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Preface

Introduction to the special issue of *Ecological Modelling*: “Advances in Modeling Estuarine and Coastal Ecosystems: Approaches, Validation, and Applications”

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ABSTRACT

The development and application of ecosystem models in estuarine and coastal systems has grown exponentially over the past four decades. Models have become ensconced as major tools for both heuristic study of ecosystem structure and function as well as for informing management decisions, particularly with respect to cultural eutrophication. In recent years an ever-expanding toolbox of modeling approaches is being offered to complement traditional methods. This expansion of modeling in estuarine and coastal science was exemplified by four sessions devoted to modeling at the 2007 biennial conference of the Estuarine Research Federation in Providence, RI. We felt the time was right to propose a special session of *Ecological Modelling* to synthesize talks from these sessions to present the state of the art in coastal and estuarine modeling. The collection of papers contained in this special issue presents a diversity of traditional and novel modeling approaches, methods for assessing model validity and predictability, and the utility of models in management applications. We believe that together these papers provide an excellent overview of current approaches to modeling estuarine hydrodynamics, water quality, and ecosystem/food web dynamics, applications of complex and relatively simple modeling approaches, applications in both deep and shallow coastal systems, goals relevant for both heuristic and management applications, and perspectives based on traditional mechanistic model development as well as more recent alternative approaches.

1. History

> “*A complex field such as oceanography tends to be subject to two opposite approaches. The first is the descriptive, in which several quantities are measured simultaneously and their interrelationships derived by some sort of statistical method. The other approach is the synthetic one, in which a few reasonable although perhaps oversimplified assumptions are laid down, these serving as a basis for mathematical derivation of relationships.*”
>
> Gordon A. Riley (1946)

With these words, Gordon Riley began his classic description of the first mechanistic, numerical model of a marine ecosystem and illustrated the power of the synthetic approach in environmental research. The novelty of Riley’s approach was to expand upon the Lotka–Volterra equations which describe the population dynamics of predators and prey (Lotka, 1925, 1932; Volterra, 1926):

$$\frac{dN_1}{dt} = N_1(r - gN_2)$$

$$\frac{dN_2}{dt} = N_2(fgN_1 - d)$$

where N_1 and N_2 are the size of the prey and predator populations, respectively, r is the intrinsic growth rate of the prey, g is the grazing or attack rate of the predators, f is the efficiency with which predators are able to incorporate consumed food into new offspring, and d is the predator death rate. Riley formulated each rate process as a function of environmental variables such as temperature, irradiance, and nutrient concentration; thus the field of marine mechanistic modeling was begun. Riley’s models of phytoplankton (Riley, 1946) and zooplankton (Riley, 1947) on George’s Bank were subsequently combined into a coupled nutrient-phytoplankton-zooplankton model 2 years later in an analysis of plankton dynamics in the western North Atlantic (Riley et al., 1949). Given the relative lack of field observations and mechanistic understanding of processes at the time, Riley’s close fits between predictions and observations were impressive indeed.

Since these early beginnings, Riley’s approach has formed the basis of efforts to develop numerical ecosystem models in aquatic systems with increasing complexity and detail, from models of plankton cycles and nutrient-plankton interactions up to full ecosystem models complete with biogeochemical cycling of multiple carbon and nutrient pools, dissolved oxygen, and suspended sediments, and state variables for various biological components from multiple phytoplankton and zooplankton groups to benthic primary producers, benthic consumers, and fish (e.g., Wetzel and Wiegert, 1983; Hofmann, 2000; Giblin and Vallino, 2003). Using the publication history in the primary literature as a proxy for development and application of aquatic ecosystem models, development began in earnest in the late 1960s and 1970s, with initial application as heuristic and synthetic research tools in the study of coastal

