; Mayer, 2008; Belussi and Caldari, 2009; Nielsen and Müller, 2009 for discussions that compliment and contrast this supposition).

[2] This definition, however, can be further expanded to refer to diversity at all levels of biological structure, from gene through to the given example of species through to the diversity of phenotypes (and so on).

[3] It has been claimed that redundancy of species contributes to, among other system properties, insurance against ecosystem collapse (i.e. system stability). Thus, it should not be assumed that the lack of a unique function within an ecosystem makes a given species any less valuable than one that could be deemed to be 'functional' (see Yachi and Loreau (1999); Loreau (2000) and their associated references).

[4] Fundamental niche and realised niche refers, respectively, to all niches that a given organism can fill in the absence of competition and the specific (observed) niche a given organism does fill.