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FROM ORDER TO CAUSES

A personal view, concerning the principles of syndynamics

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Honolulu – 2000
INTERNET EDITION

"… in nature there is no ending and no standing still, but only an ever coming and ever going."

Anton Kerner von Marilaun 1863

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L. Orlóci

April 2000, Honolulu

PREFACE

Science's approach to finding governing principles is remarkably standard: order observed, precise description made, causes sought. Newton's deterministic laws of motion came about this way, and so did the Darwin-Wallace theory of species evolution by means of natural selection, Mendel's statistical rule of particle-based inheritance, and the Kerner doctrine of community development by mechanisms for which the modern ecological term is "facilitation". [1]

The question to be put is not about the validity of the order-to-causes paradigm. It worked in the past, working now, and there is no reason to assume that it will not work for future scientific studies. [2] The

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[1] Sir Isaac Newton (1642-1727), Alfrad Russel Wallace (1823-1913), Charles Robert Darwin (1809-1882), Gregor Johann Mendel (1822-1884), Anton Kerner von Marilaun (1831-1898).

[2] An interesting parallel of this is seen in DNA research which reached the stage that biologists now can draw maps of DNA strands in the manner of a four letter nucleotide alphabet, ACGT. With precise description given, order can be sought in the human genome, and when found, questions can be asked that lead to understanding the gene, its nature, and broader connections.

central question is rather the identity of process characteristics about which a general theory of syndynamics[3] can grow.

How to go about with the identification of key process characteristics? The practical approach focuses on the process trajectory. Technically speaking, the structure involved is a map of the trajectory in phase space constructed from observational data. The data may come from direct measurement of community transitions on permanent plots, from counting pollen grains of different taxa in sediments of different ages, or from space-for-time substitution in surveys of transects that qualify as surrogate developmental (time) series.

The trajectory's map is examined with an eye for morphological regularities. The argument supporting this approach draws upon the fact that the trajectory mapping is symptomatic of the syndynamic response to factor influences, and indirectly, of the governing principles of syndynamics. Symptoms include the mode or level of linkage to

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[3] Pronounced sün-dí-nam'iks. Two things are implied: (a) the science whose objective is the study of community change, (b) change itself. The general principles of Syndynamics describe fundamental truths about the process. Neither phylogeny nor ontogeny is implied, only changes are meant of the compositional and structural type.

initial conditions, directedness and chaoticity in the transitions, attractor behaviour, periodicity, self-similarity, parallelism, and others.

The following sections emphasise both notion and the modus operandi. Case examples illustrate the theoretical points, and a voluminous bibliography rounds out the presentations.

1. TERMINOLOGY

1.1 The reader will find, hopefully, not overly annoying that in the text in the core context the term “syndynamics” replaces the common term “succession".[4] What necessitates the change is a basic dissatisfaction with the usual definitions in college texts and dictionaries. According to the electronic version of Webster’s New World Dictionary & Thesaurus (Macmillan 1977), succession is

> “the slow, regular sequence of changes in the regional development of communities of plants and associated animals, culminating in a climax characteristic of a specific geographical environment”.

The process perceived by Webster’s authors is in all likelihood a case of syndynamics that Kerner (1863) described and especially Clements (1916) articulated. Compositional transitions are implied under an exceptionally stable regional climate. To those observing syndynamics at this scale, action-reaction feedback comes into view as the dominant causal mechanism.

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[4] Reference is made to Anderson (1986) and Fekete (1985) for comprehensive reviews and references, regarding the concept and uses of "succession".

1.2 Webster's succession concept has only limited utility by being limited to a special case of syndynamics. A more useful definition must be broad, unconstrained by process speed, regularity, climax properties, or area extent. Syndynamics is understood exactly in this broad sense.

1.3 Two other terms to be clarified are “order” and “regularity.” Since colloquial speech uses these terms interchangeably, it should be well-advised to clarify their meanings:

> a) "Order" implies things having an ordered arrangement as opposed to having a haphazard arrangement. Statements in a usable computer program are ordered by the logic of the tasks to be performed. Successive states in the syndynamic process have unique order, where at least one of the non-trivial parameters is on an increasing or a declining trend. The order of the A C G T nucleotides in the DNA strand make the individual genes unique.
>
> b) While "order" emphasises unique arrangements, "regularity" conveys a sense of consistency, uniformity, or habit of behaviour. Order and the lack of order both may be regularly or irregularly appering events.

2. CAUSES AND CAUSAL THEORIES

2.1 Anything existing has a cause, but neither its exact nature nor its exact mechanism need be simply obvious. The orbital motions of the planets are example. Ages of observation from the ancients to the Moors (8th to 15th centuries), Copernicus (1473-1543), Brahe (1546-1601) and Galileo (1564-1642) preceded Kepler's (1571-1630) precise description of the planetary orbits, and Newton's discovery of the principle cause, gravity.

2.2 Focusing on the precise description of order first and then searching for causes constitute the methodology that produced the great biological theories of the 19th Century. These theories were the culmination of scientific inquiries that began early in the 18th Century at about the time when Newton's work was ending and Linné's (1707-1778) just beginning.

2.3 After Newton, the mathematical sciences entered a dormant period and biology came into the forefront. New orders were discovered and propositions of their causes followed. Botany was leading the way with synergistic expansions of knowledge in two main directions: the taxonomic and the plant geographic. While the taxonomic line embraced the revolutionary idea that organisms can be usefully arranged into categories based on shared developmental characteristics. the plant geographic line adapted a definite ecological slant.

The notion of plant classification was familiar already to the ancients, but the groupings were purely arbitrary. Classification criteria started to be scientific when the emphasis shifted to natural groupings. This development is seen in Linné's "Systema Naturae" (1735) and "Species Plantarum" (1753), and in Jussieu's "Genera Plantarum" (1789).. The "natural taxonomy" evolved further in de Candolle's "Prodromus" (1824 -73), Bentham and Hooker's "Genera Plantarum" (1862-1863), and in Engler's "Syllabus der Pflanzenfamilien" (1892) which increasingly relied on arrangement of taxa along developmental lines.

Works highlighting the plant geographic line includes the "Essaie sur la Géographie des Plantes" of Humboldt and Bonplan (1805), Willdenow's "Grundriss der Kräuterkunde zu Vorlesungen Entworfen" (1810), and Barton's "The Geography of Plants" (1827).[5]

2.4 The population and community ecology of an entire region has received modern scientific level treatment first time in Kerner's "Das Pflanzenleben der Donauländer", published in 1863. This work is best known for putting forward the doctrine of community development.[6]

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[5] More details in Polunin (1960).

[6] Kerner keenly observes Nature and deduces from the observation of coincidences a linkage of special pattern to time. This leads him to the doctrine of community development.. Conard (1951). characterises Kerner's work as "… the immediate and direct parent of all later works on [dynamic] plant Ecology.". Considering that Conard was writing this around 1950, he must have had in mind the direct flow of ideas from Kerner to his contemporaries through benchmark work by Hult (1881), Warming (1895), Cowles (1899), Clements (1916,1936), Cajander (1926), Braun-Blanquet (1927), Phillips (1935), Tansley (1946), and possibly many others.

The central core in the Kerner doctrine is the recognition that plant communities are developmentally linked in time. The linking mechanism, as Kerner saw it, is the tendency of populations already present in the community to prepare the site for populations arriving from outside.[7] The modern term for this tendency is "facilitation" or "action-reaction feed back". Community development was described by others as "succession".[8]

2.5 While Kerner's doctrine is the first scientific theory regarding community dynamics, the Darwin-Wallace theory of evolution by the use of natural selection is the first theory to unify biological thinking about populations. The idea is expounded in Darwin's book: "On the Origin of Species by Means of Natural Selection", published in 1859.[9]

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[7] Development of thought from Alexander von Humboldt (1769-1859) to Kerner's thinking is obvious. But as Sukopp (1987) remarks, Humboldt's views are "more aesthetic than scientific".

[8] H.S. Conard translation pointedly avoids calling the developmental process "succession", a term on which Hult (1881) appears to have priority (see Clements 1936).. But whether it was Hult, or Thoreau in 1863 (see Anderson 1986) is really immaterial. Kerner has formulated a comprehensive theory in which, as Conard puts it, paraphrased, all the fertile ideas which have since been developed in ecology are present in embryonic form. (See also footnote 4.)

[9] The idea of evolution was not new by any stretch of imagination to the times of Wallace or Darwin. Other scientific theories already existed about species evolution. Buffon (1707-1788) and Lamarck (744-1829) should be mentioned. Substantial oppositions voiced has been voiced against the Darwin-Wallace theory since it formulation, particularly against the idea of slow, gradual evolution. Kozo-Polyanskiy (1937) argues, for example, that without moments of explosive evolution the increase in the number of species at the rate as it actually happened in the angiosperms during the Cretaceous

After Darwin, the morphological similarities in species could no longer be viewed in the static terms of taxonomies past, but rather taxonomies had to be formulated in terms of groupings that express common ancestry.

Interesting to mention that both the doctrine of community development by facilitation and the theory of evolution by use of natural selection springs from observations of biological diversity in relation to environmental diversity. But in sharp contrast, while Darwin's book became bible in schools of biology, Kerner's doctrine – the root of the holistic ecosystem view, a high level notion very much at the core of ecological thinking -- was largely ignored.

2.6 The approximate 3:1 ratio that turned up in Mendel's notes of his pea plant experiments, was probably the first probabilistic law discovered about inheritance. A far-reaching consequence of the 3:1 ratio for science at large is the message that there are laws that are statistical, true in the long run, but not in all cases.

It should be mentioned that at about the time when Mendel was doing work with his pea plants, Galton (1822-1911) and Pearson (1857-1936) were developing new ways to manage chance-related errors in the analysis of biological data. But beyond the statistical connection, Mendel's main significance is in the seminal nature of his work. A relatively short one and a quarter century later – short when compared to the time elapsed in astronomy before an explanation emerged for planetary motion -- genetics managed to assemble sufficient knowledge to map the human DNA.. The order revealed in the structure of the DNA has, in all consequences towards cracking the genetic code, a level of significance comparable to Kepler's mathematical map of planetary motion that lead to Newton's explanation of why do the planets do not fly off their orbits.

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would not have been possible. Hitching (1982) makes the points that Darwinism has been tested and failed on several counts: (i) gaps in the fossil record suggest evolutionary leaps; (ii) genes are stabilizing mechanisms and tend to minimise the chances of new forms; (iii) random mutation, occurring at the molecular level, cannot account for the explosive increases in the diversity and organisation of life.

2.7 The proposition that society's class order is symptomatic of the state reached in social evolution -- having to do with the means of production, the ownership of the production tools, and the frictions that the class order generates in society -- have found most complete exposition in the works of two Germans political philosopher, Karl Marx (1818-1883) and Friedrich Engels (1820-1895). They theorised that evolution inevitably leads to a more just and more equitable social order than the one they saw existing in contemporary Europe. They also argued that the process toward this supreme social order can be hastened by revolution. Their call to arms went out in "Das Manifest der Kommunistischen Partei" in 1848. The first sentence of the Manifest: "Eine Gespenst geht um Europa”[10] conveys even to the present reader a feeling of the heavy, explosive social atmosphere that existed in contemporary Europe. Interestingly, the Manifest had nothing to do with the revolutions that swept Europe in 1848, but it had very much to do with 20th Century social dynamics all over the world, so much so that by the 1950's more than 50% of the world population was ruled by Marxist regimes. What Marx and Engels could not possibly foresee were the many opportunities for their theory to be misused to support imperialistic objectives and other forms of suppression. The new turning point in the Marxist saga came in 1989 with the people’s demolition of the Berlin wall that a Marxist regime built around itself. Marxist regimes failed en mass economically and imploded politically, opening the prospects of freedom and independence to the peoples of many countries in Europe and elsewhere.

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[10] "A specter is haunting Europe.”

3. THE EVIDENCE

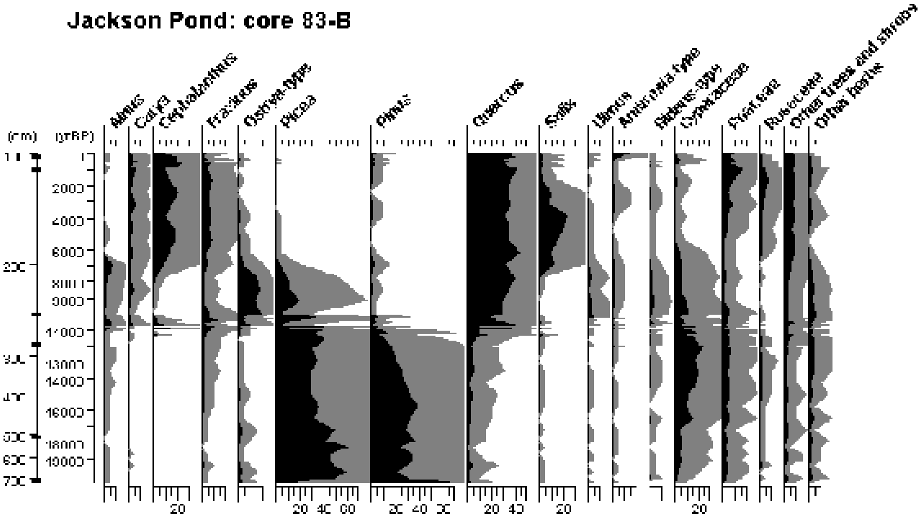
3.1 It is intuitive that the fact of syndynamics, the process, cannot be reasoned out from first principles any better than the fact of fluid turbulence can be from the first principles of physics. The evidence has to come from observation, direct or indirect. These involve in the case of Syndynamics, the science, permanent plot experiments, paleopollen and tissue analyses, and surveys of surrogate time series.

a) The data set in Table 1 is typical for direct observation of the process.

Table 1. The de Smidt data from Atlantic Heathland (after Lippe et al. 1985). A data in the form of point-cover estimates are given. Legend of symbols: BG - bare ground; EN - Empetrum nigrum; CV - Calluna vulgaris; ET - Erica tetralix; MC - Molinia caerula; RA - Rumex acetosella; JS - Juncus squarrosus; CP - Carex pilulifera; OS - other species.

Year	BG	EN	CV	ET	MC	CP	JS	RA	OS
1963	57.1	17.9	8.60	11.6	0.0	0.2	0.0	4.7	0.0
1964	44.0	25.0	13.7	12.2	0.0	1.1	0.2	3.9	0.0
1965	32.7	34.9	13.9	14.3	0.0	0.5	0.0	3.7	0.0
1966	27.5	36.8	20.0	14.1	0.1	0.9	0.2	0.3	0.1
1967	19.7	46.1	21.0	10.8	0.1	0.7	0.4	0.5	0.7
1968	10.7	54.2	22.2	10.6	0.7	0.6	0.4	0.0	0.5
1969	6.70	55.7	23.3	10.4	0.3	2.0	0.7	0.1	0.7
1970	5.80	61.1	23.7	6.90	0.2	1.2	0.7	0.2	0.3
1971	9.50	57.6	24.7	6.60	0.4	0.6	0.4	0.0	0.3
1972	8.40	62.1	23.7	3.60	0.3	1.2	0.1	0.0	0.6
1973	4.40	67.9	21.3	3.30	0.2	0.6	0.4	0.0	2.0
1974	8.50	58.1	25.8	4.70	0.6	1.3	0.7	0.0	0.4
1975	9.20	62.2	24.3	2.50	0.6	0.9	0.2	0.0	0.1
1976	9.90	58.2	24.9	3.70	0.6	1.1	0.7	0.0	1.0
1977	19.6	48.4	23.5	5.70	0.3	1.2	0.4	0.1	0.9
1978	12.1	58.1	22.7	4.80	0.4	0.4	0.0	0.2	1.3
1979	9.30	65.1	20.3	2.70	0.0	1.5	0.1	0.2	0.9
1980	7.30	68.2	21.5	1.20	0.5	1.0	0.1	0.1	0.2
1981	5.40	65.5	20.8	4.60	1.0	1.6	0.4	0.3	0.6

b) Dated paleopollen and plant tissue data, such as the set from which Figure 1 is constructed, are the only source for reliable information about long-term syndynamics.



Site Name:	**Jackson Pond: core 83-B**
Contact:	**Wilkins, G.R.**
Place:	**USA: Kentucky**
Lat/Lon.	**37.5N / 85.7W**
Altitude (m):	**212**
Samples/Variables/Dates:	**58 / 115 / 6**
Age Range:	**-25.35-20462.31**

☑ 5X Exageration

Primary Scale Age

Fig 1. The Jackson Pond pollen diagram copied from internet site

http://www.ngdc.noaa.gov/cgi-bin/paleo/ftpsearch.cgi

Dark shaded area in pollen diagram: original scale. Light shaded area: magnitude exaggeration 5x.

Delcourt and Delcourt (1987) discuss the use of pollen spectra in paleoecology. He (1999) describes techniques and enumerates problematic aspects. Györffy and Zólyomi (1996) offer useful comments on the consequences of sediment disturbance in the interpretation of human historical events.

The mixing of taxonomic levels is typical in paleopollen data. This is an unavoidable anomaly in paleopollen sampling and identification. Orlóci and Orlóci (1985), Orlóci and Stoffella (1986), Pillar and Orlóci (1991), and Pillar (1999) discuss solutions to a taxonomic problem in a different paradigm class, but in contexts relevant under the general circumstances of Paleoecology. Libby (1955), Lowe and Walker (1984, Sec. 4.2.5), and Lowe (1997) are recommended texts regarding aspects of sediment core dating, sampling, pollen calibration, and other related techniques.

Remarkably, Kerner (1863) mentions the utility of old sediments as sources of evidence for successive changes in the community. Kerner makes reference in this regard (Chapter 9 in Conard 1951) to a Professor B. Cotta of Freiberg and the animal remains that Cotta discovered in deep "lösz" on the Hungarian lowlands. But the earliest use of paleopollen spectra to reconstruct paleocommunities is linked to names like Anderson (1896), Lagerheim (1902), and Post (1916). The time component in the reconstruction was not accurate beyond what could be expected from sediment depth-to-time substitutions. In fact, sediment dating did not have a direct method until the advent of isotope analysis.[11]

c) Surrogate time series were the main traditional way of syndynamic studies to capture the time dimension. In these, time past is an ordinal quantity linked to assumptions about the conditions at points in the site of the community. Kerner's (1863) study of vegetation distribution on an alluvial fen at Achen Lake in Tirol is an example. Kerner links space (the ground pattern of communities) to time (sediment age) and discovers composition-based developmental connections.[12]

3.2 The records in Table 1 and the spectrum in Figure 1 are readily interpreted in terms of different taxa entering the community or dropping out, or changing their pollen densities as time passes. The graphs of Figure 2 present another way of displaying the changes in relative terms. In this, pollen densities are expressed as deviations from

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[11] See the ^{14}C dating technique of Libby 1955, for example.