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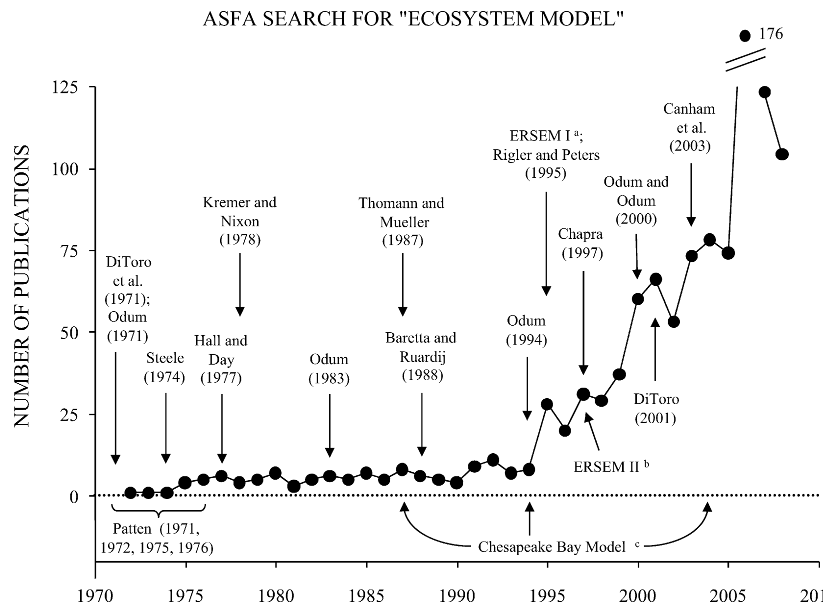

Fig. 1. Number of publications returned using the term "ecosystem model" in the Aquatic Sciences and Fisheries Abstracts (ASFA) online database, with some major milestones in coastal marine and general ecosystem modeling highlighted. ERSEM stands for European Regional Seas Ecosystem Model; [a]Baretta-Bekker (1995); [b]Baretta-Bekker and Baretta (1997); [c]HydroQual (1987), Cerco and Cole (1994), and Cerco and Noel (2004).

marine ecosystems (Fig. 1). This period is exemplified by the multi-volume series, *Systems Analysis and Simulation in Ecology*, edited by B.C. Patten (1971, 1972, 1975, 1976), the synthesis of H.T. Odum's systems modeling approach based on thermodynamic principles and energy systems language (Odum, 1971), the early modeling text by Hall and Day (1977), and development of models in particular coastal systems such as the Sacramento-San Joaquin Delta, North Sea, and Narragansett Bay (DiToro et al., 1971; Steele, 1974; Kremer and Nixon, 1978).

Model development continued through the 1980s which also saw the beginnings of the use of models for guiding management of coastal systems, most notably in the Chesapeake Bay (HydroQual, 1987; to be followed later by Cerco and Cole, 1994 and Cerco and Noel, 2004). Models of increasing biological and biogeochemical complexity began to emerge such as the aforementioned Chesapeake Bay models, models of the Baltic Sea (e.g., Stigebrandt and Wulff, 1987), and the model of the Ems Estuary (Baretta and Ruardij, 1988) which later became the basis of the European Regional Seas Ecosystem Model (ERSEM). This period also saw the production of key water quality modeling texts (e.g., Thomann and Mueller, 1987; to be followed later by Chapra, 1997 and DiToro, 2001) and a new text by H.T. Odum which expanded the application of his systems modeling approach (1983, to be followed by the 2nd edition in 1994 and Odum and Odum, 2000).

In the 1990s the use of models practically exploded (Fig. 1), which we attribute to (1) the widespread acceptance of modelling as a mainstream research tool (see also Canham et al., 2003 and the preface by Solidoro et al., 2009 in another recent special issue of *Ecological Modelling*) and (2) the increasing availability of personal computers capable of running simulation models. This period saw increasing use of models in management, including applications in Long Island Sound and Massachusetts Bay (HydroQual, 1991; HydroQual and Normandeau Associates, 1995), and the development of models of increasing complexity, incorporating most major components of coastal systems and their food webs (e.g., Baretta-Bekker, 1995; Baretta-Bekker and Baretta, 1997). While this increase may be somewhat overemphasized in the primary literature (i.e. Fig. 1) as many early models were published as book chapters or in the grey literature, models have only continued to grow in their use in both research and management and have become fundamental to efforts in the United States to mitigate the effects of cultural eutrophication on coastal systems (EPA, 1999; NRC, 2000; Giblin and Vallino, 2003; Harris et al., 2003).

