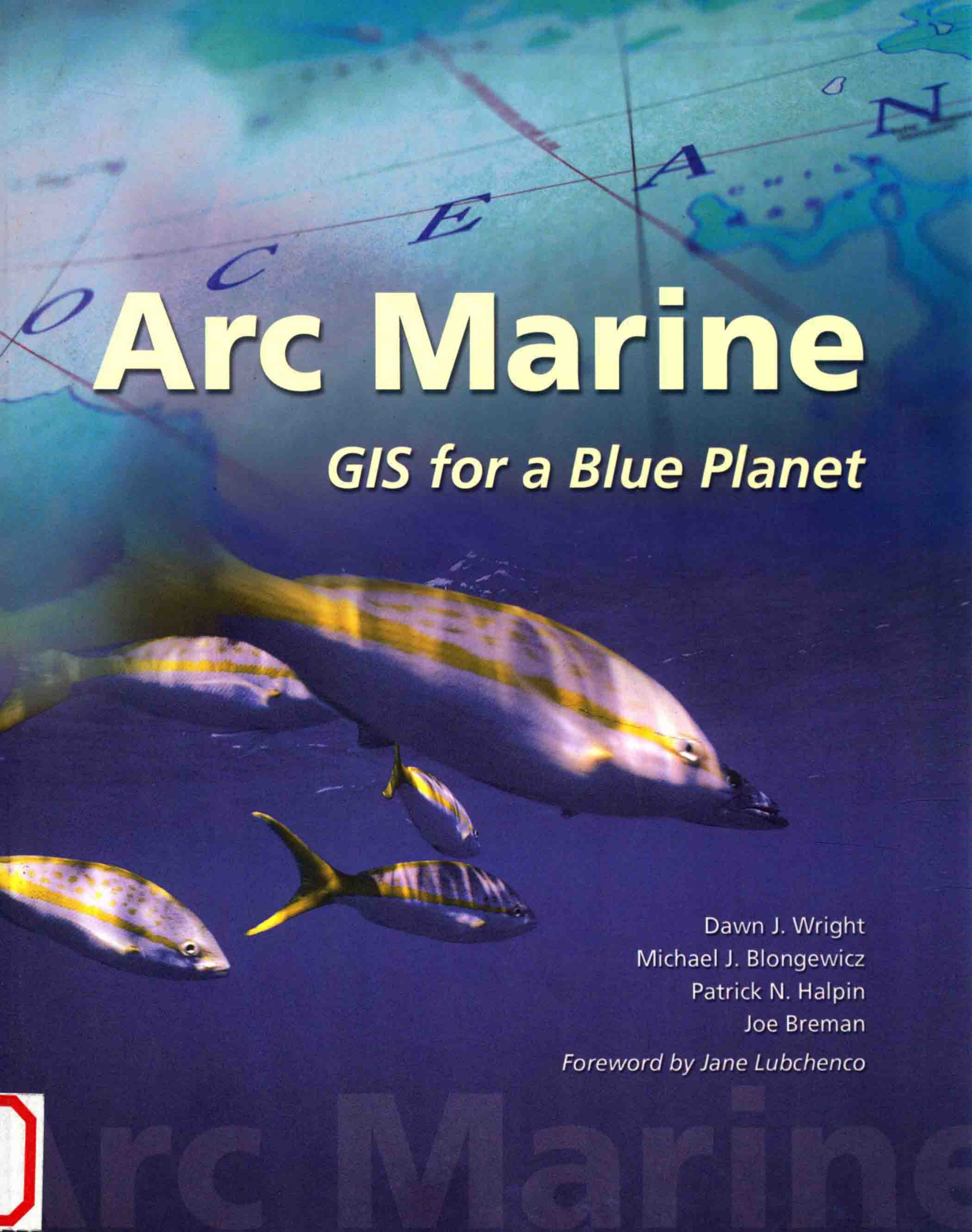

Arc Marine

GIS for a Blue Planet

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Michael J. Blongewicz
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Foreword by Jane Lubchenco