[12] Wildi and Schütz (2000) describes a case of space-for-time substitution in which fractional time series from permanent plots in a region are spliced into a single chain thereby creating a surrogate time series, a "prediction" of syndynamics, as it were, in the time perspective of centuries. The permanence of the same kind of climate is assumed.

random expectation. A practical definition of random expectation is given by the fraction ,

$$Q_{ij} = \frac{X_{i.}X_{.j}}{X_{..}}$$

This is a familiar expression from contingency table analysis. Q_{ij} is the pollen density expected if the process in which it is an outcome were ruled entirely by chance. The X symbol represents a row total ($X_{i.}$), a column total ($X_{.j}$), and grand total ($X_{..}$). The rows correspond to taxa and the columns to relevés. The number of taxa is p and the number of relevés is q.

Contingency table analysis and the construction of deviation graphs are explained elsewhere in detail (Orlóci 1991, He and Orlóci 1998).[13] Here it will be sufficient to note that in the analysis, the total chi-squared is partitioned into additive components. Based on these, there will be as many component p x q tables of deviations, and sets of deviation graphs, as there are independent chi-squared components.

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[13] The task is automatic in application program CONAR8.EXE. See the appendix for details.

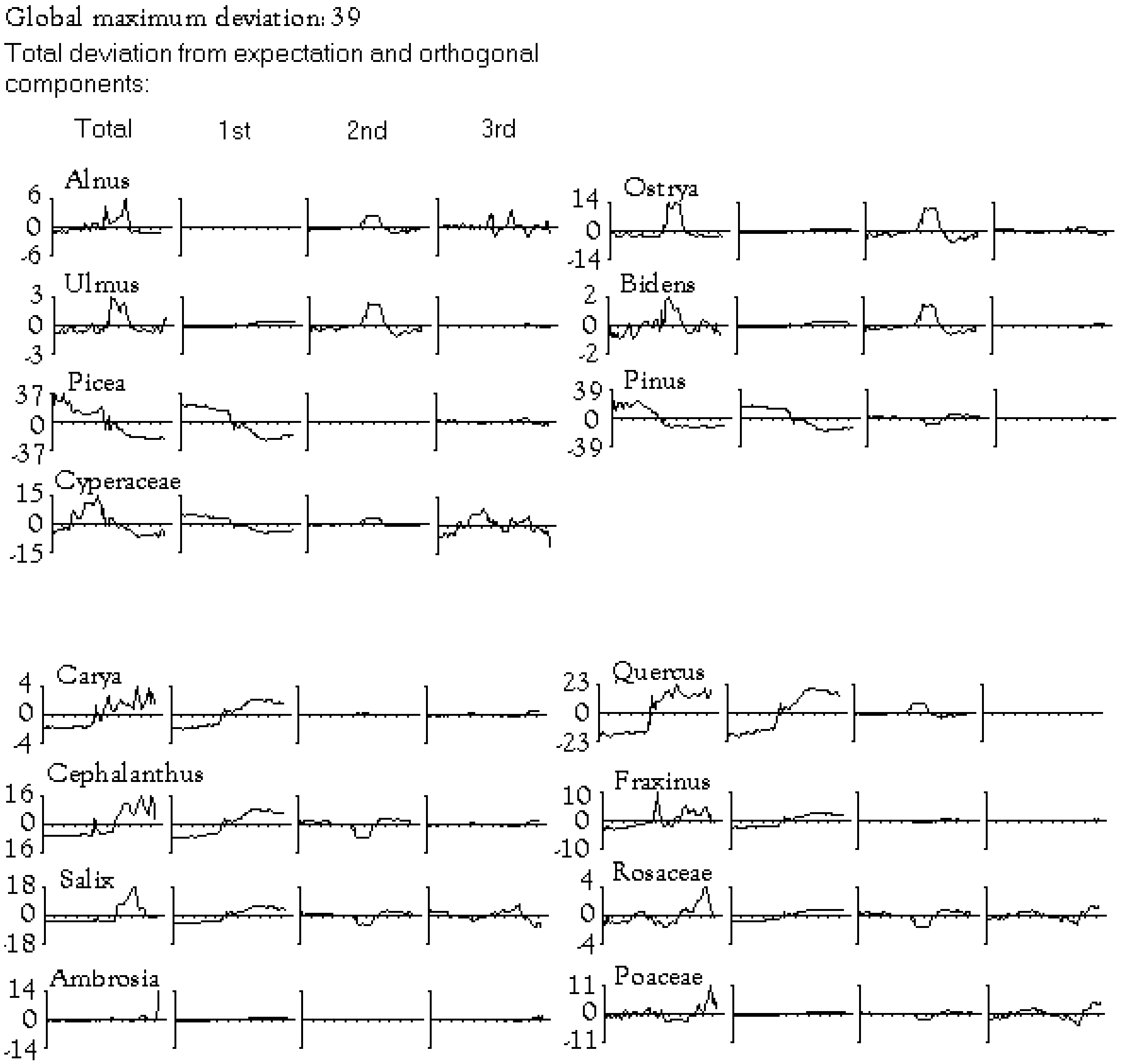

Figure 2. Graphical representation of taxa from the Jackson Pond sample, based on the deviation of their observed pollen densities from random expectation (explained in the text). The data source is the same as in Figure 1. Horizontal scale represents elapsed time. Tick marks on the horizontal axes are set at 2000-years steps. The scale starts at 20,600 years before present. The number of time steps in the plot is 103. This number has come about by linear interpolation of 58 observed points (plaeorelevés) . The graphs are grouped in sets. The first graph in any set displays the evolution of a taxon's total deviation from random expectation. The other graphs in the set display canonical partitions of the total chi squared, ordered according to the size of the corresponding global canonical correlation. The maximum deviation in the figure is the maximum observed value in the set (taxon Pinus). See Orlóci (1991) for technical details of partitioning.

The deviation graphs in Figure 2 identify Picea, Pinus (on the decreasing trend), Quercus (on the increasing trend), and Ostrya (with maximum at midrange) as leading taxa in their groups. The zero base line in the graph corresponds to random expectation. Further to be noted is that a zero score in the raw data can appear as a nonzero deviation.

Ascending and descending trends are clear in the first partition (second graph in any set of Figure 2). In the second partition, unimodal trends are frequent. Trended component of variation largely depleted by the first two partitions, only random oscillations remain to be portrayed by the third and subsequent partitions. The partition statistics are as follows:

	Canonical correlation	Chi-squared value	Cumulative % of Chi-squared accounted for	Total chi-squared	Degrees of freedom	Rank
#1:	0.7582	5920.58	65	9131	1632	16
2:	0.2236	514.92	87			
4:	0.1963	397.00	92			
5:	0.1427	209.66	94			
6:	0.1373	194.18	96			
…	…	…				
16:	0.0219	4.93	100			

Although the rank of the product matrix is 16, all but traces of the total chi-squared are accounted for by the first 4 partitions.

4. PHASE SPACE

4.1 The common geometric notion of Cartesian reference space is applicable. It has remarkable simplicity, and a great advantage in that its linear nature will make non-linear structures appear as curved objects. Figure 3 illustrates this well.

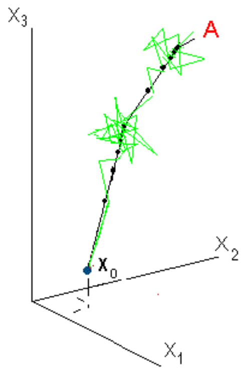

Figure 3. Taxon-based reference system (X_1, X_2, X_3) and the time axes (X_o to A). The co-ordinates are quantities of taxa in the community. The sampling units (community states, paleorelevés) appear as trajectory points.[14]

Two fictitious process trajectories are displayed in Figure 3. One is Markov (line with dots) and the other (zigzag line) corresponding to the raw data. $\boldsymbol{X}_o = (X_{o1}\ \ X_{o2}\ \ X_{o3})$, the null state, is the point at which the

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[14] A reference space need not be based on taxa as dimensions. Bartha, Cárán and Podani (1998), for example, used Juhász-Nagy's information theoretical coenostate descriptors as reference axes. Wildi (1998) used local maps of species and vegetation types as points.

observational time begins. Every trajectory point is in the past except the attractor "A" that keeps receding into the future. Present does not exist.

Under realistic circumstances the number of taxa is expected to be much greater than 3 and in reality there are as many different null vegetation states as there are different sites. The points on the trajectory line are the tips of the paleorelevé vectors with origin at the zero point of the reference system. When paleorelevés are taken at equal time intervals, the point distances on the trajectory line in the mappings are proportional to process velocity in the intervals.

A unique thing about Figure 3 is the inclusion of the time dimension. This is marked by the trajectory line that emerges from $\boldsymbol{X}_O$.

4.2 One of the trajectories given in Figure 3 is assumed to be a Markov chain mapping. Feller (1957) is the premier reference on Markov chains for the statistically minded ecologist.

Wagonner and Stephens (1970), Horn (1981), Usher (1981), Lippe et al. (1985), van Hulst (1992), Horváth and Csontos (1992), Wagner and Wildi (1997), Balzter (2000) and Wootton (2001) present examples of ecological application. Orlóci, Anand, and He (1993) describe a solution to the problem of determining transition probabilities in the case of survey type vegetation data. The method relies on the gains and losses of taxa in the site, measured in steps and averaged. It is important to remember that the fitted Markov chain is a postdiction and it does not guarantee the reliability of a Markov prediction. It should help remembering also that the stationary Markov chain, a time series of community states, requires two things to be completely defined:

a) Community composition at initial state described in quantitative terms, i.e., relevé $\boldsymbol{X_o}$.

b) Set of transition probabilities, i.e., matrix $\boldsymbol{P}$**.**

As regards the frequently asked question, whether or not the Markov chain has memory, the answer is yes for path and no for attractor. This is to be understood in the sense that the attractor exist irrespective of the initial condition. That is, different initial conditions define a new trajectory path, but any initial condition will lead to the same attractor, provided that $\boldsymbol{P}$ stays unchanged. But a constant ***, i.e.*** **a perfectly** constant attractor, is an impossible state of existence in the trajectories world.

It is imperative in Markov manipulations that the relevés are taken at equal time intervals. Furthermore, the time step should be narrow and the period length (the elapsed time from $\boldsymbol{X_o}$) should be long. Regarding the elements of $\boldsymbol{P}$, the element where row h and column i intersect is the probability of a given taxon h (row entity) being replaced in the next time step by another taxon i (column entity). The sum of the probabilities in any row of $\boldsymbol{P}$ is unity. The sum of elements of any column need not be unity.

Based on $\boldsymbol{X_o}$ and $\boldsymbol{P}$, Markov relevés can be computed simply by recursively applying the equation,

$$\boldsymbol{X_{t+1}} = \boldsymbol{X_t}\,\boldsymbol{P}$$

such that $t=0, 1, 2, 3, \ldots$ up to $\boldsymbol{X_{t+1}} \cong \boldsymbol{X_t} = \boldsymbol{X}$. The chain has perfect regularity and it converges on the point attractor $\boldsymbol{X}$. Another property, typical for stationary Markov chains ($\boldsymbol{P}$ remaining constant), is this: any state $\boldsymbol{X_t}$ is somewhat more distant from the previous state $\boldsymbol{X_{t-1}}$ than it is from the next state forward $\boldsymbol{X_{t+1}}$. This property is obvious from inspection of Figure 3 (see also Orlóci and Orlóci 1988, Orlóci, Anand and He 1993). Another property is the processes memory for the past: $\boldsymbol{X_t} = \boldsymbol{X_{t+1}}\,\boldsymbol{P^{-1}}$**.** In theory this allows exact backtracking. But backtracking is an obvious impossibility in either computation, because of random rounding errors, or in nature, because the natural process never produces carbon copies.

4.3 The described cases of Markovity involve discrete states. But in nature, the syndynamic process is continuous. The use of a discrete Markov chain is practical necessity for the simple reason that only discrete states can be described in an ecological survey. When $\boldsymbol{X_t}$ is a paleorelevé, the series $\boldsymbol{X_0}$, $\boldsymbol{X_1}$, $\boldsymbol{X_2}$, … defines the sample process trajectory.

4.4 The trajectory mappings in Figure 3 invoke a notion from ballistics. The projectile is a community's state, moving through time in the direction of a target A. The conditions that set bounds on the target constitute the "attractor" or "attractor conditions". It should be useful to keep the following points uppermost in mind about attractors:

a) Generally speaking, the attractor can be a fixed point. This is the point where a pendulum comes to rest, if its motion is unperturbed, or as a matter of fact, the point at which Markov chain comes to rest if ***P*** remains constant. The position-by-velocity trajectory of the pendulum is a decaying spiral. The phase space mapping of a Markov trajectory is like the straight segments of the less convoluted trend line in Figure 3. There is a crowding of states as the attractor is approached. The Markov attractor may, of course, oscillate or even move into new regions of phase space under general change of conditions that bring on changes in ***P***. Where this happens the Markov chain becomes a “moving” Markov chain. This is illustrated in Figure 3 where the straight line brakes off and a new process line begins.

b) A stable ***P*** is unnatural. When its elements vary under random effects, the attractor broadens into an entire region in phase space around A, the most likely target. It is noted that random perturbations will blur both the appearance of state-crowding and process-directedness. Random perturbation will sharpen the appearance of a phase structure, fast moving linear at the beginning and chaotic later as the process slows approaching A.

An attractor responding to deterministic and random influences is a "strange attractor" (Lorenz 1963). Vegetation attractor movement is predictable only to the extent of delineation of its broad ballistic limits. This is so because ecological laws narrow the possible effect of random transitions.

Table 2. Data sources. Latitude and longitude figures are rounded to degrees.

Location	Latitude	Longitude	Period length (years)	Contact person
Jackson Pond, Kentucky, U.S.A.	37^{o} N	85^{o} W	20.5 K	G.R. Wilkins
Lagoa das Patas, Amazonas	0^{o} N	67^{o} W	42.2 K	P.E. De Oliviera
Atlantic Heathland, Holland	52^{o} N	6^{o} E	19	Lippe et al. 1985

4.4 The left-hand graph in Figure 4A portrays the Markov chain fitted to real data.[15] The null state is the 1963 relevé, $\boldsymbol{X}_O = (57.1\ \ 17.9\ \ 8.6\ \ 11.6\ \ 0.0\ \ 0.2\ \ 0.0\ \ 4.7\ \ 0.0)$. The transition probabilities given below reflect gains and losses through time

.76480	.13945	.05628	.02656	.00116	.00455	.00148	.00339	.00234
.01323	.95375	.01660	.00688	.00154	.00344	.00143	.00045	.00268
.01304	.05180	.92028	.00606	.00134	.00325	.00130	.00044	.00250
.01924	.11058	.04133	.81922	.00128	.00413	.00146	.00060	.00217
.02685	.12406	.04602	.01709	.77525	.00476	.00188	.00063	.00345

---

[15] Transition probabilities and Markov scores are generated in FITMARKO.EXE. Program PCAR8.exe supply co-ordinates for Eigenprojections, Stereor8.exe draws stereograms, and Plotr8.exe draws scattergrams. See the Appendix for details.

.03093	.13603	.05083	.01703	.00158	.75754	.00172	.00149	.00284
.04221	.15201	.06296	.01743	.00191	.00460	.71411	.00139	.00338
.09055	.17091	.07742	.04942	.00067	.00549	.00139	.60338	.00077
.02908	.18118	.06217	.01409	.00186	.00509	.00235	.00054	.70364

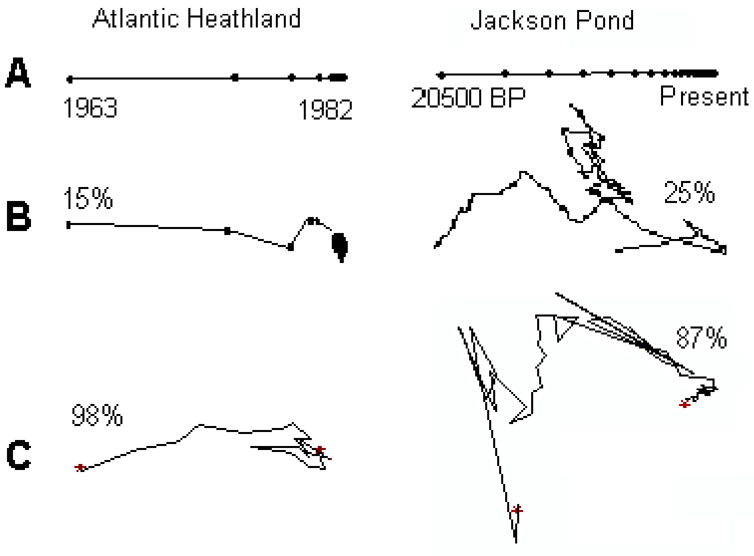


Figure 4. Eigenprojections of process trajectories as identified. The graphs in row C are mappings of the natural trajectories. The 2-dimensional mappings recovers 98% and 87% of the original distance configuration The graphs in row A correspond to the fitted Markov chain. The graphs in row B, adapted from Anand (1997) with revisions, illustrate the effects of 15% and 25% random perturbation. The perturbation is applied to transition probabilities. The Atlantic Heathland graphs use data from Table 1. The Jackson Pond graphs use the same data as Figure 1. Table 2 contains site information.

