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## Inventing the Ecoscope

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When asked what analytical methods one should employ to investigate the behavior of whole ecosystems, most ecologists likely would point to simulation modelling as the avenue of choice. Sensing the potential of this tool and its growing popularity in other realms of ecology, the governors of the Scientific Committee for Oceanic Research (SCOR) invoked in 1977 a Working Group (WG#59) to assess the potential that simulation modelling offered to biological oceanographers. The ensuing critique (Platt et al. 1981) was less than a ringing endorsement of mathematical modelling. The Group encouraged the use of mathematical models to quantify isolated biological processes, such as photosynthesis by algae or filter feeding by mesocrustaceans. Single processes often were dominated by one or a few controlling parameters, and frequently models of the mechanisms behind these processes yield reasonably accurate predictions.

As the horizons of biological models are expanded to include multiple process, however, their track record of predicting system behavior quickly wanes. Many ecologists still believe that all that is necessary to achieve acceptable predictions from whole ecosystem models are more precise parameter estimates and greater resolution into component processes. The Working Group warns against false optimism in this regard, pointing out that prediction ability more often than not erodes as models are resolved into finer components. They warned that the underlying idea of ecosystems as a mechanical clockwork (an implicit assumption of all coupled process modelling) is flawed, possibly fatally so.

Criticism is a relatively easy task, and the Group was anxious lest biological oceanographers get the mistaken message that it is futile to attempt to describe whole marine ecosystems in quantitative fashion. WG#59 thus set about to recommend other avenues via which investigators could quantitatively describe biological communities. One of their recommendations was that biologists have placed

too much emphasis on stocks of organisms and chemicals and not enough on the more difficult to measure processes that link populations together. Accordingly, the Group sponsored a North Atlantic Treaty Organization (NATO) Advanced Research Institute to foster greater awareness of the importance of measuring and describing material and energy flows among ecosystem compartments (Fasham 1984).

I was an active member of WG#59 and its successor WG#73, Ecosystem Theory in Relation to Biological Oceanography, and our consensus to encourage research on ecosystem flows engendered a major shift in my own research directions. I was aware that merely assembling flow measurements into "spaghetti diagrams" or "bird's nests" rarely leads to significant new insights into ecosystem functioning. Absent for the most part were methods for appraising such diagrams in systematic and analytic fashion. My first "discovery" lay in finding a way to quantify what could be called the dual features of activity level and organization that lie inherent in every flow diagram. I was enthralled to find that increases in the measure I called "network ascendancy" (Ulanowicz 1980, 1986) appeared to encapsulate most of the attributes of developing ecosystems that had been enumerated by Eugene Odum (1969).

Encouraged by what I perceived to be a new way to look at ecosystem development, I searched for other ways to make sense of the jumble of transfers that occur in any ecosystem. One method for quantifying indirect bilateral transfers in ecosystems had been borrowed from economic analysis by Hannon (1973). Janusz Szyrmer and I were able to reformulate this "Input-Output" methodology so as better to address the particular concerns of the ecologist (Szyrmer and Ulanowicz 1987). Furthermore, with encouragement from Michael Kemp, I was able to transform most complicated webs of exchanges into something that resembles Lindeman's "trophic pyramid," or linear chain of

transfers via discrete trophic levels (Ulanowicz and Kemp 1979; Ulanowicz, in press). Finally, I spent much effort finding a way to identify and isolate the pathways for recycle within a network of flows (Ulanowicz 1983).

I assembled these four basic network analyses into one computer package, NETWRK (Ulanowicz and Kay 1991). Meanwhile, WG#73 sponsored a workshop to test evolving methods (including NETWRK) for analyzing ecological flow networks (Wulff et al. 1989). However, it soon became obvious to all concerned that developments in theory and methodology were fast outpacing the acquisition of full data sets with which these methods could be tested and exercised. To find data on each and every exchange in an ecosystem is a laborious and too often an impossible task. If any progress were to be made in characterizing ecosystem function via their network configurations, some way had to be found to interpolate and/or extrapolate from an incomplete ensemble of available data on a particular network to its full complement of flow values.

The development of such "inverse methods" was already underway within WG#73 (e.g., Vezina and Platt 1988; Vezina 1989), unfortunately without any knowledge of the earlier accomplishments of J. J. Polovina et al. in creating ECOPATH. Drs. Pauly and Christensen, however, were quite aware of the potential of Polovina's methods and astutely decided that what was needed was to put ECOPATH into a "user-friendly" form and to promulgate its use among that diverse network of aquatic ecologists worldwide with whom ICLARM maintains close contact. The result was ECOPATH II - the foundation upon which this book is based - and the motivation they provided their associates to use the package was the ICES poster session held in Copenhagen. I had been unaware that they were circulating some of my analytical methods as part of ECOPATH II, when one day a parcel appeared in my mailbox containing some 50 or more quantified foodwebs, replete with accompanying ascendancies. It was perhaps the most startling and gratifying moment of my professional career.

The heavens were opened to us by Galileo and his telescope; the world of microbes by Pasteur and his microscope. It may not be much of an exaggeration to say that the realm of ecosystems is being opened to us by Polovina, Pauly and Christensen through their "ecoscope". For that is what ECOPATH II and its associated analyses represent - a macroscope through which to view the structure and functioning of entire ecosystems. Anytime the barriers to observing a new scale of phenomena fall, a flurry of exciting discoveries inevitably follows. For now vision through the ecoscope may be akin to looking "through

a glass darkly," but the picture is certain to sharpen during the next few years.

For my own part, I am confident that what we are seeing through the ecoscope is no clockwork. Nor is it, as Clements suggested, an organism. It is an "organic system," which is to say that certain components behave in mechanical fashion, whilst the ensemble as a whole possesses a "propensity" (Popper 1990) to develop in a particular direction. What is most important is that this propensity is in some measure autonomous of the specific nature of its parts.

Currently our attention is focused on the structure of organic systems. Perhaps the best analogy to the present state of affairs in ecosystem research is that we are at the point where medicine was at the time of Leonardo Da Vinci and his marvelous drawings of the human anatomy. It is thus that the burgeoning endeavor of comparing ecosystem networks might aptly be called "comparative ecosystem anatomy" (Wulff and Ulanowicz 1991). In due time the ecosystem's counterpart to physiology will emerge, but for now this book represents the largest exposition to date of models that can be used by both practitioners and theoreticians alike.

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