Review: Statistics for spatio-temporal data—a new frontier
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Statistics for spatio-temporal data—a new frontier

Cressie, Noel, and Christopher K. Wikle. 2011. **Statistics for spatio-temporal data.** Wiley Series in Probability and Statistics. Wiley-Blackwell, Hoboken, New Jersy. xxii + 588 p. $84.95, ISBN: 978-0-471-69274-4.

Key words: Bayesian hierarchical modeling; empirical hierarchical modeling; statistical theory.

Statistics and ecology are inseparably linked. Ecological research and theory development relies on data from controlled experiments or observations from natural environments that are inherently noisy and variable. Ecological pattern and processes are spatial and temporal in nature; hence, it is clear that statistics that explicitly consider space and time are needed. While this view holds for experiments, it is much more critical for studies on broad-scale natural phenomena (i.e., watershed observations, global change, and fragmentation of landscapes) for which experimental setups are difficult or impossible. Especially in these cases an assumption of independence of observations is not warranted and statistical tools are needed to deal with such situations.

The book *Statistics for spatio-temporal data* by Noel Cressie and Christopher K. Wikle is an impressive account of the state of the art in spatio-temporal statistics, for which the authors need to be highly commended. It contains comprehensive descriptions of theories and tools that will be important for most ecological studies. Even students in ecological programs should be exposed to spatio-temporal thinking and some of this book will undoubtedly make its way into ecology curricula. The first chapter, "Space-time: the next frontier," may even prove useful as reading material in introductory ecology subjects. This chapter discusses, in beautiful prose, the nature of spatio-temporal data and the critical issue of uncertainty in data and models in the context of scientific research from description, explanation, and generalization to making predictions and policy development.

However, even as early as page 17, the book will be hard to digest for even advanced and quantitatively inclined students in non-mathematical subjects or environmental practitioners. From there on, the book implicitly assumes profound familiarity with probability theory, matrix algebra, calculus, and Bayesian statistics. This book defines classical statistics to include both frequentist and Bayesian approaches and describes correlation and regression analyses as "blunt instruments"; such is the level of innovative advancement in the book as compared to currently taught statistical principles in most ecological curricula world wide.

The book is not meant for bedtime reading and is structured in an encyclopedic way, similar in style to Cressie's 1993 opus (*Statistics for spatial data*. Wiley and Sons, New York). The book contains dense and comprehensive chapters that review temporal statistics (Chapter 3), spatial statistics (Chapter 4; detailing geostatistical, lattice, point, and spatial random processes somewhat parallel to the structure of Cressie (1991/1993)), a relatively less technical chapter on spatio-temporal visualization (Chapter 5), and a basic chapter that deals with spatio-temporal modeling (including a review of spatio-temporal covariance functions, relaxing the stationarity assumption, spatio-temporal kriging, and stochastic partial differential equations). Chapter 7, entitled "Hierarchical dynamical spatio-temporal models," is possibly the least accessible chapter to many ecologists, with applications in control theory and fluid dynamics, but it also contains also an example of stochastic cellular automata models of a raccoon rabies epidemic. Chapter 8 then addresses implementation issues and inference for processes and parameters in linear and nonlinear models that include Kalman filter and smoothers, Gibbs Sampler, and Monte Carlo Markov Chain implementations.

The last chapter contains four examples: sea surface temperature six-month forecasting based on a 30-year period; satellite remote sensing of global aerosol values; forecasting of the Eurasian Collared Dove invasion in the U.S. using bird observations from 1986–2003 to predict the period until 2020; and a study to predict near-surface wind fields using relatively high spatial resolution, but intermittent satellite scatterometer data. Of these examples, only the latter is multivariate, with wind field data from medium-range weather models as a dependent variable.

The epilogue concludes: "Finally, we believe that spatio-temporal statistics has a large, and mainly untapped role to play in public policy. That is, as the questions we are faced with (e.g., global climate change, water resources, hunger, economic stability) become more critical to society in general, we believe strongly that honest quantification and accounting of uncertainty must play a bigger role in decision making . . . ." The book is an important step in this direction and is, without doubt, a valuable contribution that will find a broad readership.

The book makes excellent use of color throughout. Equations that relate to different levels of the hierarchy of data, process, and parameter models are color coded and the book has a large number of color illustrations. It is also very noticeable that each chapter has extensive bibliographical notes that help the reader to understand the past development of thoughts for particular topics.

Nearly half a century ago, Stephan Valvanis (1959. *Econometrics*. McGraw-Hill, New York) pictured statistical theory in the context of maximum likelihood parameter estimation:

> *Econometric theory is like an exquisitely balanced French recipe, spelling out precisely with how many turns to mix the sauce, how many carats of spice to add, and for how many milliseconds to bake the mixture at exactly 474 degrees of temperature. But when the statistical cook turns to raw materials, he finds that hearts of cactus fruit are unavailable, so he substitutes chunks of cantaloupe; where the recipe calls for vermicelli he uses shredded wheat; and he substitutes green garment dye for curry, ping-pong balls for turtle's eggs, and for Chalifougnac vintage 1883, a can of turpentine.*
>
> — Stephan Valvanis

Has the situation changed? We are currently seeing an explosion of spatio-temporal data. Earth-observing satellites repeatedly image the world at pixel resolutions in the decimeter range and data at 250 m resolution will soon to be available in hourly time intervals. Ground-based 3D imaging and low-cost airborne imagery is readily available and will accompany ecological field data. The difficulty will be to deal with heterogeneous observational data from the past that may have a very limited spatial and/or temporal representation. Even though locally highly accurate and important, some field campaigns may be of very little value for regional assessment and rather constitute an expensive method to generate random numbers for management decision making. Such data can nevertheless be very precious because they may be the only historical account from a particular location and analysis will benefit from those "sharp tools" that Cressie and Wikle describe.