General sample information and the pollen frequencies are downloaded from internet address, http://www.ngdc.noaa.gov/cgi-bin/paleo/ftpsearch.cgi , at time of last use in this example:

```
# 08 Dec 96
# Raw Counts - All Pollen Types
# Site name:  Jackson Pond
# Place:    USA: Kentucky
# Latitude:   37.27.00N  (  37.45  )
# Longitude:  85.43.00W  ( -85.716667)
# Elevation(m): 212
# Sigle:    JACKSON
# Entity name:  core 83-B
# Contact person: Wilkins, G.R.
# Radiocarbon dates:
# Depth Thk Age  SDup  SDlo  Lab no. Basis  Material
```

```
# 133.0  10 120  50  50  A-3870 U  fibrous peat
# 160.5  11 940  80  80  A-3871 U  organic silty clay
# 220.5  11 10040 190 190  A-3872 U  organic silty clay
# 270.0  14 11860 250 250  A-3873 U  organic silty clay
# 510.0  10 17750 270 270  A-3874 U  silty clay
# 705.0  10 20330 630 630  A-3875 U  silty clay
# Chron name:   Wilkins et al. 1991
# Age model:  linear interpolation
# Chron notes:  Ages extrapolated beyond last C-14 date based
                on deposition time between last two C14 dates.
# Age basis:
# Depth Thk   Age  AgeUp  AgeLo  RCode
#  93.0   0   -33  -33  -33 TOP
# 133.0  10   120  170   70 C14
# 160.5  11   940 1020  860 C14
# 220.5  11 10040  10230 9850 C14
# 270.0  14 11860  12110  11610 C14
# 510.0  10 17750  18020  17480 C14
# 705.0  10 20330  20960  19700 C14
# Publications:
Wilkins, G.R., P.A. Delcourt, H.R. Delcourt, F.W. Harrison, and M.R. Turner. 1991. Paleoecology of
    central Kentucky since the last glacial maximum. Quaternary Research 36:224-239.
Wilkins, G.R. 1985. Late-quaternary vegetational history at Jackson Pond, Larue County, Kentucky.
    Thesis. The University of Tennessee, Knoxville, Tennessee, USA.
# GPD ASCII Format
# 11 Dec 96
# Percentages for the top 15 pollen types
# Site name:    Jackson Pond
# Place:      USA:Kentucky
# Latitude:     37.27.00N  (  37.45  )
# Longitude:    85.43.00W  ( -85.716667)
# Elevation(m):   212
# Sigle:      JACKSON
# Entity name:    core 83-B
# Contact person:   Wilkins, G.R.
# Chron name:     Wilkins et al. 1991
# Reliable age bounds:  -25.3500003814 - 20462.30859375
 17 58
  1 Aln  A Alnus
  2 Car  A Carya
  3 Cep  A Cephalanthus
  4 Fra  A Fraxinus
  5 Ost-t  A Ostrya-type
  6 Pic  A Picea
  7 Pin  A Pinus
  8 Que  A Quercus
  9 Slx  A Salix
 10 Ulm  A Ulmus
 11 Amb-t  B Ambrosia-type
```

```
 12 Bid-t  B Bidens-type
 13 Cypae  B Cyperaceae
 14 Poaae  B Poaceae
 15 Rosae  B Rosaceae
 16 Other trees and shrubs
 17 Other herbs
95, , -25
           .57  4.35  8.51  3.03  1.89   .19  4.64 32.73  2.08  .76 18.35   .95  2.65  7.76   .38  8.70  2.46
100, , -6
…
```

See the source file for complete record.

5. SCALE AND PERCEPTION

5.1 The observer's scale is defined when process period length and time step width are chosen, variables selected, or other decisions made that can influence perception. Only in possession of detailed information about the scale can the process trajectory be meaningfully interpreted. Scale effect overlooked, frivolous arguments will likely follow, shadow boxing as it were, such as in the notorious climax-hypothesis controversy about which a good part of North American ecological discourse revolved in the first half of the 20th Century. [16]

5.2 Historically, ecology has focused attention on syndynamics at three levels of the spatial and temporal scale hierarchy. These levels are identifiable by the processes that dominate the observer's view:

a) Dominance sorting. This appears most clearly at the site (stand, patch, gap) level and at short period length, easily linked to population level processes, such as tolerance and inhibition (Connell and Slatyer 1977),

---

[16] The importance of scale in understanding ecological phenomena is now broadly accepted, none the least as a result of Greg-Smith's (1961, 1983) work emphasising the multi-scale nature of community patterns and environmental factors, and the scale imposed limits of their perception..

life history type (Grime 1979), cohort senescence (Mueller-Dombois 1992), reproductive strategies (Harper 1977), and propagule bank composition (Egler 1954). Permanent plot studies supplied the evidence.

b) Facilitation or action/reaction feedback. The facilitation effect comes into view most clearly at an intermediate period length under a reasonably “stable” regional climate.

Quantitative records about compositional changes forced by facilitation are hard to find, although anecdotal evidence abound. The story of conifer monoculture cultivated on siliceous sand in sites previously covered by mixed deciduous forest in cool temperate climate, causing ortstein development within one or two rotations and in turn, inviting a new set of species to invade the site, comes to mind. One of the problems with finding hard evidence of facilitation in progress is that permanent plot records rarely go back far enough to allow facilitation to show itself. The other reason has to do with the nature of paleopollen records. Although, the sediments have manifestations of facilitation in progress, time step width in the records is usually too broad to allow a clear isolation of the it.

c) Precession dynamics or secular succession. This process dominates the observer's view at the power of resolution like in the usual kind of paleopollen records (Delcourt and Delcourt 1987) where the time step is very wide and period length is spanning significant shifts in the global climate. Broad vegetation shifts are seen clearly. Delcourt and Delcourt (1987) present a map of syndynamics from eastern North America at this resolution, redrawn in Figure 5.

Some described the broad shifts as "secular succession". The term "precession dynamics" could be better for good reasons. Consider the Milankovitch (1941) cycles in the orbital movements of the Earth and recall that one of these has to do with the “precession of the equinoxes.” The precession cycle has period length of about 22,000 years and is demonstrably inducing major climatic shifts on the Earth's surface. It makes good sense to take cue from Milankovitch and use "precession dynamics" for the case of broad, climate-related, non-feedback type vegetation shifts. To use the adjective "secular" for this type of dynamics, a term implying a thing to most users that has nothing to do with vegetation, is definitely forced.

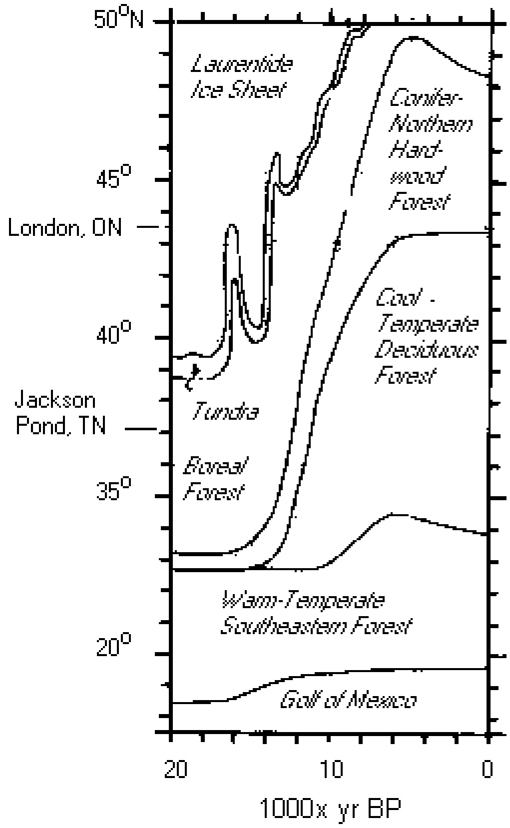


Figure 5. Vegetation shifts over 20,000 years in Eastern North America within a belt along roughly longitude 85° W. Graph outline scanned from Delcourt and Delcourt (1987, Figure 1.4). Vertical scale: northern latitudes. Horizontal scale: thousand years before present. See discussion in original publication and remarks in the present text.

5.3 Syndynamics should be observable in the pollen spectrum as far as compositional changes are concerned, even at short time periods. But the recording technique have to detailed beyond what practical

considerations allow. Time and expenses are saved when the time step is broad and irregular.

5.4 It should be mentioned, at the cost of being repetitious in stating the obvious, that syndynamics is a unified process. The isolation of dominance sorting, facilitation, and precession dynamics as process components is an entirely arbitrary analytical manoeuvre. Yet, the analytical partitioning of the process into component is useful. The fact of the matter is that partitioning is the only practical way to construct a reasonably accurate quantitative picture of the process and to isolate the causes.

6. TRAJECTORY MORPHOLOGY

6.1 The trajectory can follow any regular or irregular path (Figures 3, 4). It is intuitive to assign significance to the turns and twists as manifestations of compositional changes in the community. The change is dramatic when the turns are at sharp angles and when the line segments per unit time are long.

6.2 Examination of the Atlantic Heathland trajectory (Figure 3C, left) reveals several interesting characteristics of the process. Although the chances for random innovations must be simply enormous at the change of environmental regimes after heavy grazing and fire, the process is obviously neither globally aimless nor entirely deterministic. In fact, a two-phase structure exists. Linear determinism dominates the first rapidly moving phase, up to around year 7, and chaotic oscillations thereafter, as if the process would have arrived at an equilibrium state, where it would remain until the attractor conditions change.

6.3 Interpretation of the Jackson Pond trajectory (Figure 3C, right) should take into account the fact that the sample involves 17 taxa which the author of the data set selected (see Section 4.4). The trajectory mapping traces events that come through in the changes of the 17 taxa. It should also be mentioned that the paleorelevés were taken at different time intervals. The interpolation to fill in the gaps, and dimension reduction that occurred in Eigenanalysis (see the explanations below) will likely affect the interpretations.

Eigenanalysis is the algebraic core of Principal Components Analysis (Hotelling 1933). Goodall (1954) called the technique as “ordination” first and other's followed. Ordinations arrange objects on axes as points based on their resemblances. There are two basic transformations in most ordination techniques: raw data to resemblance values and resemblance values to new co-ordinates.

Given p variables and n units, there will be $p(p-1)/2$ or $n(n-1)/2$ resemblance values from distinct comparisons, depending on the mode of analysis. The resemblance values describe a structure in the sample. Resemblance functions and alternative ordination strategies are reviewed in Orlóci (1978). Useful application programs to help calculations have been written by Podani (1992, 1994, 1997), Wildi (1996), and Pillar (1999).

The second transformation starts with the resemblance values and produces a description of the sample in terms of t sets of n ordination co-ordinates. An ordination is said to be parsimonious if these sets are independent. A parsimonious ordination produces co-ordinate sets such that t is much smaller than p. Eigenanalysis is a parsimonious linear method of ordination.

Eigenanalysis can lead to the same solution on two alternative pathways delineated by the characteristic equations:

$$\boldsymbol{AA'}\alpha=\alpha\lambda \qquad (1)$$

$$(\boldsymbol{A}'\boldsymbol{A})(\boldsymbol{A}'\alpha)=(\boldsymbol{A}'\alpha)\lambda \qquad (2)$$

(see Orlóci 1966, 1967). In these $\boldsymbol{A}$ is a row-centred $p \times n$ data matrix and α is *a* $p \times t$ matrix of component coefficients. The t columns in matrix α are the normalised Eigenvectors of $\boldsymbol{AA'}$. λ is a t-valued vector of Eigenvalues (called generalised variances). Note that $\boldsymbol{A}$ has the same definition in (1) as it does in (2). Also, $\boldsymbol{AA}'$ is a $p \times p$ product matrix defined for the p rows in $\boldsymbol{A}$. Further, $\boldsymbol{A}'\boldsymbol{A}$ is an $n \times n$ product matrix defined for the n columns of $\boldsymbol{A}$.. Since the component scores of the n column entities of $\boldsymbol{A}$ are defined by $\boldsymbol{Y}=\boldsymbol{A}'\alpha$, the same scores can be obtained directly by way of (2) as the elements in the Eigenvectors of $\boldsymbol{A}'\boldsymbol{A}$. Adjustment is required such that the sum of squares of elements in any of the Eigenvectors of $\boldsymbol{A}'\boldsymbol{A}$ will be equal to the corresponding Eigenvalue. An analysis via (2) is practical when p is larger than n.

The following definitions should be helpful for users of multivariate analysis in ecology:

$\lambda = (\lambda_1 \lambda_2 \ldots \lambda_t)$ – Eigenvalues

Y_{ij} - component score of relevé *j* on component *i*

$\boldsymbol{Y}_i \boldsymbol{Y}'_i = \lambda_i$ for any *i*

$A_{hj} = \dfrac{X_{hj} - \overline{X}_h}{\sqrt{n-1}}$ -- "centring" of taxon (variable) *h*

X_{hj} - value of taxon *h* in relevé *j*

$\overline{X}_h$ - sample mean of taxon *h*

α_{hi} - ith component coefficient (direction cosine) of taxon h relative to Eigenvector i

$\alpha'_i \alpha_i = 1$ for any *i*

$\alpha'_h \alpha_i = 0$ for any i,h; this does not exclude the possibility of higher order correlation between the components.

$L_{\%} = 100 - E_{\%}$ where $E_{\%} = \dfrac{100 \sum_{i=1}^{t-k} \lambda_i}{\sum_{i=1}^{t} \lambda_i}$ -- information loss by discarding the last *k* sets of component scores.

$E_{i\%} = \dfrac{100\,\lambda_i}{\sum_{i=1}^{t} \lambda_i}$ - efficiency of ith Eigenvector in accounting for variation in the sample.

The decision to discard the last *k* sets of component scores is ideally the outcome of a statistical test on the null hypothesis

$$H_0 : E(\lambda_{t-k+1}) = \ldots = E(\lambda_t)$$

Here *E* signifies "expectation". When H_0 is true, *i.e.* the *k* smallest population variances are equal, the point cluster in the subspace of the *k* components is hyperspherical. Such a cluster shape indicates that variation in that subspace lacks a linear trend. Provided that *n* is large, H_0 is true, the population distribution is multivariate normal, and the sample is taken at random, the test criterion

$$\chi^2 = -(n-1) \sum_{i=t-k+1}^{t} \ln \lambda_i + (n-1)k \ln \frac{\sum_{i=t-k+1}^{t} \lambda_i}{k}$$

will have the theoretical Chi-squared distribution (see Anderson 1963; Morrison 1976, pp. 296) with degrees of freedom

$$\nu = \frac{k(k+1) - 2}{2}$$

The popularity of the test in statistics justifies reminder that the regularity conditions as listed may never be fully satisfied, and the test as described may never be fully justified.

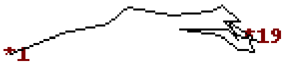
6.4 A potentially informative representation of the ordination configuration is in the manner of a stereogram pair. The construction requires three sets of co-ordinates $(\boldsymbol{Y}_1, \boldsymbol{Y}_2, \boldsymbol{Y}_3)$. These are adjusted so that the i^{th} set will have values in the 0 to a_i range. It is practical to select an upper limit $a_i = 3.3\, R_i/k$ where R_i is the observed range in the i^{th} set and k is the largest R_i of $\boldsymbol{Y_1, Y_2, Y_3}$. For convenient viewing, the viewing points are selected with left and right co-ordinates:

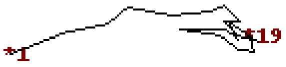
$Y_{1L} = 1.287$ cm	$Y_{1R} = 2.112$ cm
$Y_{2L} = 1.287$ cm	$Y_{2R} = 1.287$ cm
$Y_{3L} = 9.9$ cm	$Y_{3R} = 9.9$ cm

The first two axes have zero origin at the bottom left corner of the stereograms (maximum box width 3.3 cm). The third axis is height. A given point j has stereo co-ordinates

$$Y_{ijk} = \frac{Y_{3L} Y_{ij} - Y_{ik} Y_{3j}}{Y_{3L} - Y_{3j}}$$

for $i = 1,2$; $k = left, right$. Precision plotting should be used, and no excessive enlargement or reduction, to avoid blurring the stereo image. The stereo pair of the Atlantic Heathland trajectory looks like this[17]:





Component scores are the co-ordinates. The numerical results of component analysis are given in the following table:

---

[17] Stereograms are drawn by Program STEREOR8.EXE based on the scores written by Program PCAR8.EXE. See the appendix for more details.

```
COORDINATE FILE: lippe9x19.tru
NUMBER OF ROWS (VARIABLES): 9
NUMBER OF COLUMNS (INDIVIDUALS): 19
OPTION: VARIANCE/COVARIANCE

VARIANCE,COVARIANCE MATRIX
   208.525   -202.332   -56.945    41.696    -2.401    -2.945    -1.713    19.881   -3.670
  -202.332    209.542    51.613   -50.061     2.348     2.583     1.186   -18.687    3.854
   -56.945     51.613    19.587   -11.058      .706      .815      .642    -6.266     .873
    41.696    -50.061   -11.058    17.613     -.576     -.491     -.110     3.864    -.996
    -2.401      2.348      .706     -.576      .079      .032      .026     -.230     .015
    -2.945      2.583      .815     -.491      .032      .204      .057     -.265     .010
    -1.713      1.186      .642     -.110      .026      .057      .062     -.175     .027
    19.881    -18.687    -6.266     3.864     -.230     -.265     -.175     2.267    -.374
    -3.670      3.854      .873     -.996      .015      .010      .027     -.374     .264

EIGENVALUES AND PERCENTAGES
        Eigenvalue      %     Cumulative %
1:          438.19   95.64           95.64
2:           14.38    3.14           98.78
3:            4.79    1.04           99.83
4:             .34     .07           99.90
5:             .22     .05           99.95
6:             .16     .03           99.98
7:            .056     .01          100.00

EIGENVECTORS
1:      -.684    .686    .183   -.155    .008    .009    .005   -.065    .013
2:      -.495   -.463    .379    .622    .002    .021    .034   -.096   -.016
3:       .127   -.220    .774   -.559    .017    .001    .022   -.150   -.006
4:      -.345   -.322   -.167   -.342    .080    .423    .182    .633   -.119
5:      -.169   -.191   -.173   -.174   -.110   -.047    .100   -.141    .912
6:      -.029    .004    .136    .020    .035   -.789   -.058    .589    .086
7:      -.110   -.121   -.178   -.118    .881-   .211    .179   -.267   -.067

COMPONENT SCORES
    AXIS 1    AXIS 2    AXIS 3    AXIS 4    AXIS 5    AXIS 6    AXIS 7
   -13.001    -1.503     0.026    -0.040     0.016    -0.005     0.052
    -9.529    -0.183     0.146     0.215     0.009    -0.025    -0.029
    -6.174     0.380    -0.941     0.105    -0.071     0.164    -0.052
    -4.705     1.374     0.066    -0.301    -0.057    -0.151    -0.001
    -1.782     0.869    -0.040     0.145     0.060     0.002    -0.019
     1.045     1.124    -0.464    -0.128    -0.026     0.058     0.102
     1.988     1.501    -0.439     0.210     0.071    -0.129    -0.027
     3.147     0.535    -0.215     0.083    -0.087     0.033    -0.058
     2.040     0.531     0.306    -0.066    -0.105     0.125    -0.017
```

3.013	-0.362	0.250	0.000	-0.046	-0.011	-0.059
4.506	-0.792	-0.570	-0.085	0.280	0.078	-0.013
2.402	0.418	0.703	0.171	-0.038	0.028	0.020
2.965	-0.572	0.526	-0.014	-0.171	0.044	0.012
2.191	0.014	0.707	0.129	0.110	0.035	0.046
-1.092	0.116	0.981	-0.012	0.113	-0.081	-0.006
1.681	-0.282	0.220	-0.126	0.125	0.126	0.001
3.238	-1.234	-0.389	-0.049	0.021	-0.152	-0.095
4.167	-1.449	-0.187	-0.084	-0.181	-0.035	0.006
3.899	-0.486	-0.686	0.138	-0.024	-0.106	0.137

6.5 The graphs in row B of Figure 4 reveal an interesting behaviour of the Markov process: transition probabilities buffeted by small random influences transform the simple trajectory, characterised by total linear determinism, into a complex trajectory of two phases. The initial phase carries the imprints of the Markov chain. The second phase is an oscillating attractor. Orlóci and Orlóci (1988) and Anand and Orlóci (1997) make points about this.