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Foreword

The oceans are so vast and bountiful that for most of human history they have been thought of as infinitely resilient and inexhaustible. The mantra "Dilution is the solution to pollution" characterized attitudes toward oceans as convenient places for waste disposal. The mere idea that oceans could be overfished or disrupted was inconceivable. Fast-forward to the present. Evidence of disrupted ocean ecosystems abounds: A quarter of the world's most important fisheries are vastly depleted; 90 percent of the large fishes have disappeared due to overfishing; hundreds of "dead zones" (areas with oxygen levels too low to support most marine life) have appeared in the last few decades due to nutrient pollution from agriculture, livestock operations, and sewage; harmful algal blooms are increasing due to this nutrient pollution and the introduction of nonnative species, for example, via ballast water; sea level is rising, oceans are warming, and storm intensity is increasing because of climate change; and the oceans are becoming more acidic as they absorb about half of the carbon dioxide being released from the burning of fossil fuels and clearing of forests. In a very short period of time, the bounty of oceans has been depleted and ocean ecosystems have become seriously disrupted.

Because this depletion has serious social and economic consequences, there is increasing interest in devising solutions to recover the bounty and resilience of ocean ecosystems. In the United States, the Pew Oceans Commission and the U.S. Commission on Ocean Policy have made comprehensive recommendations on solutions. The Joint Oceans Commission Initiative and others are taking up the challenge of implementing these recommendations. Many states and other nations are evaluating their own policies and practices.

Emerging evidence indicates that some solutions are both feasible and effective—for example, modifying fishing gear to reduce habitat destruction and inadvertent impacts on nontarget species; establishing networks of fully protected "no take" marine reserves to protect habitat and allow fishes and invertebrates to recover, mature, and produce immense numbers of young; reducing land-based sources of pollution; protecting critical coastal wetlands from development; reducing introduction of nonnative species; aligning the economics of fishing with conservation interests; improving ocean governance; and more.

However, the diversity of drivers causing ocean changes and the different scales of ocean processes present challenges in understanding and evaluating problems and solutions. Civil society, managers, policy makers, business and industry, and scientists need better tools to visualize, examine, manipulate, and evaluate data and information. Scientific data and information play critical roles, but they must be organized and presented in ways that are understandable, relevant, useable, and credible. For the oceans, GIS has been a powerful tool because it integrates many kinds of data (for example, marine geology with marine biology, chemistry, ocean currents, etc.) in order to see the larger picture. It can turn the numbers that data represents into interpretations that help people understand what is happening and what different solutions would accomplish. This book is about applying GIS to the ocean, more efficiently and effectively than before, by using the latest available approaches in this exciting, evolving technology.

The power of GIS lies in its flexibility for both scientists and nonscientists. The organized structuring and layering of data allows accurate representations of information that can be tailored to the needs and interests of users by location, spatial extent, and type of information desired. Oceanic and coastal features, including natural and built structures, can be visualized and manipulated. For scientists, a data model such as Arc Marine is invaluable in enabling better management and sharing of data with other scientists, policy makers, and the public.

The publication of *Arc Marine: GIS for a Blue Planet* comes at a critical time. Oceans, and indeed the entire planet, are changing at faster rates, over broader scales, and in fundamentally new ways. As documented in the Millennium Ecosystem Assessment, these environmental changes have immediate consequences to human well-being. Hence, there is great urgency in addressing these problems and making a transition to sustainability. Scientific information is vital in helping society understand what is happening and the likely consequences of possible solutions. This is especially true for the oceans that to most people are normally represented simply as large blue areas on a map. New tools such as those described in this book provide unified approaches to and frameworks for processing, mapping, and sharing critical information about the oceans. These tools will inform and guide impending decisions and determine whether we can indeed recover the lost bounty and resilience of oceans.

