Ecological Modelling 382 (2018) 63–82

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Review

Bibliometric review of ecological network analysis: 2010–2016

Stuart R. Borrett[a,b,*], Laura Sheble[b,c], James Moody[b,d], Evan C. Anway[a]

[a] Department of Biology and Marine Biology and Center for Marine Science, University of North Carolina Wilmington, Wilmington, NC 28403, United States
[b] Duke Network Analysis Center, Social Science Research Institute, Duke University, Durham, NC 27708, United States
[c] School of Information Sciences, Wayne State University, Detroit, MI 48202, United States
[d] Department of Sociology, Duke University, Durham, NC 27708, United States

ARTICLE INFO

Keywords:
Ecosystem
Social network analysis
Scientometrics
Food web
Biogeochemical cycling
Urban metabolism
Network science
Materials flow analysis

ABSTRACT

Ecological Network Analysis (ENA) combines modeling and analysis used to investigate the structure, function, and evolution of ecosystems and other complex systems. ENA is applied to network models that trace the movement of thermodynamically conserved energy or matter through the system. Investigators use ENA to answer a range of questions such as the following. What is the impact of fishing on the marine food web? Which species control the flux of nitrogen in an estuary? What is the ecological relationship among species in the food web when direct and indirect influences are considered? Would a proposed regulation make a city more sustainable? The field has grown since its inception in the 1970s, but it has rarely been systematically reviewed. This absence of reviews likely hinders the development of the field as a whole, obscures the diversity of its applications, and makes it difficult for new investigators to learn, develop, and apply the techniques. The objective of the work presented in this paper was to systematically review ENA research published in 2010 through 2016 to (1) identify the topic diversity, (2) expose methodological development, (3) highlight applications, and (4) assess collaboration among ENA scholars. To accomplish this, we used a combination of bibliometric, network (e.g., social network), and feature analyses. Our search identified 186 records. A topic network built from the bibliographic records revealed eight major topic clusters. The largest groups centered on food webs, urban metabolism, and ecosystem theory. Co-author analysis identified 387 authors in a collaboration network with eight larger components. The largest component contained 56% of the authors. This review shows ENA to be a topically diverse and collaborative science domain, and suggests opportunities to further develop ENA to better address issues in theoretical ecology and for environmental impact assessment and management.

1. Introduction

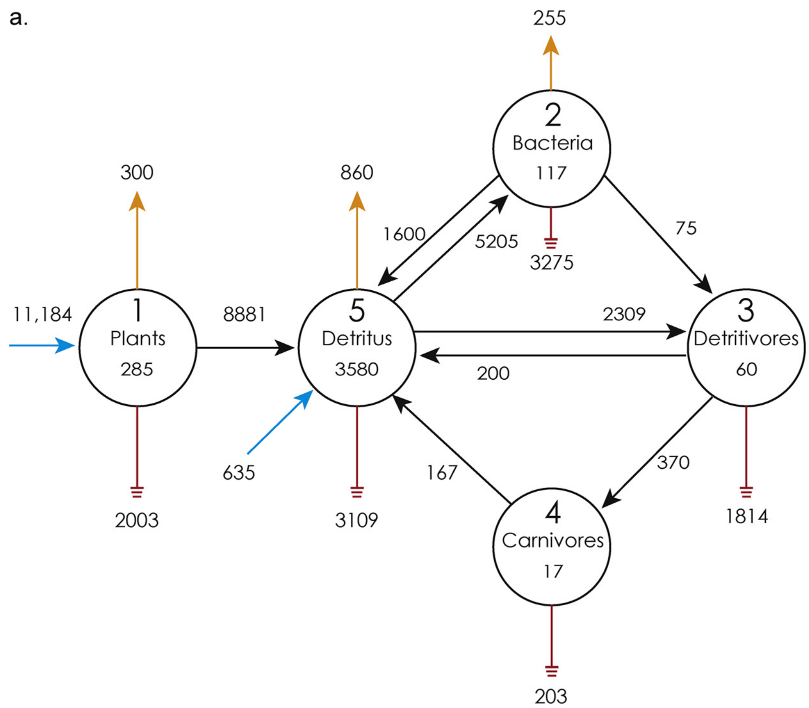
Ecological Network Analysis (ENA) is used to investigate ecosystem structure and functioning (Hannon, 1973; Jørgensen, 2007; Patten et al., 1976; Ulanowicz, 1986), and is one component of the broader field of network ecology (Borrett et al., 2014; Proulx et al., 2005). ENA techniques have been applied to characterize food web organization (Baird et al., 1998; Bondavalli and Ulanowicz, 1999; Pezy et al., 2017; Rakshit et al., 2017), assess ecosystem maturity or status (Christensen, 1995; Ulanowicz, 1980), trace biogeochemical cycling in ecosystems (Christian and Thomas, 2003; Small et al., 2014), and characterize the sustainability of urban metabolisms and other socio-ecological systems (Fan et al., 2017; Zhang, 2013; Zhang et al., 2009). Responding to the need for ecosystem-based management and recognizing the ability of ENA to characterize the whole ecosystem, multiple papers have called for the increased use of ENA to guide ecosystem assessment and management (Dame and Christian, 2006; de Jonge et al., 2012; Longo et al., 2015; Zhang, 2013). This push includes the use of ENA system metrics as indicators of good environmental status in the EU Marine Strategy Framework Directive (European Parliament and Council of the European Union, 2008). To prepare for this anticipated increase in ENA applications for environmental decision-making, to help advance the field, and to better enable new investigators to learn, develop and apply the ENA approach, we reviewed publications in the field between 2010 and 2016.

