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Effective Ecology

Seeking Success in a Hard Science

Roger D Cousens

with Mark R T Dale, Alkistis Elliott-Graves, Michael J Keough, Gerry P Quinn, Joshua I Brian, Jane A Catford, Jannice Friedman, Alyson C Van Natto, Bruce L Webber, Daniel Z Atwater, Maria Paniw, Chris M Baker, Thao P Le, Marc W Cadotte and Françoise Cardou

Effective Ecology

Ecology is one of the most challenging of sciences, with unambiguous knowledge much harder to achieve than it might seem. But it is also one of the most important sciences for the future health of our planet. It is vital that our efforts are as effective as possible at achieving our desired outcomes. This book is intended to help individual ecologists to develop a better vision for their ecology – and the way they can best contribute to science.

The central premise is that to advance ecology effectively as a discipline, ecologists need to be able to establish conclusive answers to key questions rather than merely proposing plausible explanations for mundane observations. Ecologists need clear and honest understanding of how we have come to do things the way we do them now, the limitations of our approaches, our goals for the future and how we may need to change our approaches if we are to maintain or enhance our relevance and credibility. Readers are taken through examples to show what a critical appraisal can reveal and how this approach can benefit ecology if it is applied more routinely.

Ecological systems are notable for their complexity and their variability. Ecology is, as indicated by the title of this book, a truly difficult science. Ecologists have achieved a great deal, but they can do better. This book aims to encourage early-career researchers to be realistic about their expectations: to question everything, not to take everything for granted and to make up their own minds.

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‘The scientist is not a person who gives the right answers, he is one who asks the right questions.’

Claude Lévi-Strauss

‘Without questions there are no answers. And without answers no truth, no progress, no future.’

Victor Canning

The elevation of ecology beyond the delivery of plausible answers to mundane matters depends on challenging accepted wisdom, defining crucial questions and delivering inspired solutions. Critique – of ourselves and of others – needs to be central to that process.

Contents

Preface

Scientists are consumers of information, not just producers of it. What others do, write and claim to have demonstrated through their research, influences the way that we think. We use their results, interpretations and conclusions to formulate our own ideas and to place our own results in context.

We probably regard ourselves as highly discerning consumers – after all, we are scientists! But the reality is that like any other consumers, we tend not to read the fine print! How often do we critically dissect every method applied or examine every individual assumption that a study makes, from its formulation to its final conclusions? There is far too much literature to read everything in that sort of detail.

In any case, the brevity of modern publications means that many basic details are left out. We are forced to place considerable trust in our colleagues and on our peer-review systems. We trust some sources of information more than others, based on the reputation of the journal or of the scientist. We assume that the researchers knew what they were doing and that those adjudicating on the work were good enough to identify any problems.

We must have considerable faith that other researchers did not make mistakes.

The evidence, however, is that errors in published papers are common. Many of these are perhaps minor and inconsequential, but some have the potential to completely undermine the authors' conclusions. It is not difficult to appreciate how errors can be made and published. If you are like me, you do not understand every detail of every method that you use in your studies, or every nuance involved in their best application.

Your scientific tool-box contains a wide range of items. You try to become sufficiently knowledgeable about them, because you want to do the best job that you can. But you are not perfect: you cannot expect to be! You may seek advice from someone who appears to know more than you, who perhaps taught you. Because of the vastness of the literature, it is impossible for you to read and appreciate everything that has been written about even one method. Your data might not fit all the criteria that the method technically requires, but you think that they may be 'near enough' (and there may not be a better method). You hope that your conclusions will be reliable and that any inabilities on your part, along with mere bad luck, will not mislead the rest of the ecological scientific community.

If you are asked to review a manuscript – and you consider that it is on a subject with which you are sufficiently familiar – you do the best you can with the information available. If you have concerns, you ask that the authors respond to your criticisms or questions, or you might reject the paper. But often you will know no more about the methods than the paper's authors. You cannot be expected to spot every mistake, because you do not have all the information – or the time – for a forensic analysis.

Most journals seek the views of only two or three reviewers, for the good reason that we are all very busy. Such a small sample size has low powers of discrimination (we would seldom accept such low power in our experiments!) and the variance of opinion is high.

It is not just technical errors that have the potential to mislead scientists. We make inferences, from our results – and from other published papers – that may turn out to be wrong. It is quite common for me to be unconvinced by some aspects of studies that I read. I might have done things differently, I might have drawn different conclusions from the same data, or I might not know what to conclude: to me, the study is far less persuasive than to the authors. I cannot necessarily say that the researchers were wrong, but I can have doubts; and some of these doubts may later turn out to be warranted.