Jane Lubchenco

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Preface

During the past several years, ESRI, with significant user-community input, has been building application-specific data models for ArcGIS software in many industries and scientific disciplines. Notable for the marine GIS community is the marine data model initiative, also called Arc Marine. Other industry data models have common touch points to Arc Marine, such as Arc Hydro, Groundwater, Climate and Weather, Petroleum, and the S-57 for Electronic Navigational Charts. In tandem with these efforts, the marine GIS community has grown significantly during the past few years. "Marine GIS community" is defined as users who apply GIS to the coasts, estuaries, marginal seas, and deep ocean. The community includes academic, government, and military oceanographers; coastal resource managers and consultants; marine technologists; nautical archaeologists; marine conservationists; marine and coastal geographers; fisheries managers and scientists; ocean explorers/mariners; and others.

This book reports the initial results of a successful effort to create and define a data model for this community, one that supports better management of complex spatial analyses within a variety of marine applications. Included are descriptions of database projects that focus on mapping the ocean floor, fisheries management in the water column, marine animal tracking in the water column and on the sea surface, nearshore and shoreline change, temporal analysis of water temperature, and the integration of numerical models. Our goal has been to create a database design that facilitates the collection of dynamic and multidimensional data from the oceans, seas, and coasts, and to provide a more logical way to represent these in the object-oriented world of the geodatabase.

The development of common, interoperable GIS tools based on such a framework can be immensely valuable: tools for data input, distributing or serving data, improved performance in data processing and analysis, and creating new information from the data. Designed with the data model in mind, these tools combined create useful ways to work with marine sensor data and human observations.

The data model improves our ability to manage and exchange large marine datasets using a framework that can be shared and implemented across many platforms and applications. The standards and best practices that have emerged from the case studies, lessons learned, and tutorials combine to form a diverse set of resources for the marine GIS practitioner to draw from.

As you use this book as a reference or laboratory manual, please refer to and download the many resources, including the core Arc Marine data model, at the accompanying mirror Web sites: http://dusk.geo.orst.edu/djl/arcgis/ and the Marine link at http://support.esri.com/datamodels. These sites include the Arc Marine design templates, the Arc Marine reference poster, a tutorial on using Arc Marine, sample datasets, background documents, Microsoft PowerPoint files, and links to Arc Marine tools.

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Contents

Foreword Professor Jane Lubchenco *vii*
Preface *ix*
Acknowledgments *xi*

Chapter 1 Introduction 1

Chapter 2 Common Marine Data Types 9

Chapter 3 Marine surveys 21

Chapter 4 Marine animal data applications 45

Chapter 5 Implementing time series and measurements 81

Chapter 6 Nearshore and coastal/shoreline analysis 107

Chapter 7 Model meshes 141

Chapter 8 Multidimensional GIS 163

Chapter 9 Epilogue 177

About the authors *183*
Index *187*

1
chapter one

Introduction

Just as fish adapted to the terrestrial environment by evolving into amphibians, so GIS must adapt to the marine and coastal environment by evolution and adaptation.
M. F. Goodchild (2000)

Our ability to measure change in oceans and along coasts is increasing, not only because of improved measuring devices and scientific techniques, but also because new GIS technology is helping us better understand the marine environment. The domain has progressed from applications that merely collect and display data to complex simulation, modeling, and the development of new coastal and marine research methods and concepts. Marine GIS has evolved into an established application domain adapting a technology originally designed for land-based applications. However, a two-dimensional (2D) framework has never perfectly matched the ocean environment, where processes are dynamic and multidimensional in nature. Fortunately, technology has continually improved as increased commercial, academic, and political interest in coastal regions, oceans, and marginal seas have spurred fundamental improvements in the toolbox of GIS and extended the methodological framework for marine applications. Other challenges remain, such as how to best handle the temporal and dynamic properties of shoreline and coastal processes, how to deal with the inherent fuzziness of boundaries in the ocean, and the great need for spatial data structures that vary their relative positions and values over time. For a complete and chronological discussion of these various research challenges, see Li and Saxena (1993), Bartlett (1993a and b), Lockwood and Li (1995), Wright and Goodchild (1997), Wright and Bartlett (2000 and references therein), Valavanis (2002), Breman (2002), Green and King (2003), and Wright and Halpin (2005). The development of an effective conceptual and logical data model for marine objects and phenomena provides context and direction to meet these challenges.

