A brief history of the development of *Numerical Ecology*

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Replacement and Richness difference
1. What is *Numerical ecology*?

*Numerical ecology* is the field of quantitative ecology devoted to the numerical analysis of [multivariate] ecological data, with emphasis on community composition data.

Community ecologists, whose data are multivariate by nature (many species, many environmental variables), are the primary users of these methods.

Numerical ecology is a sub-discipline of ecology, not of statistics or other mathematical discipline.

In *Numerical ecology*, methods are chosen to answer questions and test ecological hypotheses about the data.

When tests of significance are necessary, statistical testing methods must be applicable to *multivariate non-normal* data.
2. Pioneer researchers

Numerical ecology banks upon the work of a great number of scientists. Pioneer researchers who developed important concepts and numerical methods of multivariate data analysis include:

- Paul Jaccard (Swiss Federal Institute of Technology in Zurich);
- David Goodall (until recently at Edith Cowan Univ. in W. Australia);
- Robert R. Sokal (State University of New York, Stony Brook, USA);
- John Gower (Rothamsted Experimental Station, England);
- Robert H. Whittaker (Cornell University, USA);
- Cajo J. F. ter Braak (Wageningen University, The Netherlands);

and many others, cited in the References sections of the NE books.
The field of *Numerical ecology* also developed thanks to the work of software developers. In particular:

- C.J.F. ter Braak wrote the program *Canoco*, software for multivariate ordination;
- Many developers of numerical ecology packages in the R language.
3. Foundation books

Evelyn Christine Pielou, Queens’ University, Kingston


László Orlóci, University of Western Ontario (Botany)


Roger Green, University of Western Ontario (Zoology)

4. The founding of *Numerical ecology*

*Séminaire de mathématiques appliquées à l’océanographie biologique*, Station marine de Villefranche-sur-Mer, Université Pierre et Marie Curie (Paris VI), France.

In May 1975, a dozen or so ecologists, mostly marine, sat during three days in a classroom on the second floor of a historical building of the *Station marine de Villefranche-sur-Mer* (Université Paris 6, France), metres away from the Mediterranean, to discuss developments about a new trend in the ecological literature: the statistical analysis of multivariate ecological data.

Louis Legendre (oceanographer, Université Laval) and I (community ecologist, Université du Québec à Montréal) had been independently invited to participate in the seminar.
Station marine de Villefranche-sur-Mer, Université Pierre et Marie Curie (Paris VI), Villefranche-sur-Mer, France. (Picture: Google Earth)
5. The *Numerical Ecology* textbooks

On the evening of the closing day of the meeting, sitting at the terrace of a restaurant with view on the harbour, Louis Legendre and I wrote, on a paper place mat, a list of subjects …

… that was to become the table of contents of a book about a new subdiscipline of ecology, that we published in 1979, in French, under the title *Écologie numérique*. 

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The Numerical Ecology textbooks:

- 1970
- 1980
- 1990
- 2000
- 2010

Tome 1: Le traitement multiple des données écologiques.

Tome 2: La structure des données écologiques.


Total 2 tomes: 473 pages

*Numerical Ecology.*
Developments in environmental modelling, 3.
xvi + 419 pages

Tome 1: Le traitement multiple des données écologiques.

Tome 2: La structure des données écologiques.


Total 2 tomes: 618 pages
The authors during an interview at Université de Montréal in 1986 –

Photo: *Interface*, Acfas, 1986

History of Numerical ecology
On 3–11 June 1986, Pierre and Louis Legendre (assisted by Marie-Josée Fortin, now Professor at U. of Toronto) organized a *NATO Advanced Study Workshop on Numerical Ecology* at the Roscoff Marine Station (France).

Presentations of methods of analysis by statisticians and methodologists were followed by discussions of their application to ecological problems by working groups of ecologists.

Following the workshop, a book of Proceedings was published (1987).

xv + 853 pages
The authors in 2002, in Nice, in discussion about the next edition (2012) –
Publication date: July 6, 2012

Citations of this book (all editions) > 18 000
(Google Scholars, Jan. 2018)

Numerical Ecology with R provides a long-awaited bridge between a textbook in Numerical Ecology and the implementation of this discipline in the R language. After short theoretical overviews, the authors accompany the user through the exploration of the methods by means of applied and extensively commented examples. Users are invited to use this book as a teaching companion at the computer. The travel starts with exploratory approaches, proceeds with the construction of association matrices, then addresses three families of methods: clustering, unconstrained and constrained ordination, and spatial analysis. All the necessary data files, the scripts used in the chapters, as well as the extra R functions and packages written by the authors can be downloaded from a web page accessible through the Springer website (http://www.springer.com).