This book delivers a strong argument that Valvanis' kitchen is ready for the challenge. But in my opinion the real revolution and value of this book will emerge only once recipes can be explored on the open-source stove using raw data that are willingly shared by governments and the scientific community. The examples given in Chapter 9 use relatively simple and small datasets and it remains to be evaluated if the methods are useful for research problems with data that are much more complex, voluminous, and heterogeneous in both space and time. The probability of success will be a product of ingredients and tools multiplied by the creativity of chefs. Much ecological research is done under constrained conditions, where scarce resources need to be allocated between fresh ingredients (i.e., data) and the acquisition of and training in new tools. I believe that many kitchens will continue to produce excellent output with blunt knives. But saying this, we are in the midst of an explosion where consequences of even small perturbations are difficult to predict.

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Stopping the hands of time

Jordan, William R., III, and George M. Lubick. 2011. **Making nature whole: a history of ecological restoration.** The Science and Practice of Ecological Restoration. Island Press, Washington, D.C. xiv + 256 p. $70.00 (cloth), ISBN: 978-1-59726-512-6 (alk. paper); $35.00 (paper), ISBN: 978-1-59726-513-3 (alk. paper).

Key words: adaptive management; ecocentric restoration; history; meliorative restoration; restoration.

We seem to live in a fallen world. An even casual perusal of the technical literature published in ecological journals, the "accessible" literature written for a scientifically literate but non-specialist citizenry, or the daily tabloids, blogs, and tweets rapidly reveals authoritative pronouncements of long-term ecological "imbalance," ongoing environmental catastrophes, and impending planetary doom. Striding into this breach, with their cattle standing in for extinct Pleistocene megafauna and their flamethrowers replacing unpredictable lightning strikes, come the restoration ecologists. The first restorationists were interested in returning a deposed monarch to his throne and his kingdom to its former state of innocence and grace in the face of the prevailing deity (the *Oxford English Dictionary*, 3rd edition [2010] identifies the first use of "restoration," ca. 1500, in reference to Job "*This blessid man Job thankyd god of his excellence. And of his restoracion proud neuer he.*") The now more generally used meaning of restoration—albeit number 5a in the *OED*—as reconstructing a building or an ecosystem came only much later (1663 and 1984, respectively).

Modern restoration ecologists combine these two meanings of restoration as they strive to recreate an entire ecosystem. The pragmatic goal is to reconstruct an entire ecosystem, with all its parts present and processes smoothly functioning. But there is also a sense of returning an ecosystem to an unsullied state of grace; the overarching goal of ecological restoration is to compensate for the novel or "outside" (read: pernicious, fallen) influences on the ecosystem so that it can function or behave as if these influences were not present. This type of ecological restoration—Jordan and Lubick call it "ecocentric restoration"—is distinct from other forms of land management that focus on improving one or more of the parts of an ecosystem that provide a specific, utilitarian function for people (Jordan and Lubick group these latter approaches into "meliorative restoration"). How ecocentric restoration emerged as the defining principle of restoration ecology, and how it evolved from, and then advanced in parallel with, meliorative restoration, is described brilliantly in *Making nature whole*.

In just over 200 pages of well-crafted prose (the remaining 20% of the book is endnotes and an index), Jordan and Lubick accomplish much more than simply presenting the intellectual history behind the evolution and emergence of contemporary restoration ecology. Jordan and Lubick also bring to life the personalities of the central figures in modern restoration ecology, from the well known (Aldo Leopold) to the rarely remembered (e.g., George Wright, Ossian Simonds, Volney Spalding, Edith Roberts). They illuminate the fundamental (non-economic) values of ecocentric restoration, which provides a self-conscious encounter with nature; a way of making us aware of our influence on ecosystems and landscapes; and an opportunity to pay tribute to nature's intrinsic value. They quote George Wright (then an assistant naturalist at Yosemite National Park) and colleagues as writing, in 1933, "the situation which obtained on the arrival of the (European) settlers may well be considered as representing the original or primitive condition that it is desired to maintain." Jordan and Lubick reify this idea: "old ecosystems are ecologically privileged assemblages of organisms, endowed with distinctive qualities of stability, beauty, and self-organizing capacity." What is old? "[The] condition at the time of cultural contact, the distinctive New World experience, [is] the favored objective of restorationists."

The obvious objection to this baseline—that Native Americans were already here, modifying the landscape, and so ecocentric restoration should use pre-human landscapes as the historic condition or baseline—is forestalled in two ways that further reveal the deep philosophical underpinnings of modern restoration ecology. First, this objection evaporates by definition: "restoration projects initiated by indigenous peoples are