Ecological systems are notable for their complexity and their variability. Ecology is, as indicated by the title of this book, a truly difficult science. We seek the truth of how ecological systems behave and try to generate insight that will save species – and even the planet – from extinction. Yet, philosophically, it is impossible to prove anything: we can merely weigh up evidence, of different kinds, that help us to reach an informed opinion.

Everything we do involves assumptions that may, or may not, turn out to be appropriate. We try to be dispassionate observers, but we never can be. We use human concepts to help us try to interpret what we see. We have biases, opinions and other human foibles. We have a history and a respect for others that inspires us but constrains us. Our current and future methods, and our uses of them, as I have just discussed, are fallible. We have a quality control system that is not only imperfect, but also provides inertia, maintaining a set of norms that resist change and allow weaknesses to persist. And despite all of this, ecologists are notable for their confidence in their conclusions: even though a 'due-diligence' of ecology would tell us be sceptical about everything that we read!

The primary aim of this book is to encourage early-career researchers – those who are still developing their particular type of science and having to 'sink or swim' in their chosen career – to be realistic about their expectations. To question everything, not to take everything for granted, and to make up their own minds. Their predecessors have made significant progress but very slowly and, because ecology is inherently so difficult, we remain uncertain about many (indeed most) things. But the book is not only for young researchers. It is also for any of our colleagues who are prepared to sit back and take a cold, hard look at what we have done and what we have achieved.

It is easy to conduct studies and collect data that are new, but it is hard to truly understand what they mean and to push forward the boundaries of ecological understanding. The literature to which our next generation aspires to add their names and ideas is not all 'state-of-the-art' but a range of qualities, all of it 'work in progress' that needs to be challenged, improved and accepted with caution.

The examples that we discuss in this book are intended to encourage all researchers to develop the habit of engaging in critical analysis of both their own work and that of others. Of course, we would be delighted if the superstars of our profession were also to benefit from our discussion and be inspired to engage in subsequent debate. But our primary target – early-career researchers – seldom have books written for them.

It has long struck me that debate – an open expression of differing ideas and views – is extremely limited in ecology. In particular, there is little debate about what we are trying to *achieve*. One-way communication dominates ecology: in our journals and conferences we tell others of our recent work, perhaps briefly float ideas and review the extent of knowledge. But as a way of critically examining ideas and approaches and initiating further development, these media are highly ineffective. Follow-on discourse, debate, dialogue – call it what you will – is limited, difficult and, in the case of journals, subject to extended time-lags. The much more dynamic medium of 'real time' discourse, the life-blood of the ancient philosophers, has become heavily constrained and inaccessible in modern science (not least because of issues of scale). Email, social media, forums and blogs have helped to fix some – but by no means all – of the timeliness and accessibility issues.

About 12 years ago, my great friends Bruce Maxwell (USA) and Michael Williams (Australia) helped me to start the Andina international workshops. Our aim has been to give emerging and more experienced ecologists the opportunity to participate in events tailor-made to facilitate effective, safe and inclusive discourse on what are often challenging and provocative topics. The presence of others in the same room allows the process of critical analysis to reach new levels of rigour and insight, by drawing on a huge combined intellect and a wide diversity of views and experience.

We therefore build into our meetings ways of overcoming natural reservations, social consciences and dominance hierarchies. Simple things, like going hiking together in the afternoons and relaxing together afterwards. Scale and cost remain as problems, but the feedback, from the early-career researchers in particular, has been overwhelmingly positive. Our sixth meeting is scheduled for February 2024. Our hope with this book is to reach out to a much wider audience than Andina has been able to.

The colleagues that I invited to join me in this project are a mix of youth, experience and backgrounds. Their expertise spans empirical, molecular and theoretical ecology, pure and applied modelling, philosophy and statistics, with extensive experience in journal editing, academic book authorship, program management and academic leadership. Some of them have shared experiences with me in Andina workshops; others I knew only by reputation. I am honoured to have such colleagues prepared to contribute their time and – perhaps – to risk their reputations. Importantly, most chapters involve early-career researchers: it would, I feel, have been hypocritical if they had not been included in a debate designed for such people. Indeed, we hope that journals will encourage reviews of the book by this audience.

Our contributions are subjective, biased, incomplete and almost certainly faulty in some instances. All these things are inevitable in a science in which there are few absolute answers. We will, in many places, state our personal opinions: clearly, we have strong views in some areas, about what ecologists should be trying to achieve, the strengths and weaknesses of the past and current approaches, and some things that should be changed. But we do not claim the primacy of these opinions. We do not believe that we are entitled to tell our colleagues what they should be trying to achieve; nor can we give them recipes for how to conduct their own critiques.