This book is aimed at professional researchers, practitioners, graduate students and teachers in ecology, environmental science and engineering, and in related fields such as ornithography, molecular ecology, agriculture and soil science, who already have a background in general and multivariate statistics and wish to apply their knowledge to data using the R language, as well as people willing to accompany their disciplinary learning with practical applications. People from other fields (e.g. geology, geography, palaeoecology, phylogenetics, anthropology, the social and education sciences, etc.) may also benefit from the materials presented in this book.

The three authors teach numerical ecology, both theoretical and practical, to a wide array of audiences, irregular courses in their universities and in short courses given around the world. Daniel Borcard is Lecturer in Biostatistics and Ecology and researcher in Numerical Ecology at Université de Montréal, Quebec, Canada. François Gilbert is professor in Community Ecology and Ecological Modelling at Université de Franche-Comté, Besançon, France. Pierre Legendre is Professor of Quantitative Biology and Ecology at Université de Montréal, Fellow of the Royal Society of Canada, and Highly Cited Researcher in Ecology/Environment.

**Numerical Ecology with R**

**Daniel Borcard**

**François Gillet**

**Pierre Legendre**

**Use R!**

Robert Gentleman, R. Hornik, Giovanni I. Parmigiani Series editors

Daniel Borcard - François Gillet - Pierre Legendre

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U de M

Numerical Ecology with R

A practical guide to Numerical Ecology using the R language

Links to the authors' web pages

Daniel Borcard
François Gillet
Pierre Legendre

This page provides the data sets, R scripts, R functions and several useful links related to the book entitled "Numerical Ecology with R". The R code is provided for PC and Macintosh.

Original material (as in the book)

This material includes a script to install the necessary packages, the data sets, the R scripts for all chapters (for PC and Mac computers) and several R functions. MVPARTwrap, a wrapper for package mvpart, is now available on CRAN for OS X, Windows and Linux. To install it, proceed as for any CRAN package.

Original material

Updated material, August 2012, tested with R 2.15.1

Updated material - R 2.15.1

Updated material, February 2017, tested with R 3.3.2 and including changes in the installation scripts and data sets.

Updated material R 3.3.2

Springer web page of the book
Chinese edition, 2014 –


(Translation : J. Lai, Institute of Botany, Chinese Academy of Sciences.)

Second English edition, published 20 March 2018 (xv + 435 pages)

A second Chinese edition is in press (2020):

R的数値生态学

An edition in Japanese is also in preparation:

Rによる数値生態学
Users of numerical methods and graduate students often wonder where the basic ideas of the methods we are routinely using come from and how they were developed.

This section presents a selection of papers that have changed the way ecologists have analysed multivariate data during the past 50 years …

… and the teaching of numerical ecology to graduate students in universities.

The list presented here is by no means exhaustive.
The years 1960 and 1970

• Development of redundancy analysis (RDA): *principal components of instrumental variables*, Rao (1964); *redundancy analysis*, Wollenberg (1977)

• Principal coordinate analysis (Gower 1966)

• Alpha-beta-gamma diversity concepts: Whittaker (1972)

• Time-constrained clustering: Gordon & Birks (1972, 1974)
1980–1989

• Spatially-constrained clustering: Lefkovitch (1978); P. Legendre & V. Legendre (1984)

• Metric and Euclidean properties of dissimilarity coefficients: Gower & Legendre (1986)

• Canonical correspondence analysis (CCA): ter Braak (1986, 1987)

• First distributed version of Canoco, v.2.1, software for multivariate ordination: ter Braak (1988)

• Spatial analysis as a tool for community ecologists: Legendre & Fortin (1989)
1990–1999

• The method of variation partitioning: Borcard et al. (1992)
• Co-inertia analysis: Doledec & Chessel (1994)
• Indicator species analysis: Dufrêne & Legendre (1997)
• RLQ analysis, Dolédec et al. (1996)
• Fourth-corner analysis: Legendre et al. (1997), Dray & Legendre (2008), Dray et al. (2014)
• Distance-based RDA (dbRDA): Legendre & Anderson (1999)
2000–2009

• Transformations for community composition data used in PCA (tbPCA) and in RDA (tbRDA): Legendre & Gallagher (2001)

• Spatial eigenfunction analysis –
  ➢ Asymmetric eigenvector maps (AEM): Blanchet et al. (2008)

• Concordance analysis of species associations: Legendre (2005)

• The rationale for the estimation of beta diversity by $\text{Var}(Y)$: Legendre et al. (2005)