6.6 It should be mentioned that direct random perturbation of the transition probabilities mimics nature. This is considering the fact that the population quantities are the consequence of the transition probabilities being what they actually are. This is a one-way relationship.

7. SENSITIVITY TO INITIAL CONDITIONS

7.1 Any community state (any point on the process trajectory) can be the initial state $\boldsymbol{X}_O$. When the trajectory is Markov, it converges on a fixed-point attractor, provided that the transition probabilities stay constant. This will happen no matter what the composition of the null state. Regarding the attractor, the process is insensitive to initial condition. Only the attractor conditions matter.

7.2 The verdict will have to be different though when one is considering the trajectory's path to the attractor. Each time a different $\boldsymbol{X}_O$ is selected, save the same transition probability matrix, the trajectory will fallow a different path to the same attractor. Therefore, with regard to path, the process is sensitively dependent on initial conditions.

7.3 How can sensitivity be tested? This is a trivial matter with the Markov chain. The reader is referred to Kullback et al. (1962), Çambel (1993), Orlóci et al. (1993), and Anand and Orlóci (1997) for some details and references.

7.4 An interesting consequence of the process having stationary (constant) transition probabilities is expressed by $\boldsymbol{M}_t = \boldsymbol{M}_{t+1}\boldsymbol{P}^{-1}$. This is true for any time point *t,* except *t=0,* implying that the stationary process has perfect "memory" for the past. This is to be taken in the context already discussed in Section 4.2 on the Markov chain.

8. MOVING ATTRACTOR

8.1 It is safe to say that in nature the attractor never stands still, although perception may not deem it to be that way. Alternation of linear and non-linear phases can be a tell-tail sign of a moving attractor.

8.2 Figure 5 gives a time-by-geography map of the moving attractor in Eastern North America over 20 millennia. The graph can be used in two ways, either to follow the turnover of vegetation formations in the same site or to follow formation shifts across latitudes. The bounding conditions of the attractor at any point in time are specific to the prevailing climate and vegetation formation. The table below tracks the attractor’s trajectory in the Jackson Pond site:

Location	85^{O}W 37^{O}N
Years before present	Attractor type
– 12000	Boreal forest
12000 – 11000	Mixed conifer – northern hardwoods
11000 – 0	Cool temperate deciduous forest

The process progressed to different states in the different sites. For example, in site 85^{O}W 30^{O}N, the bounding conditions of the attractor remained in the warm-temperate evergreen forest state. In site 85^{O}W

51°N, the attractor conditions are still in the Boreal Forest state. Simple calculations with the use of conditions at the southern edges of the Boreal Forest and global temperature values, reveal an interesting property of the Boreal Attractor. Its average ground velocity is around 300 km in 1000 years or 600 km per 1° C rise in the global average temperature during the 8,000 year period, starting 14, 000 years ago. [18]

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[18] The above numbers are based on the assumption that when the southern edge of the Boreal Forest started to move north from 34° N, 14,000 years ago, the global average temperature has reached about 12° C. Some 8,000 years later, the southern edge of the Boreal Forest was at 59° N and the global average temperature hovered around 16° C. Sources for paleotemperature and commentaries are found in Emiliani (1966), Webb (1992), McKay and Hengeweld (1990), Milk (1989). Se also the references therein.

9. PHASE STRUCTURE

9.1 The fact that determinism and randomness alternate in their dominance deserves further comments:

a) An interesting comparison is with fluid flow through occluded vessel (see for example Çambel 1993, p.13). Linear laminar flow is sustained up to the occlusion point. At that, flow velocity increases and if the critical velocity is reached, the flow enters a turbulent, non-linear phase. The Atlantic Heathland has signs of similar behaviour (Figure 6). The initial linear phase lasts until about 1970. At that point, an occlusion is reached, which is in the disguise of exceeded carrying capacity, and the turbulent phase begins. This phase is characterised by random directional oscillations. In this state of the community some sort of an equilibrium exists that lasts as long as the prevailing attractor conditions last. Important, the management regime of the heath is part of the attractor condition.

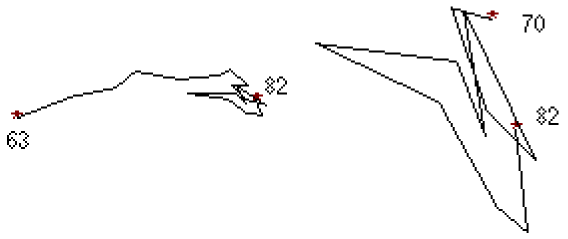

Figure 6. Atlantic Heathland trajectory with segment from 1970 enlarged.

b) Similar morphological features can be observed in the Jackson Pond trajectory, but at a different scale. There, major climate change creates the occlusion.

9.2 Determinism can be the same thing as linearity. This means process progression marked by joint unidirectional increments of the co-ordinates on phase space axes. When reversals come with high frequency and loss of proportionality, the end of the linear phase is signalled and the chaotic phase begins.

9.3 A test of the strength of overall directedness in the process is based on the comparison of two distance matrices. One is ***d***, a matrix of compositional distances, and the other, a reference distance matrix δ, a matrix of chronological differences computed for pairs of the trajectory points. It is practical to define the elements of ***d*** or δ as the Minkowski metric of order *m*:

$$d_{jk} = \sqrt[m]{\sum_{i=1}^{p} (X_{ij} - X_{ik})^m}$$

$j,k=1, \ldots, n$ (Orlóci 1978). When m is set equal to 2, d_{jk} will be a Euclidean distance. Symbol p stands for the number of co-ordinate sets (axes, taxa) and n is the number of trajectory points (paleorelevés, sampling units) that were actually observed. X is symbol for phase space co-ordinates. Sample size should be large, but it is usually small, understandably, considering the problems in long-term permanent plot experiments, or the high expenses of pollen separation, identification, and dating in sediment samples.

9.4 The definition of the reference distance matrix will affect the outcome:

a) δ defines a Markov relevé distance configuration. The Markov chain is fitted to phase space co-ordinates. Linear directedness is tested based on the probability of obtaining an at least as large divergence of two distance configurations as the observed $|\boldsymbol{d} - \delta|$, under the assumption that the compositional transitions in the community are chance driven. The reference distribution is derived in randomisation experiments under the null hypothesis that the expectation of $|\delta_{RND} - \delta|$ is zero. δ_{RND} is the distance matrix of points in a Markov chain fitted to randomised phase space co-ordinates (Orlóci, Anand and He 1993, Anand and Orlóci 1997).

b) δ is a matrix of elapsed time differences. Matrices ***d*** and δ are compared by the rank correlation coefficient (*r*). The reference distribution of *r* is derived in a randomisation experiment under the null hypothesis that compositional transitions are driven by chance, *e.i.,* the expectation of the rank order correlation is zero. It can be seen upon inspection of the numerical results in Table 3,[19] that every correlation values unusually high in probabilistic terms, except in the comparisons involving the RND trajectory. The latter is created by random permutation of the phase space co-ordinates. The results reinforce the proposition that the syndynamic process is indeed directed.

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[19] RANKCOR8.EXE is relevant program. See the appendix for details.

9.5 Strong determinism notwithstanding, reversals of direction do occur. But, a case can be made for "no backtracking" to past states in the sense that states never repeated exactly in a natural process.

Table 3. Rank correlation of relevé distances and time differences. Expected value, variance, and probability (P) of a correlation at least as large as the observed are determined by iteration in randomisation experiments. *Z* is the standard variate and *P* the probability of an at least as large Z value as the observed under expectation. *Site* descriptions are in Table 2.

Site	Observed correlation	Expected correlation	Variance	*Z*	*P*
Lagoa das Patas	0.4577	0.000841	0.000313	8.0321	<0.001
Jackson Pond	0.7685	0.016787	0.000732	8.7833	<0.001
Atlantic Heath.	0.5003	0.012589	0.000923	5.3378	<0.004
RND	0.0227	0.000652	0.000864	0.7960	<0.196

10. PERIODICITY

10.1 It is clear from what has already been presented that syndynamics behaves in manners that can be described as periodicity. But it is clear that the periodicity involved is irregular for both wavelength and amplitude. The simplest periodicity for observation is the turnover of taxa. In good part, however, structures are involved whose state variables are one or more steps removed from taxonomic composition and whose dynamics is asynchronous with population turnover . Typical state variables in this category have to do with trajectory morphology, measurable as distances, angles, velocity values, acceleration values, or information divergences. There are other types of state variables as well, such as the community's entropy state, complexity, stability, and so forth. A selected number is examined more closely in the sequel:

10.2 Process velocity. In the time interval $\Delta_t=t_{j+1}-t_j$, the process moves at an average velocity of $S_j= d_j/\Delta_j$. Symbol d_j represents the compositional distance (see above) of the trajectory points j and $j+1$. The trajectory slope in the Δ_j interval is S_j/Δ_j. Slope is indicative of acceleration. Sample distance, velocity, and acceleration graphs are given for the Lagoa das Patas and the Jackson Pond sites in Figure 7. [20]

Inspection of the graphs in Figure 7 brings up a pertinent question: "Could peaks and lows as extreme as the observed be the result of chance effects? Randomisation testing can supply the answer. A method is described by Pillar (1996, Pillar & Orlóci 1996 and references therein). The core question is, of course, what should be randomised? —

a) Relevés randomly permuted. This option limits the population of community states to those present in the sample.

b) Data entries randomly permuted within taxa. This option confines the source population to the observed pollen densities in the observed proportions.

c) Data units assorted at random among the relevés. This is equivalent to assuming that any taxon could have occurred in any quantity , not exceeding a threshold, at any given time.

    c1) Observed taxon totals retained, relevé totals allowed to change.

    c2) Both taxon and relevé totals allowed to change, only grand total retained.

It is to be noted that randomisation creates a data structure consistent with the law of chance , as defined. This structure may be totally unnatural.

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[20] STREVOL8.exe is the relevant program for computing the evolution of structural variables. See further details on this later in this section and in the Appendix ..

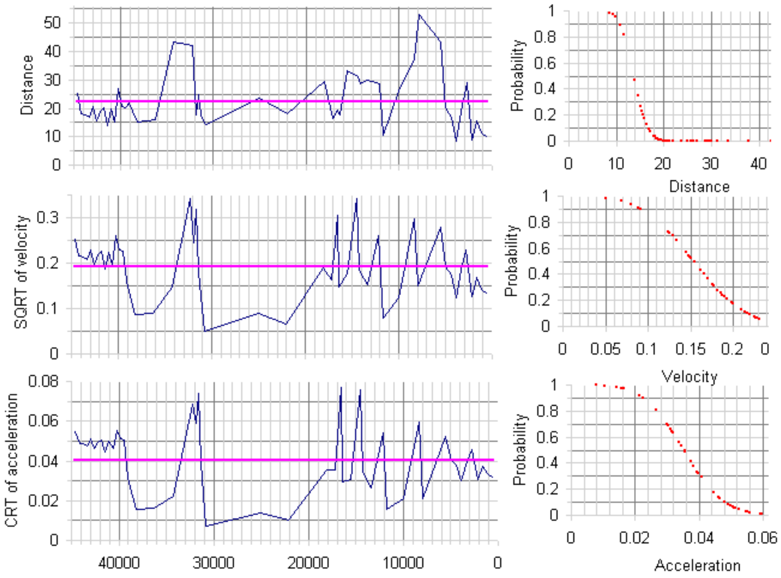

Figure 7a

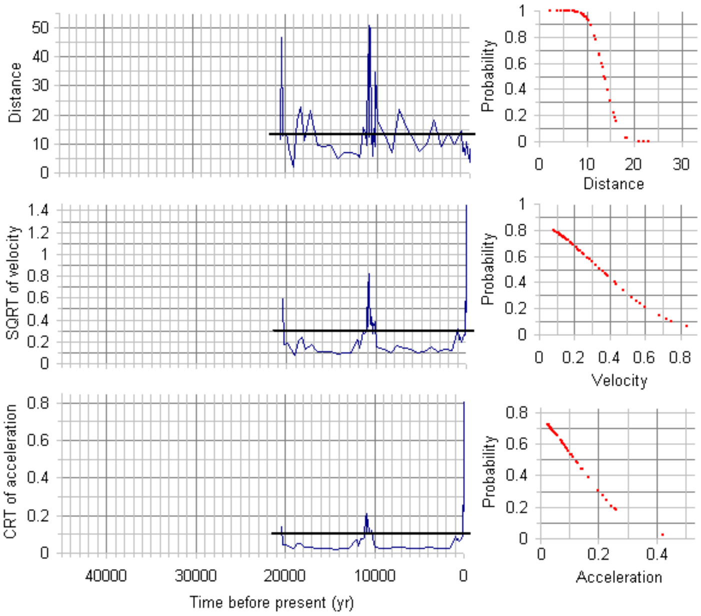

Fig. 7b

Figure 7. Sample distance, velocity and acceleration graphs, and probability diagrams for the Lagoa das Patas (7a) and Jackson Pond (7b) process trajectories. Horizontal line in bold indicates sample mean values. Low graph segments indicate periods of high stability. Probabilities measure the likeliness of a given characteristic attaining a value by chance at least as large as the value actually

measured. Probabilities are determined in randomisation experiments. Legend to symbols: SQRT -- square root, CRT-- cube root.

The probabilities given in Figure 7 are based on randomisation under option c1. The choice of c1 is supported by consideration of the fact that the quantitative participation of plant types in the pollen and propagule pool is basically taxon specific, given all the limiting conditions present in the site.

The graphs of Figure 7 have a few major peaks and lows, and many minor ones. The major peaks deserve closer examination:

a) The effects of global temperature change are seen. This is somewhat surprising in the case of Lagoa das Patas, considering the equatorial environment. The climatic effects are most obvious in the vicinity of time points 40, 38, 34, 31, 22 and 17 thousand years before present, and after that at roughly every one or two thousand years.[21] Corresponding peaks in temperature graphs, presented by others (*e.g.* Webb 1992), suggest that a small change in global temperature, one or two Celsius

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[21] The time scale is that given by the contact persons identified in Table 3. The sampling of sediments is in each case at irregular depths. Time step width varies. Some dates are based on linear

degrees, is sufficient to force a significant response in vegetation composition even in the equatorial region.

b) Similar but much amplified responses are seen in the Jackson Pond graphs under climatic effects. In this site, the vegetation formation evolves from Boreal forest, as late as about 16 thousand years ago, into a Deciduous forest in a matter of about 2,000 years. The time points around 21,000 years before present and again about at 11,000 years are marked by dramatic change. But the steep slope of the velocity gradient is most remarkable during the past 500 or so years. This may, however, be the consequence of intense anthropogenic perturbations and not strictly a response to climatic effects.

c) One should not read much into the relationship of temperature graphs and trajectory morphology. It does not validate the climatic connection of syndynamics. This is because the climatic data derives to a considerable extent on deduction of paleopollen spectra.

Work with temperature records may bring up the question of how to estimate thermal flux in a site under given change in the global average temperature. Estimates may come from the general circulation models (Mason 1990), but these supply broad regional values. The method described by

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interpolation. The original web files and references should be consulted for details of sampling, dating and other analytical manipulations.

Orlóci (1994) provides a more reliable results locally in specific cases, since it uses local ecological evidence, modern and historical. The arithmetic is illustrated by example:

Near Port Harrison, at the southern limit of the Tundra, the present annual mean temperature is about -7.5^{o}. Some 9,500 years ago the southern limit of the Tundra lay about 10 degrees farther south in the Timmins area where the present annual mean temperature is 1.3^{o}. The thermal distance of the historical and present southern limits of the Tundra is 8.8^{o}.

Assuming that the global average temperature was 12.6^{o} (this number by interpolation from published graphs) 9,500 years ago and it is 15^{o} at present, the thermal flux rate at Timmins is taken to be 8.8/2.4 = 3.7. That is, a 1 Celsius degree rise in the global average temperature is expected to produce 3.7 degree rise locally. Accordingly, the anticipated local temperature rise at Timmins in the wake of the Manabe 2xCO_2 scenario is 3.7 x 2.5^{o} or 9.3^{o}, and the anticipated annual mean temperature after 2.5^{o} global warming is 10.6^{o}. Similar calculations produce the other values as well in rows 5, 6, 7 of Table 4. It can be seen that the rate at which a given degree of global temperature rise is translated into local temperature increases is functionally related to latitude. The rates are not transferable to other regions.

10.3 Sums of squared deviations are measured in community composition terms with random expectation as reference. The definition given in section 3.2 applies. The graph in Figure 8 is the sum of the graphs under the taxon names in Figure 2. It is seen in Figure 8 that community composition at Jackson Pond approached the analytical random expectation (zero line) around 11,000 years before present. The sum of squared deviations reached maxima as glaciation was ending, again around the Hypsothermal, and at present.

Table 4. Description of conditions at the lower latitude/elevation limits of vegetation zones as identified. The southern limit of the Warm Temperate Evergreen Forest is not climatic. Values underlined are extrapolations based on TFR = -2.57538+0.12749X. In this equation, X represents the decimal equivalent of the locality's northern latitude. The value of the coefficient of determination is 0.97. Regression does not include the Mauna Kea sites. Abbreviations: Prec. – mean precipitation; Temp. – annual mean temperature; LTF – local thermal flux rate; LT - local temperature rise; ET -

expected annual mean temperature. All temperatures are given in Celsius degrees. Data in rows 3, 4 are from Walter et al. (1975), except the last two columns, obtained from Krajina (1963).