We urge readers to identify faults and improvements in our arguments and to communicate these – and alternative analyses – through appropriate, open communication media. We certainly do *not* argue that the topics of our chapters are those most in need of critique: they provide excellent examples and include the areas that we were most interested to engage with. We encourage readers to focus on our overall message and not on the fine details (many of which will always be a matter of opinion).

Our aim is to kick-start the process of critique in the scientific discipline of Ecology, rather than to pretend to present definitive statements on each topic (note that throughout the book we will capitalise the word Ecology where we refer to the bigger picture of the discipline: its community of researchers, their aims and values, the research that they do and the interactions among them).

Finally, a request for tolerance and respect. We explore topics of research rather than the work of particular individuals. However, the number of people active in a topic, and the number of leaders, can be limited and our comments in this book may be taken personally. This is unfortunate, but it is not our intention. Well-intended modern social mores placing an emphasis on the avoidance of conflict would seem to negate the benefits to be gained from the airing and resolution of differences.

Science must be challengeable, otherwise it will lose its credibility. We all learn through our mistakes and so we, the authors, must be prepared to be challenged in the same way that we challenge others.

Roger Cousens

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Chris M Baker is a Senior Research Fellow in the School of Mathematics and Statistics at the University of Melbourne, Australia, and is affiliated with the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) and the Melbourne Centre for Data Science (MCSD). His main interest is in using mathematical models to help inform the way that we manage complex systems. Projects to date have included the optimisation of management of interacting species and the impacts of species removal, such as feral cats and invasive plants, the removal of diseased Tasmanian devils from isolated regions to create devil facial tumour disease-free areas, and modelling the effect of antibiotics on microbes to develop treatment strategies that prevent the emergence of treatment-resistant infections. Most recently, he has been part of a team of modellers working on the management of COVID-19, providing advice to Australian state and federal governments.

Joshua I Brian is a Research Associate at King's College London, UK, in the Department of Geography, following a PhD with Professor David Aldridge at the University of Cambridge. His research presently focuses on the mechanisms of success of invasive plant species, with a particular emphasis on how plant enemies can facilitate or inhibit invasion. More generally, his research spans community ecology, invasion biology, parasitology and symbiosis, and previous research projects include studies of the coral reefs of Timor-Leste and the parasites of European freshwater mussels. He is particularly interested in how ecological processes vary and interact across spatial and temporal scales.

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Jane A Catford is a Reader in Ecology at King's College London, UK, and Senior Editor of the *Journal of Ecology*. She is a plant community ecologist with interests in biological invasions, environmental change and biodiversity. She is particularly interested in the causes, consequences and processes of vegetation change, and typically focuses on species invasions to tackle such questions. Past research has spanned topics that include species coexistence, community assembly, vegetation management, ecosystem restoration, ecosystem services, functional traits, novel ecosystems, climate change, disturbance and river regulation. Fascinated by mechanisms, she maintains long-term field experiments in Australia, the USA and the UK. She currently leads a five-year project *Predicting impacts of alien plant invasions on community diversity*.

Roger D Cousens is an Emeritus Professor at the University of Melbourne, Australia, with over 40 years specialising in agricultural weeds and invasive species. His approaches have featured components of field research, population modelling and statistical analysis, while he has initiated collaborative projects with quantitative geneticists, molecular ecologists, geomorphologists and social scientists. For the last decade, his passion has been unravelling the dynamics of two invasive sea rockets, their hybridisation and the role of their pollinators. Throughout his career, he has been an outspoken communicator on research practices. This book is a direct outcome of his 12 years as the convenor of the Andina international workshops, developing approaches to effective debate and in which the role of early-career researchers has been central. He has been lead author on two previous academic books: *Population Dynamics of Weeds* (Cambridge University Press, 1995 with Martin Mortimer); and *Dispersal in Plants: A Population Perspective* (Oxford University Press, 2008 with Calvin Dytham and Richard Law). He is an Honorary Fellow of the Weed Science Society of America.

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Alkistis Elliott-Graves focuses her research at Bielefeld University, Germany, on the general philosophy of science and philosophy of applied sciences (especially ecology and climate science). She is particularly interested in complex systems: what makes them interesting but also difficult to investigate? Recent publications have addressed the difficulty of making precise and accurate predictions in ecology and climate science, and what this means for the scientific status of these disciplines. She is currently working on the broader implications of this research for the relationship between traditional philosophy of science and applied scientific practice.