As we move rapidly into the information era, in which decisions are based on available data and new information is created from existing data, the body of marine knowledge has surged forward at a rate that challenges our computer capacity to store, process, and share it (e.g., Ocean Information Technology Infrastructure Steering Committee 2002; Mayer et al. 2004; National Science Board 2005). Natural phenomena such as hurricanes and tsunamis illustrate the importance of a focused effort to manage and share information, while the slower processes of erosion and climate change also influence our environment in ways that demand our attention. A data model helps us categorize and give structure to the many different ways to store and analyze marine data. The benefits and added value come in the form of geospatially enabling the data to create maps and three-dimensional (3D) scenes of the marine environment that assist in representing the information in ways that are invaluable to decision making.

A data model for marine applications is complex because of the many, varied uses of the data (as discussed in detail in chapter 2). Modern marine datasets are generated by a wide array of instruments and platforms, all with differing formats, resolutions, and sets of attributes (figure 1.1). Users must deal with a variety of data sources and a myriad of data "structures" (e.g., tables of chemical concentration versus raster images of sea surface temperature versus gridded bathymetry versus four-dimensional [4D] data). A comprehensive

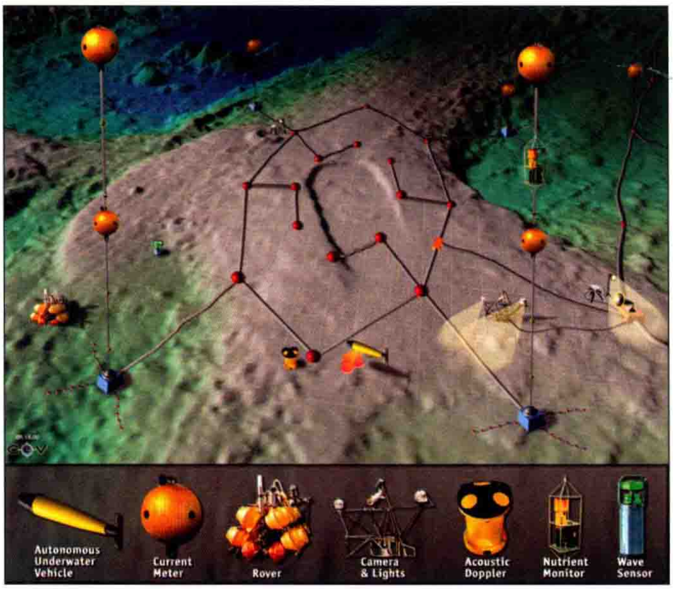

Figure 1.1 The North-East Pacific Timeseries Undersea Networked Experiments (NEPTUNE) ocean observatory envisions a hypothetical network of oceanographic instruments and vehicles to be deployed on Axial Volcano in the northeast Pacific Ocean. It is based on the existing NOAA New Millennium Observatory (NeMO) on Axial. This image also shows the many and varied sources of data that may be available from one major study site for marine GIS maps and analyses.

Graphic published by permission from NEPTUNE Program and University of Washington Center for Environmental Visualization.

data model is needed to support the much wider range of marine objects. This is essential for advanced management, cartographic, and analytical tasks. The ArcGIS marine data model, hereafter referred to as Arc Marine, endeavors to identify and organize these objects.

Just as language and the use of common symbols help us communicate and share our ideas, a data model with commonly accepted terminology and semantics (or ontology) helps us exchange information. We have spent a considerable amount of time and energy serving as translators or "semantic mediators" for a community that holds many of the same interests in gathering, understanding, and sharing information about the world's oceans and seas. Users can apply the resulting data model in many marine applications. It can serve as a starting point for the novice or as a resource for the expert in marine GIS and its implementation.