		Arctic Tundra	Boreal Forest	Mixed Conifer-Northern Hardwood Forest	Cool Temperate Deciduous Forest	Warm Temperate Evergreen Forest	Tropical Alpine Tundra (3,300m)	Tropical Subalpine Scrubland (2,000m)
1	Climatic station	Port Harrison, Quebec	Timmins, Ontario	Stratford, Ontario	Nashville, Tennessee	Mobil, Alabama	Mauna Kea, Hawaii	
2	N latitude	58° 26'	48°31'	43°22'	36° 10'	31° 42'	19°49′	19° 49'
3	Prec. mm	372	711	773	1,144	1,439	510	1020
4	Temp.	-7.5	1.3	8.3	15.6	19.8	0	4.4
5	LTF	4.9	3.7	2.8	2.1	1.5	1.8	1.8
6	LTR	12.3	9.2	7.0	5.3	3.8	4.5	4.5
7	ELT	4.8	10.5	15.3	20.9	23.6	4.5	8.9

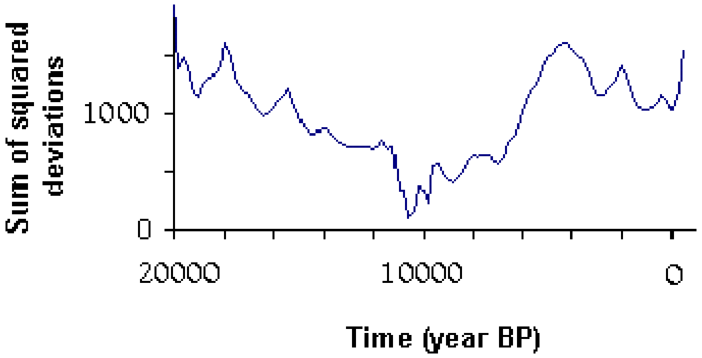

Figure 8. Evolution of compositional deviation from random expectation in the Jackson Pond site. The graph portrays the sum of the "total" deviation graphs (presented in the first column left side and right side) of Figure 2.

10.4 Diversity, biodiversity. Many methods are available for diversity analysis, but the ones that are of interest are those that allow partitioning the total diversity into components specific to sources.

The Encarta World English Dictionary defines biodiversity as the

> “range of organisms in the environment; the range of organisms present in a given ecological community or system. It can be measured in terms of the numbers and types of different species, or the genetic variations within and between species.”

Diversity thus is taken to be “range” and “range” implies counts or variation involving species. The "environment" is a community or system. The term “species” here need not mean anything more specific than a “population” or “taxa”. In fact, global studies of biodiversity can draw advantages from some functional taxa into which species records are collapsed in a hierarchical manner (Orlóci 1991, Pillar and Orlóci 1993).

The measurement of diversity is best done by functions (scales) that are site-independent, have additive partitions, specific to deemed causal factors, and can provide ecologically meaningful results. Several families of measuring functions have these properties. Some examples:

a) Index of congeneric occurrence (Simpson 1949). This index in the form of

$$SI = \frac{1}{\sum_{j=1}^{s} p_j^2} - 1$$

has limits $0 \le SI \ge 1$, provided that $p_1 + p_2 + ... + p_s = 1$. The p values indicate the proportionate representation of taxa in the sample.

b) Minkowski metric. The distance of an n-valued observational data vector $\boldsymbol{X}$ from a standard $\boldsymbol{Q}$ is measured in the form of

$$d_j = \sqrt[m]{\sum_{i=1}^{n} \left(X_j - Q_j\right)^m}$$

When m is set to 2, the Euclidean distance is defined (McIntosh 1967)..

c) Entropy and information. Rényi's generalised entropy and information functions give a highly flexible diversity measure:

$$H_\alpha = \frac{1}{1-\alpha} \ln \sum_{j=1}^{s} p_j^\alpha \ , \ I_\alpha = \frac{1}{\alpha - 1} \ln \sum_{j=1}^{s} \frac{p_j^\alpha}{q_j^{\alpha-1}}$$

where $p_j = \frac{f_j}{f_.}$. A dot in the subscript indicates summation over the subscript it replaces. H_α is called entropy of order α, defined for the s-valued frequency distribution $\boldsymbol{F} = (f_1 f_2 \ ... \ f_S)$. H_α is a diversity measure. Its magnitude is proportional to the level of disorder in $\boldsymbol{F}$. The order variable α may take on any numerical value, integer or fraction, but not negative and never exactly equal to one. The maximum diversity, ln s, is independent from α and requires that $\boldsymbol{F}$ be an equidistribution ($\boldsymbol{F}_M$ below).

I_α is information[22] of order alpha. It measures the one-way divergence of two distributions, the observed $\boldsymbol{F}$ and the standard $\boldsymbol{Q}$, both having an identical number of elements and totals. $\boldsymbol{F}$ has

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[22] Information as used here is a technical term, more akin in meaning to a “surprisal value” than to “ knowledge”.

associated least dispersed distribution, $\boldsymbol{F}_L = (f_{.}-s+1 \;\; 1 \; ... \; 1)$, and most dispersed distribution $\boldsymbol{F}_M$. The latter is an equidistribution with constant element being the mean of the values in $\boldsymbol{F}$, symbolically $\bar{f}$. Distributions $\boldsymbol{F}_L$ and $\boldsymbol{F}_M$ both are s-valued and $f_{.}$ totalled. The descriptors of $\boldsymbol{F}_L$ include s, $f_{.}$ and

$$H_{aL} = \frac{1}{1-\alpha} \ln \frac{(f_{.}-s+1)^{\alpha}}{f_{.}^{\alpha}} + \frac{s-1}{1-\alpha} \ln \frac{1}{f_{.}^{\alpha}}$$

The descriptors of $\boldsymbol{F}_M$ include s, $f_{.}$ and $H_{\alpha M} = \ln s$.

Some of the noted ecological indices of diversity are special cases of Rényi's entropy function (Hill 1973, Orlóci 1993):

$\alpha=0$	$H_0 = \ln s$	-- state (species) richness
$\alpha \overset{\lim}{\rightarrow} 1$	$H = -\sum_{j=1}^{s} p_j \ln p_j$	-- Shannon (1949, Margalef 1959. Pielou 1975)
$\alpha = 2$	$H_2 = -\ln \sum_{j=1}^{s} p_j^2$	-- log Simpson (Simpson 1949)

Shannon's entropy is the common measuring function of diversity in ecology. But it is not an ideal choice. The reason is that it measures entropy in the vicinity of α=1 where the graph of H_α can rise or fall dramatically with even relatively small changes in α. It is suggested to measure diversity away from this point at α where the H_α graph starts levelling off, or even better, give the entire graph.

A worked example (after He and Orlóci 1993 expanded) takes 646 species from Li's (1993, He and Orlóci 1993) Heilongjiang vegetation data. The species were scored by X.S. He for flora element and functional type. Flora element identifies the floristic region in which a species has its deemed centre of distribution. Functional types follow Raunkiaer's life-forms (as in Braun-Blanquet 1927). The latitude and longitude readings for Li's sampling area are 43°25' - 53°33' N and 121°11' - 135°05' E. A brief sample of the coded species data is as follows:

1	Abies holophylla 14
2	Abies nephrolepis 12
3	Acanthopanax senticosus 23
.	
646	Zigadenus sibiricus 33

Explanation of first record "1 Abies holophylla 14":

Sequence number: 1
Species: Abies holophylla
Functional type: state 1 of 5
Flora element: state 4 of 4

The raw scores are summarised as frequencies in a contingency table given as Table IVa.

Table IVa

Flora element	Functional type					Total
	Phanero -phytes	Nano-phanero -phytes	Geo-phytes	Hemi-crypto-phytes	Cham-aephytes	
Boreal	2	5	2	3	10	22
Subalpine	5	8	8	11	6	38
Montane	6	81	153	199	28	467
Forest Steppe	9	33	17	53	7	119
Total	22	127	180	266	51	646

The following are the numerical values obtained by partitions of the total species diversity:[23]

Richness

Species $H_0 = \log_2 646 = 9.334$
Flora element (*Flora*) $H_0 = \log_2 4 = 2.000$
Functional type (*Func*) $H_0 = \log_2 5 = 2.322$
Joint $H_0 = \log_2 20 = 4.322$

Diversity owing to two-way sorting (joint effect, Hj)

$$H(Flora, Func) = -\sum_{i=1}^{5}\sum_{j=1}^{4} p_{ij} \log p_{ij} = 3.068 \text{ bits} \quad E_{\%} = \frac{100 * 3.068}{4.322} = 71 \quad \text{(evenness)}$$

Diversity contributed by Functional type sorting (main effect Hbc)

$$H(Func) = -\sum_{j=1}^{5} p_{.j} \log p_{.j} = 1.957 \text{ bits} \quad E_{\%} = 60$$

Diversity contributed specifically by Functional type sorting, given Flora element (Hwr)

$$H(Func|Flora) = -\sum_{i=1}^{4} p_{i.} \sum_{j=1}^{5} p_{ij|i} \log p_{ij|i} = 1.874 \text{ bits} \quad E_{\%} = 81$$

NOTE: H(Func | Flora)=H(Flora,Func)-H(Flora)

Diversity contributed by Flora element sorting (main effect Hbr)

$$H(Flora) = -\sum_{i=1}^{4} p_{i.} \log p_{i.} = 1.194 \text{ bits} \quad E_{\%} = 60$$

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[23] Relevant program is ENTPrc.EXE for Table IVa, and ANOENrc for Figure VIIIb and Table IVb. See Appendix for some detail.

Diversity contributed specifically Flora element sorting, given Functional type (Hwc)

$$H(Flora|Func) = -\sum_{i=1}^{5} p_{.j} \sum_{j=1}^{4} p_{ij|j} \log p_{ij|j} = 1.111 \text{ bits} \quad E_{\%} = 80$$

NOTE: *H(Flora | Func)=H(Flora,Func)-H(Func)*

Diversity owing to interaction (Hm)

$$I(Flora;Func) = \sum_{i=1}^{5}\sum_{j=1}^{4} p_{ij} \log \frac{p_{ij}}{p_i p_j} = 0.082 \text{ bits} \quad E_{\%} = \frac{8.2}{2} = 4$$

Note: *H(Flora;Func)= H(Flora)+H(Func)- I(Flora,Func)*

The specific partitions above correspond to diversity of order one. Numerical results over a range of alpha from zero to 10 are plotted in Figures VIIIa,b. The letter "S" indicates "specific". Special cases are marked in the top graph. Note that the relative values are ratios:

Rajski's metric = (Joint – Interaction)/Joint
Coherence = Interaction/Joint

The other relative quantities are obtained by division of H_α or I_α by the corresponding maximum value such as richness for main effects, and the lesser of the main effects for interaction. Selected numerical values are listed in Table IVb.

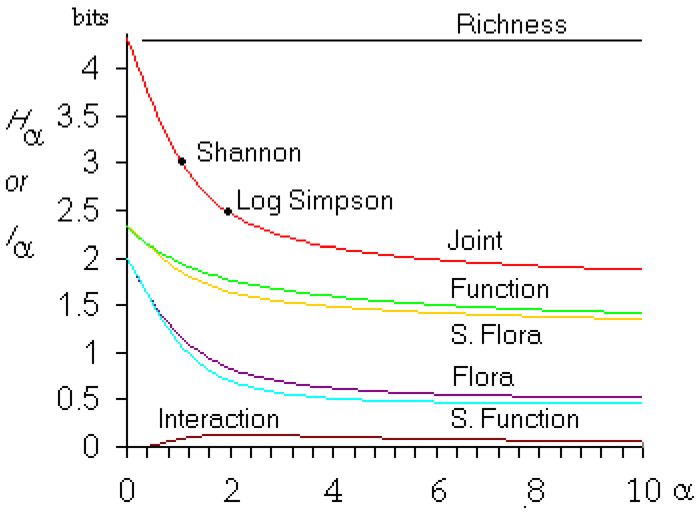

Figure VIIIa

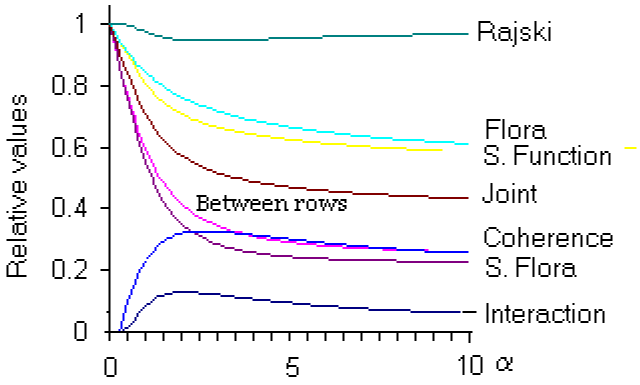

Figure VIIIb

Table IVb

Alpha	Flora	S. Flora	Func	S. Func	Joint	Inter-action	R. Flora	R.S. Flora	R. Func	R.S. Func	R. Joint	Rajski	Cohe-rence
*	Hbr	Hwc	Hbc	Hwr	Hj	Hm	HbrR	HwcR	HbcR	HwrR	HjR		
0	2.000	2.000	2.321	2.321	4.321	0	1.000	1.000	1.000	1.000	1.000	1.000	0
1	1.194	1.111	1.957	1.874	3.068	0.082	0.597	0.555	0.842	0.807	0.710	0.972	0.230
2	0.833	0.703	1.769	1.639	2.473	0.130	0.416	0.351	0.762	0.706	0.572	0.947	0.320
10	0.520	0.457	1.419	1.356	1.876	0.062	0.26	0.228	0.611	0.584	0.434	0.966	0.256

* Abbreviations refer back to formula in the text above and in the printout of ANOENrc.EXE. See Appendix.

It should be mentioned that each partition is specific to a specific structural aspect of diversity, and each can be used in diversity comparisons between sites at the same point in time or between different time points in the same site. This is irrespective of the interpretability of partitions in other than their analytical identity.

It may be of interest to test how far the observed diversity structure departs from a hypothetical maximum diversity structure. The partitions in this case are one-way divergences of order one in the manner of the formulae as given:[24]

Floristic element

$$I(Flora) = \sum_{i=1}^{4} f_{i.} \log \frac{f_{i.}}{f_{..}/4} = 504.95 \text{ nats}$$

Functional type

$$I(Func) = \sum_{i=1}^{4} f_{.j} \log \frac{f_{.j}}{f_{..}/4} = 19.09 \text{ nats}$$

Independence

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[24] The relevant application program is INFOrc.EXE. Se Appendix for some detail.

$$I(Flora;Func)=\sum_{i=1}^{5}\sum_{j=1}^{4} f_{ij}\log \frac{f_{ij}}{f_{i.}f_{.j}/20} = 37.16 \text{ nats}$$

Joint

$$I(Flora,Func)=\sum_{i=1}^{5}\sum_{j=1}^{4} f_{ij}\log \frac{f_{ij}}{f_{..}/20} = 561.09 \text{ nats}$$

The numerical values reflect the magnitude of the departure of the observed diversity structure from the hypothetical maximum. A statistical test can be performed on these values based on the theoretical chi-squared distribution, provided that the regularity conditions specified in Kullback (1959, Kullback, Kupperman and Ku 1962) are satisfied. The test criteria and results are summarised below. Note that the values given in *bits* can be transformed into *nats* by multiplication by the factor 2 ln 2

Flora element

Degrees of freedom	3
Information *I(Flora)*	504.85 nats
Chi-squared (2x *I(Flora)*xln(2))	699.86 bits
Hypothesis tested: Flora element has zero divergence.	

Functional type

Degrees of freedom	4
Information *I(Func)*	19.09
Chi-squared (2x *I(Func)*xln(2))	26.46
Hypothesis tested: Functional type has zero divergence.	

Flora element x Functional type

Degrees of freedom	12
Information *I(Flora;Func)*	37.16
Chi-squared	51.54
Hypothesis tested: Floristic element is independent from Functional type.	

Floristic element and Functional type jointly

Degrees of freedom	19
Information *I(Flora,Funco)*	561.09
Chi-squared	777.84
Hypothesis tested: Floristic element and Biological type jointly have Zero divergence.	

The probability of a divergence being at least as extreme as the observed value under the hypothesis is extremely small. This means that each divergence value indicates a level of departure from the hypothetical state that is unlikely to occur by chance alone.

Although the cases discussed involve two-dimensional sorting, the analysis can be expanded to higher dimensional frequency distributions. Attempting to increase dimensionality beyond three or four would not be simple. The reason is that the number of partitions increases rapidly with increasing dimensions and the partitions implemented would have to be guided by a reasoned choice of the structural characteristics most deserving for the test.

In the next example, Raunkiaer's life-form spectra are analyses. The data (Table IVc) are copied from Braun-Blanquet (1932, pp. 298). The diversity partitions (entropy and information of order one) are in

Table IVd[25] Information divergences of spectra, taken in pairs, are tabulated in Table IVe[26]. Divegences are computed according to

$$I(A;B) = \sum_{j=1}^{5} \sum_{i=A}^{B} f_{ij} \log \frac{f_{ij}}{(f_{Aj} + f_{Bj})/2}$$

Table IVc

Region	Raunkiaer's life-forms F	 CH	 H	 G	 TH
Normal	46	9	26	6	13
Spitzbergen	1	22	60	15	2
Death Valley	26	7	18	7	42
Seychelles	61	6	12	5	16
Connecticut	15	2	49	22	12
Paris Region	8	6	52	25	9

Table Ivd

Source	Diversity bits	Specific contribution to diversity bits	Maxima bits	Even-ness%
Total	4.398		4.906	90
Region*	2.584	2.249	2.584	NLA
Life form	2.149	1.814	2.322	93
Interaction	0.335		2.322	14

*NLA- not logically available. Spectra are standardised to equal totals (100).

Table IVe.

	Spitz-bergen	Death Vellay	Seych-elles	Connect-icut	Paris region
Normal	44	12	4	19	26
Spitzbergen		54	69	22	12
Death Valley			14	23	31
Seychelles				34	45
Connecticut					2

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[25] See application program ANOENrc.EXE in the Appendix for details.

[26] See application program INFOPAIR.EXE in Appendix for details.

It can be seen that the Seychelles spectrum is most like the Normal, Spitzbergen least like, and. The Connecticut vs. Paris region most similar. Any of these value can be the basis of comparisons, spatial or temporal.

The following example uses Rényi's (1961) generalised H_α to examine the evolution of entropy of different order over time in the Atlantic Heathland. The data are in Table 1 and the graphs in Figure 9.[27] Alpha ranges from $\alpha=0$ to 20 over years from 1963 to 1981.

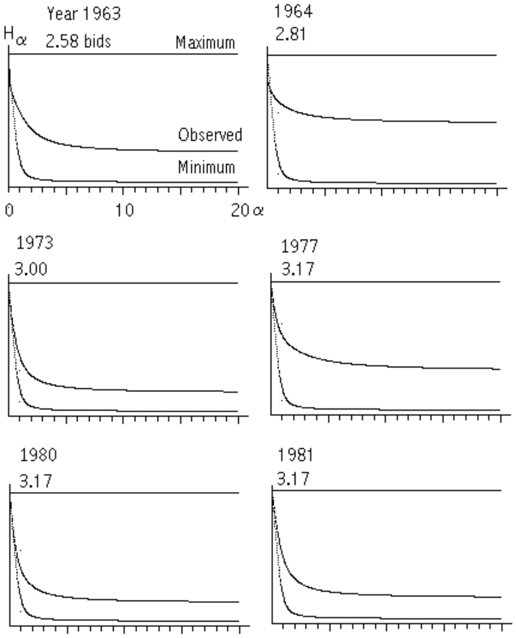

Figure 9. Graphs of entropy of order α at selected years in the Atlantic Heathland. Horizontal axis is identically scaled. Vertical axis is scaled as shown.