• Improving indicator species analysis: De Cáceres and Legendre (2009), De Cáceres et al. (2010)
2010–present

• Should the Mantel test be used in spatial analysis? Legendre & Fortin (2010), Legendre et al. (2015)

• Testing the space-time interaction in community surveys: Legendre, De Cáceres & Borcard (2010)

• Multiscale codependence analysis: Guénard et al. (2010); generalized to handle multivariate response data: Guénard & Legendre (2017)

• Test of significance of the canonical axes in RDA: Legendre, Oksanen & ter Braak (2011)

• Partitioning beta diversity: Legendre & De Cáceres (2013), Legendre (2014)

• Temporal and space-time analysis of beta diversity: Legendre & Gauthier (2014)

Numerical ecology is the result of many years of collaborative work with many dedicated researchers …
Numerical ecology has made great progress in the computer age thanks to the dedication of many developers of statistical packages, especially in the R language, who wrote software designed to analyze ecological data.

The R statistical language, created in 1990 by Ross Ihaka and Robert Gentleman at the University of Auckland, is an international project of scientific cooperation. It became freeware in 1995. The R software is distributed on the Comprehensive R Archive Network (CRAN) site. The first stable version (R 1.0) appeared on CRAN on 29 February 2000.
Among the ~12 000 R packages developed by scientists that are now available on CRAN, three are of particular importance for community ecology:


• **ade4** (D. Chessel and coauthors, University Lyon I; maintainer: S. Dray, University Lyon I. R package on CRAN in 2002.


Another important package for community ecology is described in the next few slides.
The SEDAR conference (2008)

On 26-28 May 2008, a workshop was held at Université Claude Bernard in Lyon, organised by Stéphane Dray –

to coordinate efforts among researchers developing the spatial analysis of ecological data and make plans for a new R software package.
Several participants were developers of R packages –
One of the results of this workshop is a new R package, adespatial, for spatial and time-series analysis of community data.

Under the direction of Stéphane Dray, adespatial appeared on CRAN on 06 June 2016.

New functions are still being added to this package.

In March 2018, the version of this package on CRAN is version 0.0-10.
9. Numerical ecology contributors network

The figure on the next slide describes the network of collaborators who produced the references in the 2012 edition of the *Numerical Ecology* book. Single-author references were excluded from the analysis.

The network was computed and kindly provided by Prof. V. Makarenkov, Département d’informatique, Université du Québec à Montréal, Canada.
Numerical ecology contributor network

Although the list of references at the end of a textbook is admittedly biased in favor of its authors, this network illustrates the fact that the development of data analysis methods for ecologists is the result of a broad and fruitful collaboration among many scientists.
Scientific research is efficient in universities because researchers can test their scientific developments in class with graduate students.

This interaction is the teaching–research binomial.
In the 1970’s, I had a researcher position in a research centre in environmental science at UQAM. I became Professor in Département de Physique at UQAM in 1980.

• NE course — First trial at UQAM in 1976: 12 hours + practical exercises in the course ENV 8020 “Modèles d’analyse de données écologiques” of a M.Sc. program in Environmental sciences.

• 1978: Full one-semester course at UQAM, PHY 8499 “Analyse quantitative des données écologiques”. I gave it from 1978 to 1980.

• In addition: 3 to 6 hours of lectures each year (1975, 1977, 1979) in BIO 61691 given by Louis Legendre at Université Laval.

I moved to Département de sciences biologiques, Université de Montréal, in September 1980, where I brought the teaching of Numerical ecology. The course was called Bio 6075z “Analyse quantitative des données biologiques” from 1982 to 1993, then Bio 6077 from 1995 to the present.
Teaching that course was a great incentive to develop clear explanations of the ecological and statistical concepts behind numerical ecology.

In that course, graduate students had/have to produce a research and data analysis report at the end of the course (term paper). Discussions with them sparked ideas about new methods and improvements to existing methods to answer the students’ ecological questions.

Some students developed new methods as part of their term papers and published their methods.

Most of the other students included the results of their term papers in their theses and published them in scientific papers.
11. Short courses around the world

81 short courses on Numerical ecology given in 19 countries, in 48 universities and research institutes around the world.

Australia and New Caledonia (6 courses)

- 1 course
- 2 courses
- > 2 courses
Europe
(26 courses)
Asia
(9 courses)

1 course
2 courses
> 2 courses
Canada and USA (26 courses)
America (North-Central-South) and the Caribbean (14 courses)
12. References


History of Numerical ecology


History of Numerical ecology


*History of Numerical ecology*


End of the presentation