The last two decades have also seen a growing body of work examining the role of and need for increasing complexity and spatial resolution in models (e.g., Fulton et al., 2003, 2004; Friedrichs et al., 2006; Ménesguen et al., 2007), the importance of embracing simpler, "intermediate complexity", and alternative modeling approaches (e.g., Rigler and Peters, 1995; Pace, 2001; Duarte et al., 2003), and examples of the use of multiple modeling approaches to inform coastal management (e.g., Stow et al., 2003; Scavia et al., 2004). Indeed, a variety of modeling approaches now exist and are being continually developed to allow for simulation using multiple models across a range of temporal and spatial scales, depending upon the question of interest.

In light of the large increase in the use and application of ecological models, Canham et al. (2003) edited a timely overview entitled, *Models in Ecosystem Science*, which presented a series of papers covering the status and role of models in ecosystem science, methods for validation, the use of models in management, and future challenges for ecosystem modeling. While not limited to estuarine and coastal systems, the volume presents a diversity of modeling approaches and suggests this diversity is healthy and parallels the value and importance of varied scientific approaches in general. Since a model is a hypothesis about how a system works, we view the application of multiple modeling approaches as analogous to testing of multiple competing hypotheses, and the use of multiple models to gain insight on a particular problem as an extension of the statistical multi-model inference advocated by Burnam and Anderson (2002).

2. ERF 2007 meeting

It is with this rich history that we came to the 2007 biennial meeting of the Estuarine Research Federation (ERF, now the Coastal and Estuarine Research Federation, CERF). This meeting saw an unprecedented number of sessions focused on modeling (ERF, 2007):

a. Modeling Hypoxia: Approaches and Application to Management (SCI-019)
b. Prediction and Understanding: Model Approaches, Applications and Performance (SCI-022)
c. Ecology, Modeling and Management – Getting it all Together (SCI-061)
d. Modeling – General (SCI-121)

A total of 59 oral and 20 poster presentations were contributed across these four sessions. Given this exceptional presence of modeling at the 2007 ERF meeting and the ever-increasing role of models in coastal and estuarine research and management, we felt the time was right to propose a special session of *Ecological Modelling* to synthesize talks from the four sessions and present the state of the art in coastal and estuarine modeling. In particular, this collection of papers presents a diversity of traditional and novel modeling approaches, methods for assessing model validity and predictability, and the utility of models in management applications. This issue is intended to complement the recent special issue of the *Journal of Marine Systems* (volume 64, no. 1–4, January 2007) which covered the state of the art in modeling of open ocean and shelf ecosystems, as well as the Canham et al. (2003) volume, *Models in Ecosystem Science*, by focusing on estuarine and coastal applications. The ERF/CERF meetings have always been remarkable in their integration of cutting edge estuarine science and the communication and application of this work to management needs. This culture of applied, problem-solving model development in the coastal environment is implicit in the examples collected here.

While no special issue could be entirely inclusive of the vast breadth of estuarine and coastal modeling approaches and applications, the papers in this special issue are sufficiently varied to represent this diversity as well as current issues in the field. While a typical preface might now highlight each paper and its particular contribution to the issue, as Canham et al. (2003) note it is difficult and often futile to attempt to classify models into rigid categories. Rather the papers included here highlight multiple attributes of the state of the art in coastal modeling and we prefer to let them stand on their own. We believe that together they present an excellent overview of current approaches to modeling estuarine hydrodynamics, water quality, and ecosystem/food web dynamics, applications of complex and relatively simple modeling approaches, applications in both deep and shallow coastal systems, goals relevant for both heuristic and management applications, and perspectives based on traditional mechanistic model development as well as more recent alternative approaches.

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