Figure 10 depicts the evolution of entropy of order 1 in the Atlantic Heathland over 19 years, and in the Lagoa das Patas sites over 42,200 years. Some entropy values are given in Table 5.[28]

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[27] The program that draws the graphs is ENTROGRA.EXE. See the Appendix.

[28] The relevant program is STREVOL8.EXE. See the Appendix.

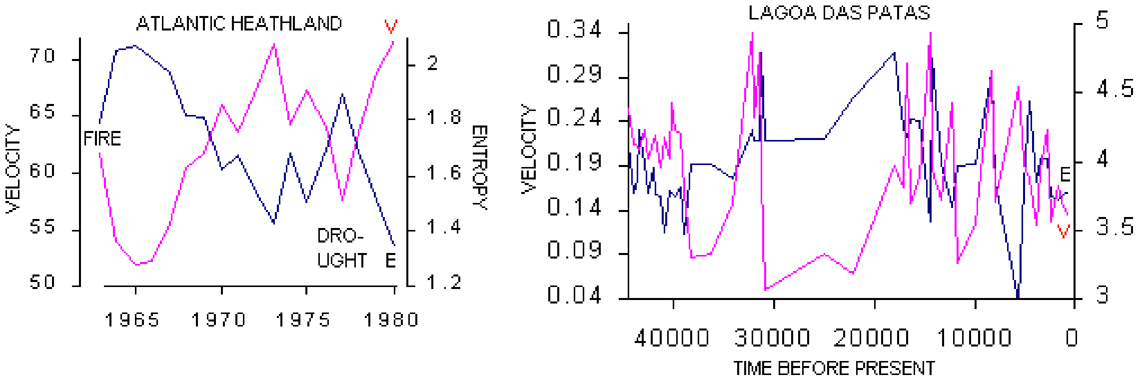

Figure 10. Evolution of entropy E of order one in two sites, with short and long process period length. Velocity graphs V are superimposed for comparison. The Atlantic Heathland graph is based on entropy values in Table 5. Note the rapid decline of entropy and rise of velocity after 1966 in the recovery progresses after intense perturbation by pre 1963 heavy grazing and fire. The Lagoa das Patas graphs are based on pollen records spanning 44 thousand years.[29] Both entropy and velocity respond sensitively to climate change. See the text for further discussion.

Table 5. Entropy values (observed, possible maxima, evenness) corresponding to the Atlantic Heathland graph (E) in Figure 10.

Year	Entropy bits	Cells*	Maximum bits	Evenness %
1963	1.79	6	2.58	69.46
1964	2.05	7	2.80	73.22
1965	2.06	6	2.58	80.02
1966	2.02	9	3.16	64.03
1967	1.97	9	3.16	62.35
1968	1.81	8	3.00	60.46
1969	1.80	9	3.16	57.07
1970	1.61	9	3.16	51.05
1971	1.67	8	3.00	55.70
1972	1.54	8	3.00	51.59
1973	1.42	8	3.00	47.40
1974	1.67	8	3.00	55.88
1975	1.50	8	3.00	50.17
1976	1.69	8	3.00	56.41
1977	1.89	9	3.16	59.88
1978	1.68	8	3.00	56.09
1979	1.50	8	3.00	50.31
1980	1.34	9	3.16	42.53
1981	1.56	9	3.16	49.30

*Number of cells with non-zero values.

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[29] The internet address for records is http://www.ngdc.noaa.gov/cgi-bin/paleo/ftpsearch.cgi at the time of preparation of the example.

Knowing the magnitude of compositional change from year to year adds to understanding of the process. This can be measured in terms of many functions. The following example uses Rényi's (1961) information divergence, in the form of

$$I_{i,i+1} = \sum_{j=1}^{s}\left(f_{ij} \ln \frac{f_{ij}}{(f_{ij} + f_{i+1j})/2} + f_{i+1j} \ln \frac{f_{i+1j}}{(f_{ij} + f_{i+1j})/2} \right)$$

Two paleorelevés are compared in this, $\boldsymbol{F}_i$ and $\boldsymbol{F}_{i+1}$, both containing records of the same s taxa. The measured values are given in Table 6 and the corresponding graph in Figure 11 for Atlantic Heathland.

Table 6. Evolution of information divergence of order one, measured in neighbour pairs of years in the Atlantic Heathland trajectory. Values in last column indicate how closely maximum divergence is approaches. Table 1 contains the basic data.

First year in pair *i*	Information divergence	Maximum divergence possible	Observed divergence as a % of the maximum
1963	2.55	118.01	2.16
1964	1.99	117.94	1.68
1965	2.82	117.87	2.40
1966	1.72	117.87	1.46
1967	2.31	117.80	1.96
1968	1.09	117.73	0.92
1969	0.72	117.87	0.61
1970	0.82	118.00	0.70
1971	0.83	117.94	0.70
1972	1.44	117.94	1.22
1973	2.24	118.00	1.90
1974	0.72	117.94	0.61
1975	0.78	117.94	0.66
1976	2.47	118.00	2.09
1977	1.92	117.93	1.63
1978	1.45	117.94	1.23
1979	1.11	118.00	0.94
1980	1.66	118.00	1.41

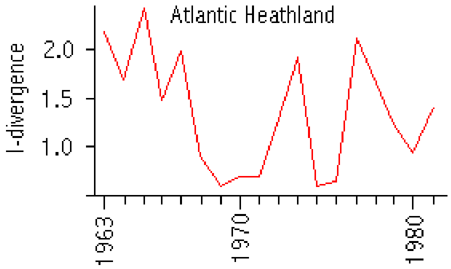

Figure 11. Graph based on data in Table 6. The divergence value at mark 1970, for example, is the divergence of the records taken in 1970 and 1971.

It is obvious that both entropy and information are irregularly periodic. The comparison of the entropy graph with the velocity graph and consideration of the effect of dramatic perturbations on entropy, make it obvious that entropy responds to perturbation in ways that defy the suggestion that entropy should be symptomatic of stability in syndynamic. [30]

Two examples reflect on the relationship of entropy, diversity, and complexity:

a) Two idealised stands, sketched in Figure 12, help with the explanations. The two stands differ in complexity in some obvious ways. But, species diversity does not show this. It is the same, exactly 2

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[30] Reference is made to Kikkawa (1986). for a review of the interpretations of complexity, diversity and stability, and the connections between them in ecological systems,

bits, in both. The difference in complexity becomes clearer in entropy terms when stratification is counted as another source. It does in fact elevate the diversity by 1 bit to 3 bits. This is not unlike saying that the total entropy in the complex stand is the sum of entropy quantities, one owing to compositional disorder and the other owing to stand structure.

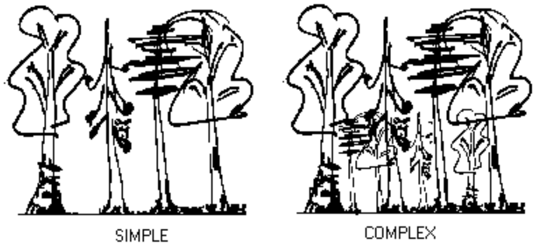

Figure 12. Sketches of stand structures. Four species are involved in different structural arrangements. See discussion in the text.

b) Anand and Orlóci (1997) suggested to measure community complexity as a difficulty in precise description. Kolmogorov's algorithmic complexity is a possible basis for this. The data needed includes species list *S* and observational vector of species proportions $p_1 + ... + p_q = 1$. The p_j values are to be translated into a code. One has to realise that there can be many different functional codes. The trick is to find among these the one that is most parsimonious. The general criterion for assessing parsimony is the average code length,

$$L(S) = \sum_{j=1}^{q} p_j l_j = H(S) + \Delta(S)$$

H(S) is entropy (order one), specific to the collection *S*. The symbol l_j is the length of the code word that replaces p_j. Note that $\Delta(S)$ is zero when *H(S)* is at its maximum value, ln *q*. It is obvious that the magnitude of *L(S)* will depend not only on the number of species (*q*) and their relative abundance (the p_j values) on which entropy depends, but also on the code word length l_j.. [31] It is to be noted further that *L(S)* incorporates logic that is only superficially different from the complexity discussed in connection with Figure 12.

Looking at qualitative definitions, Kikkawa's (1986) comes to mind: *the number of interconnections in the community*. This is obviously implicit in example a) above and it can be worked into L(s) via partitioning (Anand and Orlóci 2000). But the crux of the problem comes when one tries to come up with an actual number, or even better, descriptive vectors of interaction. Since this is an impossible task to accomplish, no absolute measure of complexity can emerge. There will be quantities specific

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[31] Computer program is available from V. De Patta Pillar (vpillar@ecologia.ufrgs.br).

to defined sets of connections or defined sets of interconnected part, and these will be the basis for comparisons within a site at different time points or in different sites at the same time point.

10.4 Another presumably irregularly periodic, but as yet untested, syndynamic variable is Numata's (1979) degree of succession,

$$DS = \frac{V}{n} \sum_{i=1}^{n} L_i d_i$$

Symbol V is a measure of the vegetation cover in the site, L_i is the life span of species i, d_i the dominance value of species i, and n the number of species in the sample. The original paper should be consulted for details and example.

11. TRAJECTORY DIMENSIONS

11.1 “Dimension” may imply nothing more exotic than the common geometric notion: 1 for a line, 2 for a plane, 3 for a cube, etc. But beyond this, “dimension” may conjure up other, less every-day kinds of notions, like a diversity dimension and information dimension of order alpha, complexity dimension, correlation dimension, etc. In each case, dimension materialises as a measured value. The following discussion broadens the concept even further.

11.2 Looking at the sample trajectory in the Atlantic Heathland (Table 1), it is 9-dimensional because it is described in terms of 9 variables. Yet, its latent dimensions in phase space are perhaps 2 or 3. It is this way because the data vectors of the taxa are correlated. In point of fact, the latent dimensionality of a linear system is always the number of non-zero Eigenvalues of the product matrix. Another notion is the "embedding dimension". Considering *s* taxa, the embedding dimension may equal 1, 2, etc. up to *s*, depending on the number of taxa used to define a specific sub-space within the sample's phase space. The order in which the taxa are taken will matter when the embedding dimension is expanded in steps, and for this reason, some criteria would have to be found to establish a unique order of the taxa. This is discussed further in the sequel.

11.3 Having an expert data set, such as De Smidt's in Table 1, the question could be asked if there existed evidence for structural self-similarity associated with the process trajectory. Self-similarity is declared on a process if some characteristic structure re-appears in similar form over and over again across several embedding dimensions, or as one could also put it, across several nesting levels.

11.4 "Structure" may mean anything in the sample that can be measured. It could be the relationship of inter-point distances, defined in terms of composition, and a cumulative frequency distribution of the distances. In the sequel, a distance structure is defined in terms of a distance matrix, and the frequency distribution is defined based on counts of distance values within defined categories. Distance and frequency are thus used as the structural variables.

11.5 Since self-similarity is sought in terms of these structural variables, the measurement of it can be based on any legitimate scale. Schroeder (1991) used a regression coefficient for this outside ecology. If Schroeder's example is to be followed, with changes to accommodate the present context, one may elect to use the number of taxa as the embedding variable. The distance matrix of trajectory points is examined for self-similarity simply by checking how similar are the regression coefficients of the distance frequencies on the threshold distance values across the successive embedding dimensions. A graph, showing the regression values (vertical axis) and embedding dimensions (horizontal axis), helps to pick the "critical embedding dimension" or the "fractal dimension" of the trajectory distance configuration.[32] "Fractal" implies nothing more mysterious than the fact that it may be expressed as a non-integer number. The critical embedding dimension is deemed having been reached where the graph of the regression coefficients starts levelling off, that is to say, the distance/frequency structure is visibly self-similar. An interesting thing is that this levelling off may not occur. When it does not, it signals that the structure under examination is not "self-similar" in the evolving process.

11.6 Speaking in general terms, the fractal dimension of an object of N parts and scale factor r is the fraction $D=\frac{\log N}{\log(1/r)}$. The fractal dimension can be the same as the Euclidean dimension. Consider, for example, the case of a 2.5x2.5 m square. The number of parts in this is 6.25, the scale factor is $\frac{1}{2.5}$ and the fractal dimension is 2. When the object is a process trajectory, the Euclidean dimension could be 2, but most likely the fractal dimension as discussed above would be some non-integer number other than 2.

How to find the numerical value of D when the object is as complex as a process trajectory? Schroeder's (1991) regression approximation can help with this. The method is adopted to the paradigm set in hands:

Step 1. When the time steps are not uniform in width, it should be a first step to establish uniformity by interpolation. This will make all pair-wise relevé distances comparable (as velocities). He (1999) makes comments on step size uniformity.

Step 2. Calculate relevé distances *r*, and then calculate for each *r* a quantity $C(r) = n(r)/N$. This is called the "correlation sum" for some trivial reason that is totally immaterial at this point. Symbol $n(r)$ represents the number of distances counted that are smaller than a given threshold distance *r*. Each value in the distance matrix has its turn to be used as a threshold distance. The value of *N* is the sum of all $n(r)$.[33]

Step 3. $C(r)$ is the base for defining yet another quantity in the manner of $D_2 := \lim_{r\to 0} (\log C(r)/\log r)$

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[32] The concept is explaned by Mandelbrot's (1975). An overview is given by Çambel (1993, Ch. 9) and relevant details are presented for practitioners by Schroeder (1990, Ch. 10). Kenkel and Walker (1993), Walker and Kenkel (1998), and Ricotta et al. (1998) describe ecological applications.

[33] N can be defined other ways such as, for example, the "squared number of points" (see Schroeder 1991, p. 220), but D_2 will not change. The regression statistics "intercept" (Step 3) will be effected.

This is now called the "correlation dimension", for no important reasons. Symbol ":=" is equivalent to reading " D_2 becomes …". The logarithm is conveniently taken to base 2. To pass from logarithm of any base "a" to logarithm of base 2, divide $\log_a r$ by $\log_a 2$. Use coefficient "b" of the regression equation $\log_2 C(r)=a + b \log_2(r)$ to approximate D_2. Variable r and $C(r)$ are structural variables. Figure 13 gives the log r x log$C(r)$ graph for the Lagoa das Patas trajectory. It should be noted that the graph given is specific to embedding dimension 1.

Step 4. Compute regression coefficients at each embedding dimension. Construct graph (Figure 14).

Structural variables other than distance can also be used. Neither the structure analysed nor the method is limited to Euclidean distance.

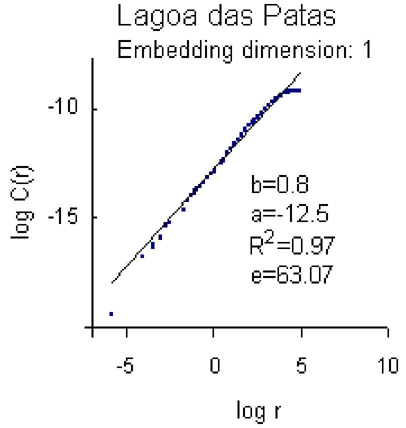

Figure 13. The relationship of structural variables $C(r)$ and r at embedding dimension. Legend to regression statistics: b – regression coefficient (estimate of D_2), a – intercept on vertical axis; R^2 – coefficient of determination; e – error sum of squares. Note that $(39.746/1775)^{1/2}$ =0.184 is the standard error of regression. The analysis uses 30 sets of 49 component scores derived from paleopollen data of 170 taxa in 49 paleorelevés. Selection is taken directly from the data source. Locality and contact person for the Lagoa das Patas data set are identified in Table 2.

11.7 The regression coefficient (*b*) in Figure 13 is an estimate of the unknown D_2. Other sample statistics include the intercept (*a*), error sum of squares (*e*), and coefficient of determination (R^2).

11.8 The evolution of Euclidean distance, angle, and information divergence is displayed in Figure 14.[34] The Euclidean distance and

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[34] FRACTAL3.EXE is the relevant program. This is described in the Aoppendix.

information divergence functions are defined in Section 10. The angle enclosed by the *u*-valued relevé vectors X_j and X_k is given by α in

$$\cos\ \alpha = \frac{\sum_{i=1}^{u} X_{ij} X_{ik}}{\sqrt{\sum_{i=1}^{u} X_{ij}^{2} \sum_{i}^{u} x_{ik}^{2}}}$$

Variable *b* increases in the case of each structural variable (not in the RND case) in a clearly defined manner up to some embedding dimension, then after that in each case its graph levels off. Variable *e* evolves on similar paths. R^2 is more or less flat and *a* tends to mirror *b*.

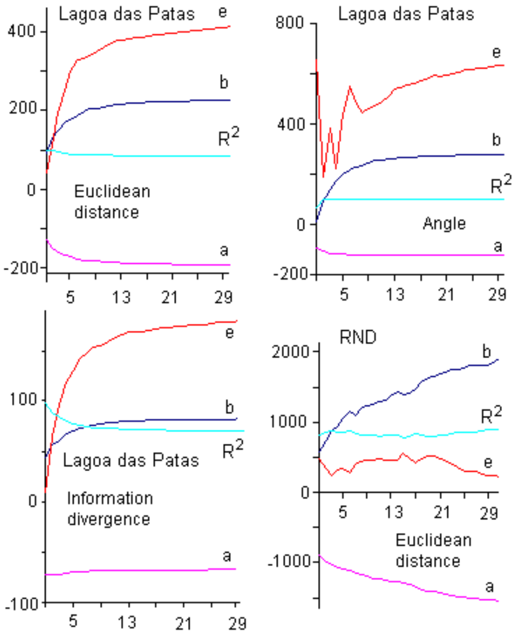

Figure 14. Structural variables and embedding dimensions in the trajectories as identified. Horizontal axis is the embedding dimension scaled from 1 to 30 (taxa). Vertical axis scales: 1x*e*, 100x*b*, 100xR^2, 10x*a* in Euclidean; 20x*e*, 100x*b*, 100xR^2, 10x*a* in Angle; 0.25x*e*, 100x*b*, 100xR^2, 10x*a* in Information

Divergence; 1x*e*, 10x*b*, 100xR^2, 10x*a* in RND. The RND data set contains random permutations of the Lagoa das Patas paleorelevés. Legend to symbols: *e* – error sum of squares for regression, *b* – regression coefficient (estimate of D_2), R^2 – coefficient of determination; *a* – intercept on vertical axis. See Figure 13 for data information and for the regression estimates obtained at embedding dimension 1. The D_2 value or equivalently the b value at the critical embedding dimension is the fractal dimension of the distance/frequency structure..