Jannice Friedman is an Associate Professor at Queen's University in Kingston, Canada, in the Biology Department. Her research examines the evolution of plant reproductive strategies in response to ecological conditions and the consequences for pollination and mating. It aims to develop a mechanistic understanding of life history decisions. Recent publications look at: the evolution of annual and perennial reproductive strategies; the consequences of variation in allocation for pollination, fitness and mating; and the effects of seasonality on plant life histories.

Michael J Keough is now an Honorary Professor at the University of Melbourne, Australia. He has a particular interest in how populations and communities respond to change, human induced and natural, and the role of recruitment in this process. He has worked on a range of systems, but deep down, he finds field experiments with invertebrates the most satisfying. He has worked hard to improve experimental design and data analysis for all biologists and, with Gerry Quinn, published the book *Experimental Design & Data Analysis for Biologists* with a supporting website (Cambridge University Press, 2002, 2023). He is also a co-author of *Monitoring Ecological Impacts* (Cambridge University Press, 2002). He is a recipient of the Gold Medal of the Ecological Society of Australia.

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Maria Paniw is a Research Fellow at the Estación Biológica de Doñana, Spain, and a Research Associate at the University of Zurich. Her research focuses on how intrinsic and extrinsic factors, biotic interactions and individual traits interact to determine population structure and dynamics. She is particularly interested in how population projections under global change can be improved by accounting for trait dynamics, environmental and spatial patterning, and trade-offs between survival and reproduction. She works with long-term data on plants and animals, including carnivorous plants, Mediterranean shrubs, meerkats, yellow-bellied marmots, African ungulates and the Iberian lynx. She also works on the potential evolutionary consequences of environmental change and the integration of multi-species seasonal population dynamics into viability analyses.

Gerry P Quinn is now an Honorary Professor at Deakin University, Australia, and was previously Chair in Marine Biology and Head of Deakin's Warrnambool campus. He has extensive research experience in the ecology of coastal marine, freshwater and estuarine ecosystems and their environmental management. He has co-authored two books: *Experimental Design & Data Analysis for Biologists* (2002, 2023) with Michael Keough and *Monitoring Ecological Impacts* with various authors (2002), both with Cambridge University Press.

Alyson C Van Natto is a PhD Candidate in the Biology Department of Queen's University, Kingston, Canada, with a keen interest in plant evolutionary ecology. She is particularly interested in the ecology and evolution of plant reproduction and life history strategies in human-altered environments. She has a passion for conservation, having worked with species-at-risk during her undergraduate and master's degrees and invasive species for her current PhD research. Most recently, she has been a part of a team of conservation biologists working to fill knowledge gaps with respect to rare plant conservation in Canada.

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1

Why a hard science needs strong critique

ROGER COUSENS

WHY ECOLOGY IS DIFFICULT

Ecology is one of the most difficult of sciences (though beware that there is a second definition of the term: Box 1.1). Many of the natural phenomena that ecologists study are of great diversity and complexity, and are inherently variable. There are so many different organisms, each with their idiosyncrasies in the ways that they live, occupying so many different environments. Every location on earth provides a unique set of living conditions, determined by their position on the globe and modified by regional and local geology and geomorphological processes. Every location differs in the groups of organisms that have found themselves there at any given point in time and that have then undergone further evolution.

How do we begin to understand it all?

Science and philosophy have provided us with an array of logical, procedural and analytical tools that we can use. There are so many questions that we might ask, any number of ways to proceed, so many things to observe or measure. But, alas, no perfect recipe as to how to proceed.

We can do a great variety of things that we recognise as components of science, each contributing fragments of evidence, like the pieces in a jigsaw puzzle. But unlike a jigsaw, the picture will never be complete and even the pieces themselves may be blurred and indistinct. The same evidence may be explained by multiple alternatives, some of which may not even have occurred to us yet. We may well have cause to wonder whether we will recognise the true explanation when we have it! Can we ever be certain of anything?

An additional layer to this complexity is that ecologists are human observers, with all the constraints that it carries. We see nature through the eyes of humans, who have been taught to view things in particular ways. We are all individuals, who vary in our interests and opinions, and in our technical and cognitive abilities. We will see the same issue in somewhat different ways, do things differently from one another, interpret the results differently and potentially gain different insights. We differ in the levels of evidence that we regard as sufficient to support our views. Different ecologists have different levels of expectation: they will vary in the vehemence of their claims and in the headlines that accompany their publications. It is quite possible that they may well reach different conclusions from the same evidence. Like professionals in any discipline, we also make mistakes, which may be inconsequential but may be more serious, undermining our efforts to make progress. Scientific convention attempts to define standards of rigour, so that this variation can be minimised, but it can never be eliminated.

Ecologists have risen to such challenges over many decades. Judging by the titles and summaries

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