For the sake of clarity, "marine" (as in marine community, marine applications, and marine GIS) throughout this book refers to deep oceans and coasts. In the past, a distinction was made between ocean and coastal GIS because they developed fairly independently of each other (Wright 2000; Bartlett 2000). In this way, traditional oceanography departments in North America often grouped biological, chemical, physical, and geological studies of the ocean as "oceanography science programs" while creating a separate category for coastal studies, particularly if the emphasis was on coastal resource management. In general, ocean applications of GIS have traditionally been more in the realm of basic science, whereas coastal applications, due in part to the intensity of human activities, have encompassed basic and applied science and policy and management. But this is fast changing. Both subdomains collect similar datasets and have common interests and needs in terms of GIS implementation. In other words, the datasets are the same, regardless of how they are used (for basic or applied science, conservation, education, applied commercial use, etc.). As such, an essential data model should be applicable to all. Therefore, Arc Marine is for people applying GIS to the coasts, estuaries, marginal seas, and the deep ocean: academic, government, and military oceanographers; coastal resource managers and consultants; marine technologists; nautical archaeologists; marine conservationists; marine and coastal geographers; fisheries managers and scientists; ocean explorers/mariners; and so on.

Why Arc Marine?

As noted by Bartlett (2000) and Li (2000), rigorous modeling of data before attempting to implement a GIS database is one of the most important lessons to be learned from collective experience in the application domain of marine GIS. Data models lie at the heart of GIS, determining the ways in which real-world phenomena may best be represented in digital form. With regard to ESRI products, many marine and coastal practitioners and organizations have invested in the coverage or shapefile data structure (under the rubric of a "georelational data model"). Although this has largely been successful, there have been important shortcomings, such as the inability to distinguish between a feature that merely marks a location from one that may actively collect some form of data. In recent years, ESRI has introduced a new object-oriented data model called the geodatabase, in which GIS features are "smarter," that is, they can be endowed with "behaviors" and more complex relationships. "Behavior" here primarily means providing the basic data input and data quality safeguards to ensure clean, consistent data. A geodatabase allows people to build validation rules, apply real-world behavior to features, and combine or link them to tables using relationship classes. For instance, a point representing a seafloor marker can be readily distinguished from a point that actually does something, such as a transponder that sends an acoustic pulse back to the surface. A line representing a coast can be attributed with time-varying sequences or intervals to enable it with behavior that more closely represents a dynamic shoreline. These capabilities are especially useful for large enterprise databases of geographic information (i.e., a GIS integrated in multiple departments or sections within an organization, institute, observing system, large project, etc.). For an overview of ArcGIS object and geodatabase concepts, see Zeiler (1999) or Arctur and Zeiler (2004).

One key benefit of the ArcGIS data model is its ability to help users take advantage of the most advanced manipulation and analysis capabilities of the GIS, particularly the capacity of the geodatabase to respond to events and processes acting on it (just as the marine environment itself is acted on by events and processes). For users, Arc Marine provides a basic template to implement a marine GIS project. This facilitates the process of extracting, transforming, and loading data (ETL), in addition to data input, formatting, geoprocessing, and analysis. For developers, it provides a framework for writing program code and maintaining applications. While ArcGIS data models do not create formal data standards, they do promote existing ones. This helps managers simplify data integration at various jurisdictional levels (i.e., local, state/provincial, national, global). Using a common data model (and the accompanying data structure) helps users merge disparate data sources, particularly as the exchange of Internet information becomes paramount. Data sharing and growth cycles accelerate if many people and organizations rely on the same model as their foundation.

Arc Marine aims to provide more accurate representations of the location and spatial extent of marine features and to help users conduct more complex spatial analyses of this data. The model also guides users in new approaches that effectively integrate marine data in space and time. The specific goals of the model include the following:

- Creating a common structure—a geodatabase template—for assembling, managing, and publishing marine data in ArcGIS. For example, the model is specified in an industry-standard modeling notation called the Unified Modeling Language (UML). Because UML code is easily converted to an ArcGIS geodatabase (or to data structures in other GIS packages), users can immediately begin populating the geodatabase rather than designing it from scratch.
- Producing, sharing, and exchanging data with a similar format and structure design.
- Providing unified approaches that encourage development teams to extend and improve ArcGIS for marine applications.