What do these mean in process terms? – high redundancy of taxa, and for that reason, mandated structural self similarity beyond a specific embedding dimension. The RND case is different. There, the rise of *b* is continuous, R^2 changes little while *e* undergoes irregular oscillation, and *a* mirrors *e* rather closely.

11.8 A given embedding dimension *u* implies that the analysis is performed with the first *u* variables taken in order, or with the first *u* Eigenvectors when Eigenanalysis precedes regression manipulations. Related to what has been discussed in the previous paragraph, the smaller the critical embedding dimension, that is, the sooner the levelling off occurs, the higher is redundancy in the sample. In other words, fewer than the total number of taxa can describe the full-dimensional distance configuration. The expansion of the list beyond that point, does not improve materially one's view of the process.

When redundancy is considered in this manner, it is quite conceivable that by taking the taxa in a different order, a different outcome will be seen. Establishment of a unique order of taxa is thus a problem to be solved. The reader may consult Orlóci (1978, p.26 et seq.) regarding schemes of redundancy analysis for character ranking that could help to minimise the critical embedding dimension.

11.9 It is clear that the dimension calculations serve a definite purpose: to determine the level of self-similarity in the trajectory. But whatever the outcome, the critical embedding dimension, or the lack of one, is characteristic of the trajectory. It can be made a basis for comparisons and categorisations.

11.10 An interesting fractal behaviour has been discovered by May (1976) while playing with the logistic equation $x_{t+1}=ax_t(1-x_t)=ax_t-ax^2_t$. Recursive iterations through values of *t* at different values of the scale factor *a* generate a bifurcation diagram. An anecdotal discussion is found in Gleick (1987, p. 71) that puts the results into perspective.

12. PROCESS PARALLELISM

12.1 Von Post (1944) examined some composite paleopollen diagrams from different sites and discovered a reoccurring regularity in the diagrams' morphology. This gave him the idea of parallel vegetation development in different regions. Selling (1948) may be consulted for interesting applications of the van Post method in the Hawaiian Islands.

12.2 The von Post approach is an ingenious way to compare pollen diagrams, but it is not the most convenient one on first site for probabilistic testing of regional parallelism. The testing is more easily done in direct comparisons of trajectory mappings. The method to be described measures parallelism as the level of co-ordination determined based on the point-by-point similarity of trajectories in the manner used by and Orlóci (1998) and He and Orlóci (1998).

12.3 Any trajectory point (the tip of any observational vector **X**) is endowed with the potent property of undergoing stochastic oscillations, and as such, being at an *a priori* uncertain locus of phase space at any future point in time. It is justified, therefore, to regard the **X** vector actually observed, as a member of the point swarm, any one of which could have materialised if chance dictated it that way. One cannot know exactly the radius of the point swarm, only make provision for it in the manner of expanding tolerance belts around the tip of **X**. In the examples to be discussed, the radius starts at 0 and increases incrementally in small steps up to some arbitrary upper percentage limit. The percentage applies to the size of the phase space co-ordinates.[35]

12.4 Comparisons of two trajectories (A,B) is conveniently done by the topological index[36]

$$C_{AB} = \frac{M}{p(s-1)}$$

---

[35] "Tolerance belt" here should not be confused with the probabilistic "confidence belt" used in statistical estimations to handle the sampling error. The role of the tolerance belt is to help incorporate the possible effects of process stochasticity in comparisons of trajectory points.

[36] "Topological" is used here with the explicit purpose to link similarity with the general notion of topography. "Topology" is then the study of the topography of objects as in land surveys, landscape ecology, etc. "Topology" is definitely not intended here to imply the mathematician's study of geometry on a "rubber sheet" as S. Smale has used the term to make vivid the nature of the concept.

The value of C_{AB} ranges from 0 to 1. Letter M is symbol for the number of matching scores (on all axes), p the number of axes for the trajectory with the lesser number of axes, and s the elapsed period length in uniform time step units for the trajectory with the shorter period length. The comparison involves only the chronologically common portion of the trajectories. The theoretical expectation of C_{AB} is taken to be 0.5 under the assumption that compositional transitions are ruled by the equal chance law. Values above 0.5 indicate co-ordination, and below 0.5 discordance, both more intense than expected.

12.5 The method by which trajectory co-ordinates are transformed into "forward" and "backward" scores, before matches are counted, obeys the following conventions:

a) “Present" refers to the same time point or the same narrow time interval in all trajectories. In paleopollen sampling, the top sediment horizon may miss being consistently from the present by a wide margin when erosion, decomposition, or other perturbation has been active. Because of this, it makes sense to repeat the comparison of the trajectories at varying lag of forward or backward shift. The aim is maximisation of C_{AB}.

b) It is assumed that trajectory points are separated by the same time interval. Interpolation is used to establish a uniform time step width.

c) All co-ordinates on all axes undergo transformation in the following manner:

> "0" is assigned if the tolerance belt around the given point includes the other compared point. If it does not, then:
>
> > "+" is assigned if the co-ordinate value of the given point is greater than the co-ordinate value of the chronologically next (forward) point on the same axis.
> >
> > "−" is assigned if the relation is reversed.

d) When matches are counted, reference axes have to be paired between the trajectories. There is no natural way for pairing the axes of reference systems when the trajectories come from different floristic sites. To overcome this problem, the axes may be paired in a manner that will maximise the value of C_{AB}. A method is described in the example below.

12.6 The first example involves fictitious trajectories, shown in Figure 15 (after He and Orlóci 1998). The co-ordinates are simulated paleopollen densities (see Table 7).

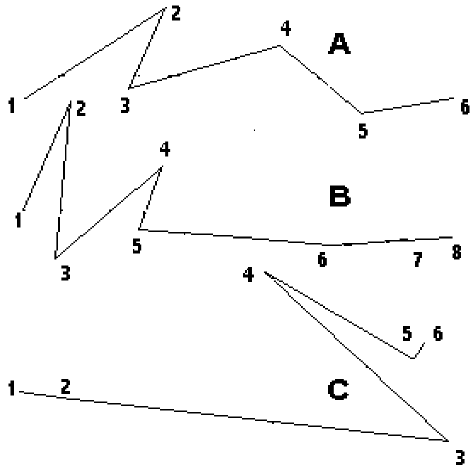

Figure 15. Trajectories from fictitious sites A, B, C. Numbers indicate relevé points. The co-ordinates are listed in Table 7. Example adapted from He and Orlóci (1998) with revisions.

Table 7. Co-ordinate data (Part a) and rankings (Part b) corresponding to the trajectories in Figure 15. Columns headed by Sc contain directional scores assigned according to the rules described in the text. Subscripts 1 and 2 indicate the axes of the reference space in which the graphs of Figure 15 are drawn.

Time steps	X_{A1}	Sc	X_{A2}	Sc	X_{B1}	Sc	X_{B2}	Sc	X_{C1}	Sc	X_{C2}	Sc
Column #	1	2	3	4	5	6	7	8	9	10	11	12
Part a												
8					13		14					
7					25		21					
6	12		26		21		07		10		71	
5	38		45		48		20		19		70	
4	31		28		42		11		99		62	
3	59		27		68		10		61		93	
2	74		23		90		09		92		77	
1 (present)	91		26		120		10		94		80	

Part b

8					1		6					
7					3	+	8	+				
6	1		2		2	—	1	—	1		3	
5	3	+	6	+	5	+	7	+	2	+	2	—
4	2	—	5	—	4	—	5	—	6	+	1	—
3	4	+	4	—	6	+	3	—	3	—	6	+
2	5	+	1	—	7	+	2	—	4	+	4	—
1 (present)	6	+	2	+	8	+	3	+	5	+	5	+

The following are some of the numerical results:[37]

a) Trajectories are compared in pairs. The paired axes are (X_{A1}, X_{B1}) and (X_{A2}, X_{B2}) for *A* and *B*, (X_{A1}, X_{C2}) and (X_{A2}, X_{C1}) for *A* and *C*, and (X_{B1}, X_{C2}) and (X_{B2}, X_{C1}) for *B* and *C*. The choices of axes for pairing are indicated by local maxima in the correlation matrix:

	X_{B1}	X_{B2}	X_{C1}	X_{C2}
X_{A1}	.943	-.082	.429	.657
X_{A2}	-.217	.156	.000	-.489
X_{B1}			.371	.771
X_{B2}			-.861	.290

b) The counts and other numerical results for *A,B* (columns 2, 6 and columns 4, 8, Part B, Table 7) include *M*=10, *p*=2 and *s*=6. Based on these, C_{AB} = 1.0 or 100%. This implies that trajectories *A* and *B* are indistinguishable in terms of their topology. The set of similarity values and probabilities (α) are as follows:

Trajectory pairs	*AB*	*AC*	*BC*	Expectation theoretical	Expectation iterated	Bias
C	1.0	0.60	0.60	0.500	0.519	0.019
α	0.003	0.46	0.46			

The *C* value measures the strength of topological similarity. The probability value indicates the chances that a *C* value at least as large as the observed could occur by chance when syndynamics is ruled by random transitions. Speaking as if one were dealing with real trajectories, the evidence points to perfect process co-ordination in sites *A* and *B,* and weak co-ordination in sites *AC* and in sites *B,C*.

c) Up to this point the tolerance radius was set to zero. When it is raised to say 25%, the results are different:

Trajectory pairs	*AB*	*AC*	*BC*	Expectation theoretical	Expectation iterated	Bias
C	0.7	0.4	0.4	0.500	0.390	0.110
α	0.06	0.57	0.57			

Taking 0.39 as the critical similarity value, trajectories *A* and *B* still appear co-ordinated, but trajectories *A,C* and *B,C* appear definitely discordant.

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[37] The relevant program is TRAJCOGR.EXE. See the Appendix.

12.7 Results are presented for the Lagoa das Patas, Jackson Pond, and RND comparisons in Figure 16 and in Table 8 over the full range of tolerance limits.

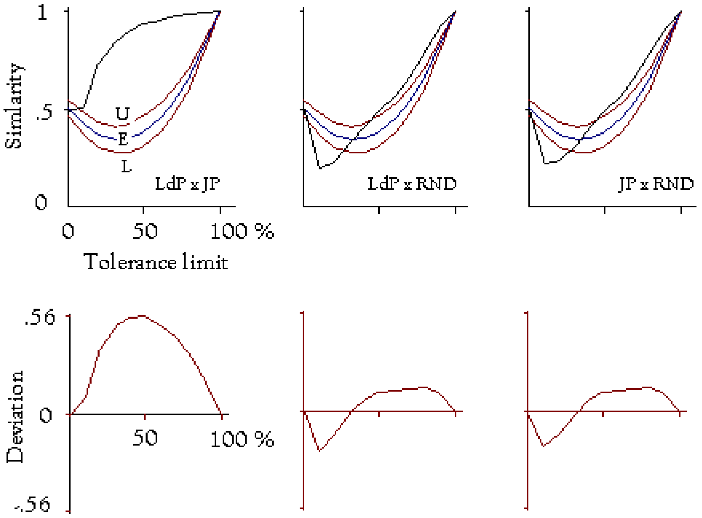

Figure 16. Graphs of the topological similarity index (OB column in Table 8, vertical axis in graphs) and the deviations of similarity from random expectation (column E in Table 8). Similarity values are maximised by choice of lag shift up to 10 time steps. Horizontal axis: expanding tolerance limit. U and L: limits of the 0.95 probability confidence interval. RND: a fictitious trajectory under the assumption of random transitions. LdP: Lagoa das Patas. JP: Jackson Pond.

Some comments are in order:

a) Time step width is interpolated to 100 years. Time points match between the trajectories. The period lengths are accordingly 205 steps (JP), 446 (LdP), and 446 (RND). Each is described by 3 sets of principal components co-ordinates. .

b) The tolerance radius is incremented in 10% steps from 0 to 100%. Computer power permitting, the increments should be made much smaller to improve precision. Regarding tolerance limits, suppose that a given trajectory point's co-ordinate on a given axis is 10 and the co-ordinate of the next point on the same axis is 12. The difference is 2. The two points will appear indistinguishable at a tolerance radius of 25%, since the limits 7.5 and 12.5 include 12. The tolerance limit chosen will thus affect the transformation of the co-ordinates into +,0,- scores. This will, in turn, influence the perceived level of co-ordination in the trajectories

c) The iterated expectation (E) is an average similarity, obtained in a large number of iterations based on random permuted co-ordinate values. V is symbol for the variance of E.

d) The confidence limits (LL and UL) are based on the Normal distribution with mean E and variance V.

e) Trajectories are shifted with lag 0 to 10 in unit time steps. That the upper limit 10 is not a sufficiently large value is apparent from the fact that lag 10 comes up I each case as the lag at which the similarity index is maximal. With sufficient computing power, the upper limit value of the lag should be made dynamic..

Table 8. Numerical results from comparisons of the Lagoa das Patas (LdP), Jackson Pond (JP), and RND trajectories. Legend of symbols: TL — percent tolerance limit; E — iterated expected similarity under the assumption that the true trajectories are neither co-ordinated nor discordant; V — iterated variance of the expectation; LL and UL — limits of the 0.95 probability confidence interval about E; Lag — the number of time steps by which the trajectories have to be shifted to make the observed similarity maximal; OB — observed similarity; OB-E — deviation of observed similarity from expectation; α — probability of an at least as extreme deviation as the observed.

TL %	E	V	LL	UL	Lag	OB	OB-E	α
Trajectory pair: LdP x JP								
0	.5051	.0005	.4615	.5487	10	.4885	-.0166	.77
10	.4222	.0008	.3671	.4773	10	.5163	.094	.0033
20	.368	.0011	.304	.432	10	.732	.3639	.0033
30	.341	.0012	.2721	.4099	10	.8398	.4988	.0033
40	.3467	.0014	.2728	.4207	10	.897	.5502	.0033
50	.384	.0015	.3083	.4596	10	.9395	.5555	.0033
60	.4472	.0013	.3768	.5176	10	.9526	.5053	.0033
70	.5383	.0011	.472	.6045	10	.9787	.4404	.0033
80	.6659	.0007	.6131	.7187	10	.9869	.3209	.0033
90	.8226	.0003	.7868	.8583	10	.9983	.1757	.0033
100	1	0	1	1	10	1	0	1
Trajectory pair: LdP x RND								
0	.5051	.0005	.4615	.5487	10	.5179	.0128	.2733
10	.4222	.0008	.3671	.4773	10	.1944	-.2279	1
20	.368	.0011	.304	.432	10	.2238	-.1442	1
30	.341	.0012	.2721	.4099	10	.3235	-.0176	.7633
40	.3467	.0014	.2728	.4207	10	.4101	.0633	.01
50	.384	.0015	.3083	.4596	10	.4885	.1045	.0066
60	.4472	.0013	.3768	.5176	10	.5637	.1164	.0066
70	.5383	.0011	.472	.6045	10	.6601	.1218	.01
80	.6659	.0007	.6131	.7187	10	.8006	.1347	.01
90	.8226	.0003	.7868	.8583	10	.9183	.0956	.0066
100	1	0	1	1	10	1	0	1
Trajectory pair: JP x RND								
0	.5051	.0005	.4615	.5487	10	.4934	-.0117	.73
10	.4222	.0008	.3671	.4773	10	.2189	-.2034	1
20	.368	.0011	.304	.432	10	.232	-.1361	1
30	.341	.0012	.2721	.4099	10	.3088	-.0323	.9233
40	.3467	.0014	.2728	.4207	10	.4035	.0568	.0166
50	.384	.0015	.3083	.4596	10	.4869	.1029	.01
60	.4472	.0013	.3768	.5176	10	.562	.1148	.01
70	.5383	.0011	.472	.6045	10	.665	.1267	.01
80	.6659	.0007	.6131	.7187	10	.8006	.1347	.01
90	.8226	.0003	.7868	.8583	10	.9166	.094	.01
100	1	0	1	1	10	1	0	1

f) The observed similarity values is the maximum of maxima in the sense that it is taken at a point on the curve where the deviation from expectation is maximal and at a lag that maximised the similarity. The statistics at maximum deviation are as follows:

Sites compared	Observed similarity (OB)	Iterated expectation (E)	OB-E	95 % confidence interval		Tolerance limit %	Lag in time step units	α
				Lower limit	Upper limit			
LdP x JP	.940	.384	.556	.308	.460	50	10	<0.01
LdP x RND	.194	.422	-.228	.367	.477	10	10	1.00
JP x RND	.232	.368	-.136	.304	.432	20	10	1.00

The high level of process co-ordination in LdP and JP, and the high discordance in both trajectories with RND are noteworthy as a general tendency.

g) The last column contains the probability that a similarity value at least as extreme as the one actually observed could occur by chance when the trajectories portray pure random transitions. Probabilities help to categorise the observed similarity value expressed as a percentage $(100(1-\alpha/0.5)$. The categories are: being the expected kind when near zero, being discordant when large negative, or being concordant when large positive.

h) When two trajectories of chance transitions are compared, the similarity and deviation graphs are like in Figure 17. The corresponding numerical values are given in the table:

TL %	E	V	LL	UL	Lag	OB	OB-E	α
Traj pair: RND x RND								
0	.5509	.0006	.5004	.6014	0	.585	.034	.09
5	.5196	.0008	.4627	.5766	0	.5646	.0449	.08
10	.4796	.0007	.4258	.5334	0	.4897	.0101	.43
15	.4518	.0008	.3974	.5061	4	.4557	.0039	.38
20	.4225	.0008	.3678	.4773	4	.4421	.0195	.22
25	.4082	.0005	.3613	.4551	4	.4285	.0203	.19
30	.4051	.0006	.3564	.4537	9	.4013	-.0038	.52
35	.4065	.0007	.3526	.4605	9	.4149	.0083	.34
40	.4146	.0007	.3613	.4679	9	.4353	.0207	.19
45	.4282	.0005	.3816	.4747	9	.4693	.0411	.05
50	.4571	.0008	.4016	.5125	9	.4693	.0122	.26
55	.4815	.0007	.4303	.5327	9	.4625	-.019	.76
60	.5191	.0009	.459	.5791	9	.4693	-.0498	.97
65	.5519	.0007	.4977	.6062	9	.5374	-.0146	.66
70	.6059	.0008	.5511	.6606	9	.6054	-.0005	.46
75	.665	.0008	.6083	.7216	9	.653	-.012	.63
80	.7225	.0006	.6744	.7706	9	.6938	-.0287	.87
85	.7851	.0005	.7399	.8302	9	.7346	-.0505	.99

90	.8651	.0004	.8259	.9044	7	.8435	-.0217	.82
95	.9419	.0001	.9185	.9653	0	.9387	-.0032	.68
100	1	0	1	1	10	1	0	1

Note, that in Figure 17 here too maxima are shown in the same manner as before.