ENA studies are distinguished from other types of network analyses in ecology by both the type of network model used and the collection of analyses applied to interrogate the system. In ENA, the network model follows the flow of energy or nutrients through the ecosystem (Fath et al., 2007; Hannon, 1973; Wulff et al., 1989). These models use a single thermodynamically conserved tracer so that the networks function like resource-distribution maps. Network nodes represent species, functional groups, or non-living resource pools, and the directed edges indicate the transfer of the resources between nodes (e.g., eating,

* Corresponding author at: Department of Biology and Marine Biology, University of North Carolina Wilmington, Wilmington, NC 28403, United States.
E-mail address: borretts@uncw.edu (S.R. Borrett).

https://doi.org/10.1016/j.ecolmodel.2018.04.020
Received 28 November 2017; Received in revised form 23 March 2018; Accepted 29 April 2018

a.



b.

$$\mathbf{F}=\begin{bmatrix}0&0&0&0&8881\\0&0&75&0&1600\\0&0&0&370&200\\0&0&0&0&167\\0&5205&2309&0&0\end{bmatrix},\ z^T=\begin{bmatrix}11184\\0\\0\\0\\635\end{bmatrix},\ e=\begin{bmatrix}300\\255\\0\\0\\860\end{bmatrix},\ r=\begin{bmatrix}2003\\3275\\1814\\203\\3109\end{bmatrix}$$

$$X=\begin{bmatrix}285\\117\\60\\17\\3579\end{bmatrix},\ \text{living}=\begin{bmatrix}\text{TRUE}\\\text{TRUE}\\\text{TRUE}\\\text{TRUE}\\\text{FALSE}\end{bmatrix}$$

Fig. 1. The Cone Spring ecosystem model is a common example of the network model type used for Ecological Network Analysis (Williams and Crouthamel, unpublished). Here the model is shown in both its diagram (redrawn from Ulanowicz, 1986) (a) and matrix (b) representations. The flow matrix $\mathbf{F}_{nxn}$ is oriented from row to column (i→j). The inputs (z), exports (e), respirations (r), and storage or biomass (X) values are shown as separate vectors. The living vector has logical values (TRUE or FALSE) that indicted whether the corresponding node is living, which is an important distinction for some ENA algorithms such as Mixed Trophic Impacts.

excretion, death). The Cone Spring model of energy flow through the aquatic ecosystem (Williams and Crouthamel, unpublished; Ulanowicz, 1986) is a frequently used example due to its simplicity (Fig. 1). Multiple methods exist to build this type of model including a phenomenological energy or nutrient budget approach (Ulanowicz, 1986), the use of linear inverse modeling methods (Saint-Béat et al., 2013b; van Oevelen et al., 2010; Vézina and Pace, 1994; Vézina and Platt, 1988), bioenergetics modeling as implemented in the Ecopath software (Christensen and Walters, 2004; Polovina, 1984), and the construction of dynamic simulation models (Fath et al., 2007; Kazanci, 2007; Moore and de Ruiter, 2012; Patten et al., 1976).

Given this type of energy or material flow model, ENA scientists then apply a distinctive set of network analyses to these models. Building on previous work (Borrett and Lau, 2014; Fath and Borrett, 2006; Fath and Patten, 1999; Ulanowicz and Wolff, 1991), we have categorized the analyses into six related groups based on their analytic goals and underlying mathematics (Fig. 2): structure, flow, storage, environ, control, and impact analyses. For example, the structural analyses focus on the binary network topology and often count the number of different types of pathways (e.g., walks) among the nodes (Borrett et al., 2007; Borrett and Patten, 2003; Patten, 1985a). The flow and storage analyses include approaches built directly on economic input-output analyses (Barber et al., 1979; Finn, 1976; Hannon, 1973; Latham, 2006; Matis and Patten, 1981; Szyrmer and Ulanowicz, 1987) as well as an information diversity framework (MacArthur, 1955; Rutledge et al., 1976; Ulanowicz, 1986, 1980). The environ, control, and impact analyses are derived from the flow and storage analyses, often leveraging the input and output perspectives. Most of these analyses generate whole network descriptors of the system organization and function (Borrett and Lau, 2014; Kazanci and Ma, 2015) such as cycling (Finn, 1980, 1976) and flow efficiency and system robustness (Fath, 2015; Goerner et al., 2009; Patricio et al., 2004; Ulanowicz et al., 2014). While the analyses can be applied to a single model, it is often effective to use the networks as a response variable (Christian et al., 2005; Memmott, 2009) to compare two or more models of different systems (Baird et al., 1991; Borrett et al., 2016; Christensen, 1995) or the same system at different times or under different conditions (Christian and Luczkovich, 1999; Heymans et al., 2002; Ray, 2008; Whipple et al., 2014).

ENA has a long history of development (Fasham, 1985; Hannon, 1973; Patten et al., 1976; Platt et al., 1981; Ulanowicz, 1980; Wulff et al., 1989). Pinpointing a specific origin point for what we call ENA is