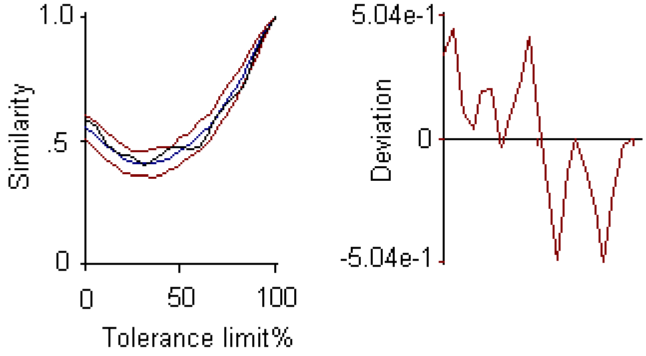

Figure 17. Similarity and deviation graphs for the RND x RND comparison. See explanations in the text.

12.10 At this point the question can be asked:

Observing the graph's unique shape in Figures 16 and 17, would it not be better to use the entire graph rather than just a single similarity value to characterise trajectory parallelism?

The dilemma is the same as in the problem of choosing between point diversity and curve diversity. The point is just a point, but its presentation is simple. The curve is a “picture”, and for that reason, it has very high information content.

13. THE MAKING OF A THEORY

13.1 On first thought, one may say that a theory should be valid if it invoked ideas about *what*, *how, why*.[38] Proceeding in steps, when the *what* was handled adequately, the *how* can be posed, and then an answer to the *why* can be attempted. It is a fact that the answer in terms other than some crude approximation is probably impossible on first attempt. Rather, it+ should grow around itself through successive attempts, often by different workers.

13.2 Explanation of the orbital mechanics of planets comes to mind for an example. It took ages literarily – and many theories embraced and then ditched – before a clear enough picture emerged, enabling Kepler to answer the *how* question in mathematically precise terms and Newton to explain *why* the planets do not fly off their orbits. Clearly, *why* was the most difficult question, because it draws on intangibles. It could not be put before the tangibles were adequately described.

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[38] Wiegert (1988) and the relevant sections in Anand (1994, 1997) should be consulted.

13.3 In the above regards, syndynamics (the process) falls into the difficult-to-fathom category. An event past, it leaves only fuzzy traces behind of its existence from which the paleoecologist may try to postdict the true process characteristics. What are the tangibles of this "syndynamics"? They are objects, mainly paleopollen or other plant tissues remains, trapped intact in sediments, air and water trapped in ancient ice, and the likes. The tangibles convey information about changes in community composition, the timing, and the environment. What are the intangibles? These are characteristics that do not have the objective presence of, say, the pollen grain, and do not leave behind "footprints", like the plant that produced the pollen. The intangibles have to be inferred from knowledge of the tangibles.

The following concerns process intangibles revealed in the foregoing examples:

a) Alternating dominance of determinism and randomness. This is detectable in the short trajectory of the Atlantic Heathland and also in the long trajectories of Jackson Pond and Lagoa das Patas.

b) Non-stationary Markovity under cumulative random effects. Such effects were seen to lead to explosive change that force the process to exit one phase and enter another without involving environment mediation.

c) Attractor mobility. Sharp directional and point distance changes in the trajectory are the indications. Attractor movement may be a low-amplitude fluctuation. To be sustained and directional, the attractor conditions must undergo sustained directional change. Delayed response is the rule.

d) Velocity oscillations. There is a clear link of syndynamics to changes in global climatic conditions. Sustained, low process velocity appears to coincide with periods of global cooling. Interestingly, climate change need not be extreme to trigger a significant syndynamic response. The response is relatively low-intensity in the equatorial region, increasing on average with increased latitude.

e) Self-similarity (auto-correlation). The distance structure of trajectory points indicates this clearly during periods of dominant determinism.

f) Dependence on initial conditions. Different initial conditions define different trajectory paths to the same attractor.

g) Global process parallelism. Parallel syndynamic response under impact of the forcing factors on a global scale is established in the examples.

13.4 Not all facets of a system have to be considered by a theory to be general. But a general theory must hold its central tenets true across scales. Newton's laws are this kind. They apply in all places at all times, or at least they were thought to be that way. By the same token, an ecological theory formulated about phase structure, Markovity, attractor behaviour, periodicity, fractal nature, the effects of initial conditions, process parallelism, or the likes, should qualify as a general theory.

13.5 A theory can be valid even if it addresses just a narrow band of embedding dimensions. But if this fact is left ambiguous in presentations, frivolous arguments can follow, shadowboxing as it were, and perceptions clash. An example is the interpretation of facilitation. Facilitation or action/reaction feedback is undeniably one of the mechanisms that drive syndynamics, but not readily perceived at all scales. The ecologist observing compositional transitions in the short run may come down hard against facilitation and may overrate the effect of something else, say seed bank composition. The latter is, of course, a determinant of regeneration, rodent populations, etc.

14. COMMUNITY-ORGANISM

14.1 Ecologists often argue for or against the community-organism analogy. The community-organism idea is explicitly expressed in Clements' clever theorisations about succession. Tansley (1920) uses “quasi organism” when characterises the community. But it must be kept in mind that when viewed as an “organism” or “quasi organism”, the community is attributed properties that undergo a maturation process.

14.2 The organismal view in essence, is not unlike regarding a complex system as a tightly organised collection of “cells”, like in a “cellular automaton”. Each cell is connected to every other through tangible and intangible links. It is in the very nature of such a system that it will try to exclude the consequences of any types of perturbation from taking roots if those are inconsistent with the system’s internal regulation. The organism analogy is of course unnecessary to make the strong point that communities are organised, on which Greig-Smith (1986) makes strong points, and as such, acting as highly integrated complex dynamic systems they respond to perturbation in very complicated, yet repetitious ways.

15. HOLISM

15.1 Holism is implicit in the complex dynamic systems view of the community and so is the keen interest in the “big" picture. The bedfellows of this camp believe in a well-conceived overall conceptual framework that does not come perfect on first attempt of formulation, but evolves step-by-step in successive approximations through revisions, as new facts emerge about details. The discovery of new facts, such as for example the Milankovitch (1941) type regularities in planetary motion, or the aberrations in planetary motion that could cast doubt on the perfectly deterministic nature of celestial mechanics, refine the general picture, not necessarily invalidate it. This is also the same way in syndynamic studies: details that Fekete (1992) attributes to the reductionist approaches in the last 40 years are now helping the formulation of a more complete model of syndynamics without rendering obsolete the classical complex system view that puts a premium on what has been described as "emergent" community level characteristic.

15.2 Some believes that the holistic approach in ecological science is ripe to be discarded, or more charitably put, not to be embraced in dynamic studies. Some expressed the belief that a general theory should be built in steps from elementary truths that should come from site-specific studies at Harper's (1982) population level or even below, the cellular and molecular levels. But soberly, predilections and personal views notwithstanding, one has no justification to rate reductionism higher than a mode of revealing truths about details. This is exactly the point that Fekete (1992) made when suggesting that while at some scales – like as dominance sorting by our terminology and gap or patch dynamics in others (Shugart 1984) – the reductionist approach may dominate, at other scales – such as for example the Delcourts' long-term dynamics (Delcourt and Delcourt 1987) – to be adequately treated, a truly holistic community level approach is needed.

15.3 The suggestion that there is a shift towards reductionist approaches (Glen-Lewin, Peet, and Veblen 1992) is a plain misinterpretation. The fact of the matter is that Science at large is turning increasingly toward a holistic mode of thinking — a trait of reasoning in ecology at least as old as Kerner's work, and one that never ceased to be a constant among the hallmarks of ecological thinking. The need for holism is rooted in the desire to gain deeper understanding of interrelationships in complex systems. Gleick (1987) and Çambel (1993) narrate the story at a literate level. Usher (1981,1992), Shugart (1984), Fekete (1992), van Hulst (1992), Anand (1997), Anand and Orlóci (1997, 1998), and He and Orlóci (1998) make strong points about it in an ecological context. But it is with van Hulst's (2000) paper that the contemplative line in the syndynamic paradigm comes to full circle. He emphases plant scalings, general constraints and trade offs in which the generalisation of the core process of syndynamics, *i.e.* dominance sorting in gaps, should be found. These bring to mind early readings of the forest ecological classics: G.F. Morozov, A.K. Cajander, and V.N. Sukachev — to mention just a few. Walker and Kenkel's (2000) adaptive geometric studies are feeding new information into this line, and so are many other that they and van Hulst reference.

17. REDUCTIONISM

16.1 It is a fact that the reductionist approach coexisted with the community level approaches through much of the history of modern ecology. Yet few prefers even to go as far back as the relevant section in "Pflanzensoziologie" (p. 305 in English edition 1932) -- the landmark text of J. Braun-Blanquet, first published in 1927 -- where past tense is used when mentioning the study of vegetation development as a regional species replacement phenomenon. Braun-Blanquet, an ardent "holist" himself, sharply directs attention to studies by his contemporaries with interest in the principles of development, emphasising the role of populations.

16.2 An interesting co-incidence is the surfacing of the calculus-laden Lotka-Volterra approach early last century (Lotka 1925 and Volterra 1926). It started to show its monochrome banner in animal population studies about the same time as the phytosociological/ecological approach was gaining comprehensive expositions, not the least in J. Braun-Blanquet's "Pflanzensoziologie" and in F.E. Clements' “Plant Succession and Indicators” (1928). On first sight, Lotka-Volterra can appear very sophisticated, particularly to the uninvolved, easily impressed by mathematical elegance and simplicity, and very useful to the instructor starving for a good example from the life sciences in his *Mathematics 101* class. But no kind of first impression can hide the fact that while the phytosociological-ecological approach stimulated synergistic expansions of knowledge about a complex system, the ecosystem and its components, Lotka-Volterra hardly progressed beyond square one in symbolic formulations of logistics in the simplest of systems, hardly expected in natural communities. This is not to say that Lotka-Volterra, or its resurrection in life-energy terms by Huang Xi and Zu Yuangang (1999), should not be useful. The better understanding of low-dimensional model processes has been served (see May 1981, Czárán 1998 and references therein), and further benefits should come about the evaluation of population reproductive strategies, life history types, facilitation, tolerance, inhibition competition, resource related patch dynamics, seed bank related effects, cohort dynamics, etc.[39]

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[39] The reader will find explanations of the terminology in Harper (1977), Connell and Slatyer (1977),

16.4 Quotations broadcast far and wide by Peet and Christensen (1980) are instructive regarding the topics above. But the incompleteness of the message is striking in specific instances.

Some examples:

"The view of succession as a community or species replacement sequence driven by autogenic [self generated] environmental modification has been rejected.”[40] It is not clear if perception dictated rejection at a specific scale or at any scale whatsoever.

"Succession can be understood solely in terms of the interaction of evolutionary strategies [of populations] without reference to a deterministic progress toward climax." [41] Quite obviously, in hind site of course, a valid high-level notion is discarded, the attractor concept of chaos theory.

"… a complete theory of vegetation succession should be sought at the organismic, physiological, or cellular level and not in emergent properties of populations and communities."[42] One could also suggest with equal legitimacy to rewrite a model of the Kepler-Newton-Einstein universe, less the force of gravity.

Peet and Christensen (1980) categorise these utterances as expressions of the reductionist approach, “... emphasising life-histories and competitive relations of species rather than the emergent properties of communities.” They add: “To date [1980] few data have been gathered appropriate for evaluating their [the utterances’] relative utility and generality.” Now, decades later the question is being asked: “What did the reductionist approach achieve in the way of finding governing principles? ” Ritchie (1995)[43] answers: "The search for general principles governing vegetation succession has largely failed.” Some may, of course, be willing to comment, if not already did so: “not enough of the same. Give the thing more time!” Some may even embrace the ultimate ecological *conclusiuncula*: “general principles were not found *ergo* general principles do not exist.”

Grime (1979), Watt (1947), Horn (1981), Fekete (1998), Egler (1954), and Mueller-Dombois (1992).

[40] The authors refer to others for substantiation, including Connell and Slatyer (1977), Drury and Nisbet (1973), Egler (1954, 1976), Niering and Egler (1955).

[41] Pickett (1976).

[42] Drury and Nisbet (1971, 1973).

[43] See also McIntosh 1985, van der Maarel 1988, and Weiner 1995.

17. NEWTON AND THE PROVERBIAL APPLE

Folklore has it that an apple fell on Newton's head and Newton conceived the law of gravity. This is probably not true. But it really does not matter. A general truth is expressed. Clues can come from macro manifestations of the process that can lead to identification of general principles. Anyone can see that, paraphrasing Bronowski (1978), an apple is falling down and not falling up. When such a simple thing with complicated consequences is described in precise terms, pertinent questions follow and new insights revealed.

APPENDIX

Brief comments are offered at this point, regarding application programs that should help the interested reader to reproduce graphs and other results, or to workout new ones with their own data. The programs are self-contained applications, downloadable from http://publish.uwo.ca/~lorloci/.

It is appropriate to forewarn, that applications assume more than just a cursory familiarity with the topics. They are interactive and the user is frequently called upon to make technical decisions before a run can get underway.

1. In general, it is good practice to keep data file and application program in same folder. Data input is from text files with names that contain the extension .tru, and with structure usually in the form of:

```
2
5
2
3
10
5
8
8
11
6
6
81
153
199
28
9
33
17
53
7
```

Elements above are from Table IVa; 4 rows (flora element types; 5 columns (functional types)

This is file ManchuriaRaunkiaer.tru, containing the data set from Table IVa in the text .

2. The programs direct some output to the screen, but mainly to files in the folder where the programs reside. The output includes a master file, named PRINTDA, that holds vital details about the run and also results. Other files may be created, as needed, to hold the specific data that may be used to create tables, curves, etc.

3. Use program CONAR8.EXE to perform canonical contingency analysis. The graphs of Figure 2 are drawn by this application. Try the program with the data set in Table 1. Transpose the data set, so that there will be 9 rows (taxa) and 19 columns (relevés at successive time points). Enter the data on file Lippe9x19.tru in the format as in the example above. Also create an ages file, ages19.tru, a column of numbers from 1 to 19. (Note, the sequence is from present to past in this case.) CONAR8.EXE interrogates the user. Answer as follows:

```
Output file name extension: Lippe
Store intermediate results: Y
(Select Lippe9x19.tru from the explorer window)
Number of rows: 9
Number of columns: 19
```

Data set a time series: Y
(Select ages19.tru from the explorer window)
Standardization of raw data option: 1
Data adjustment as in CCTA: N
Equal block size adjustment: N
Autocorrelation: N
Correlation with position: N
Weight option: 3
Weight canonical scores by Eigenvalue: Y
Graph size: 0.65
Tick marks (in 1000 time step units): .002

The graphs are stored in BMP format. Open these in a paint file and edit.

4. Try to use MARKOR8.EXE with Lippe9x19.tru as the input file. Answer "step size upper limit" by an integer, say 4. This will trigger the programm to test for Markovity at step size 1,2,3 and 4. Select randomisation option 1 (simplest to interpret) and set % threshold to .01 or some smaller value on a more powerful PC. The smaller is the threshold, the longer will be the Markov chain segment fitted to the data. The number of iterations chosen should be large, say 100 or more. Read all text on the screen and in the PRINTDA file. These give an idea of what has been computed.

5. Program PCAR8.EXE performs linear mapping. The algorithm is dicussed in detail in the text. Test the pogram with file Lippe9x19.tru. Choose the covariance (option 2) or product moments (option 3) from the options. Structure will be retaining. Eigenvector adjustment should be as in option 1.

6. The STEREOR8.EXE program takes output (SCORES file) from PCAR8.EXE and draws a stereogram pair. The number of data points in the Lippe example is 19. Connecting the points enhances the appearance of a trajectory. Try 0% change of scale in first run and adjust the stereogram size in the second if the stereo image is not clear. Select a scale value larger than 1, say 1.1, to increase stereogram size. Scale box size to range for more realistic effects.

7. Use program RANKCOR8.EXE to test for determinism. Try it on the Lippe9x19.tru and ages19.tru files. Choose a large number of iterations, say 1000.

8. Program STRVOL8.EXE computes graphs, like those in Figure 7, that trace the structural evolution of the community. Try to run the program with the Lippe9x19.tru and ages19.tru files. In these, the relevés are arranged from present to past. Considering the short period length, randomisation option 1 is better. Randomisation within rows is more natural. Note, the relevé totals are equal. File Lippe9x19.tru contains the "density" data.

9. When the data set is of the type that He derived from Li (Section 10.4), then program ENTPrc.EXE will perform a complete entropy analysis on it. The raw records mast be stretched out into a single column, like this:
1
4
1
2
2
3
.
.

.

The actual file has 646 duplets. Output file name extension, data file name and its dimensions are requested as the program gets under way.

10. Program ANOENrc.EXE generates data for the graphs in Figures VIIIa,b. In the specific case, he file ManchuriaRaunkiaer.TRU for input hold the data of Table IVa.

11. Use program INFOPRC.EXE to perform a complete information analysis on the ManchuriaRaunkiaer.TRU data set.

12. The information divergences in Table IVe are computed by program INFOPAIR.EXE. The input data, Raunkiaer.tru contains the row vectors of Table IVc (in one-column format).

13. Use ENTROGRA.EXE to draw entropy curves such as in Figure 9. Try this program with the data from Table 1. But here the data are entered on file by years (relevés). Call this file Lippe19x9.tru. Select limits for alpha, 0 and 20. The graphs are stored in BMP files.

14. Try program FRACTAL3.EXE with the data in Lippe9x19.tru. Use the Minkowski metric option, order 2, for distance. The log C(*r*) and log r data pairs, embedding dimension 1, are stored in the first part of file GRAPHS. These are used in Figure 13. The data for the graphs in Figure 14 are stored at the end of file GRAPHS.

15. Use program TRAJCOGR.EXE to measure the co-ordination of trajectories in pairs. Any number of trajectories are permitted. Their lengths can be different, but their orientation (past to present or present to past) in the file, and the number of variables that define them must be identical. Equal time steps are required and same time step width in all trajectories. This can be established by interpolation. The input data is a sequential composite of the individual data files. Each has the same format as the Lippe9x19.tru file. In the specific case of the Jackson Pond and Lagoa das Patas trajectories, the following data manipulations were done before the analysis:

Interpolation to a step size of 100 years.
Eigenanalysis.
Extraction of 3 sets of component scores for each case and pooling these into a single (one column) file. The segments of this file contain:
3 sets of 205 entries for Jackson Pond
3 sets of 446 entries for Lagoa das Patas

The program request information about the trajectories, their size and orientation, whether data or data ranks are to be used, and the size of lag shift. Graphs are displayed on the screen and stored in BMP files. Options are available for printing all graphs separately or all superimposed in the same figure. Numerical values for the graphs are stored in file ORGANISEDDATA.

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