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The efficiency of the Partial Triadic Analysis method: an ecological application

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SUMMARY

In this paper we present a Partial Triadic Analysis (PTA) method that can be applied to the analysis of series of ecological tables. The aim of this method is to analyse a three-way table, seen as a sequence of two-way tables. PTA belongs to the family of STATIS methods and comprises three steps: the interstructure, the compromise and the trajectories. The advantage of this method is related to the fact that it works with original data instead of operators, which permits all the interpretations to be performed in a directly way. In this study we present an efficient application of the PTA method in the simultaneous analysis of several data tables and show how well-adapted it is to the treatment of spatio-temporal data. Two kinds of matrices were constructed: a species abundance table and an environmental variables table. Both matrices had the sampling sites in rows. All computations and graphical displays were performed with the free software ADE-4. An example with phytoplankton and environmental factors data is analysed, and the results are discussed to show how this method can be used to extract the stable part of species and environment relationships.

Key words: Partial triadic analysis, multi-table analysis, STATIS, species abundance, environmental factors

1. Introduction

Many generalizations of standard linear multivariate analysis, like principal component analysis (PCA) or canonical correlation analysis (CCA), have been proposed for studying three or more sets of variables. In this paper, we present an application of the Partial Triadic Analysis (PTA) method (Jaffrenou 1978), a multi-table technique, using a simple ecological data set. In particular we analysed the main temporal structure of the species assemblages and their spatial changes (and did the same for the environmental factors).

Introduced in ecological studies by Thioulouse and Chessel (1987), the PTA method aims at investigating three-dimensional data analysis (e.g. a data cube) seen as a sequence of two-way tables. In PTA all the tables must have the same rows and the same columns, but its advantage or potential is related to the fact that it works with original data instead of operators, which permits all the interpretations of the results to be performed in a direct manner. This method belongs to the family of STATIS methods, and in comparison, the PTA used in the present work allowed the optimal projection of trajectories. For example, Gaertner (2000) made an approach to studying the organization patterns of demersal species in the Gulf of Lions on a seasonal scale. However Rossi (2006) and Ernoult et al. (2006) also used the PTA for other problems. In particular, Ernoult et al. (2006) investigated the overall landscape variability through its different dimensions (space vs. time) and demonstrated the relative importance of each dimension.

Starting from an ecological perspective, the application of this method here aims to analyse the stability of the seasonality across sites of dinoflagellates assemblage in the near-shore shallow coastal area (300 m from the coast and before the surf zone) off the north-western Portuguese coast, in terms of bio-ecological categories as well as studying the stability across the sample sites of the temporal covariation structures between some environmental variables. The data for the Vila Praia de Âncora coast used in this work have been previously analysed and have already been published by Resende et al. (2007), but in a different context, with a different statistical approach and with one more phytoplankton community, the diatoms. In that work, the data were especially designed to identify the environmental variables governing the composition and structure of the species assemblages. The data were analysed from a global point of view by performing a CCA (Canonical Correspondence Analysis) (ter Braak 1986), so the between-site and within-site variability cannot be separated, which may present a problem when working with phytoplankton communities. Therefore the results may fail to be significant and reasonable.

Our purpose, therefore, is to take an approach to these data, taking into account their three-dimensional structure, analysing the dinoflagellates data cube and the environmental one by means of an appropriate multi-table analysis technique, since with this kind of data the examinations of simultaneous data sets are, in a general way, a recent practice – in particular with phytoplankton data, so we could investigate the common temporal structure derived from each site: of the dinoflagellates and of the environmental variables.

The mathematical description of PTA is presented using simple matrix notations.

2. The partial triadic analysis method

To analyse each one of the data cubes, the statistical approach used was the PTA (Blanc et al. 1998; Thioulouse and Chessel 1987). The aim of this method is to identify the structure which is common to the series of tables having the same rows (*n*) and the same columns (*p*). More precisely, PTA searches for structures that are stable among the sequence of tables.

Let K be the number of tables with n lines and p columns. The intersection of line i with the column j gives the value of the variable j at the condition i. After the initial transformations (by centralization, normalization, etc) the K tables $\mathbf{X}_k$ are obtained. Each $\mathbf{X}_k$ is a data matrix of J quantitative variables measured on the same I observations (or objects), where each element is $x_{i,j}^{k}$. According to the PTA methodology, $(\mathbf{X}_k,\mathbf{D}_p,\mathbf{D}_n)$ defines a statistical triplet, where $\mathbf{D}_p$ and $\mathbf{D}_n$ are positive definite weighting matrices for variables and observations and whose positive diagonal elements sum to 1. The PTA is a three-step procedure, namely the interstructure, the compromise and the intrastructure analyses (Lavit *et al.* 1994). Below, these three steps are explained with a description of PTA in matrix form.

First a matrix of scalar products between tables is computed (i.e., the matrix whose elements are: COVV($\mathbf{X}_k$,$\mathbf{X}_l$) = tr($\mathbf{X}_k^T \mathbf{D}_n \mathbf{X}_l \mathbf{D}_p$)). The diagonalization of this matrix provides eigenvectors. The k coefficients α_k of the first eigenvectors are then used to weight the *k* tables in the calculation of the compromise table. Then, a PCA is performed in order to establish the ordination of the different matrices. Alternatively, a matrix of vector correlations (RV) can be used to rescale the importance of the tables. Each element in this table is:

$$\mathbf{RV}(\mathbf{X}_k, \mathbf{X}_l) = \frac{\mathrm{COVV}(\mathbf{X}_k, \mathbf{X}_l)}{\sqrt{\mathrm{VAV}(\mathbf{X}_k)\mathrm{VAV}(\mathbf{X}_l)}}, \qquad (1)$$

where VAV($\mathbf{X}_k$) is the variance of the vector obtained by putting all the columns of table $\mathbf{X}_k$ one below the other. It is basically the vector variance of table $\mathbf{X}_k$, i.e. VAV($\mathbf{X}_k$) = tr($\mathbf{X}_k^T \mathbf{D}_n \mathbf{X}_k \mathbf{D}_p$). The vector correlation matrix and the vector covariance matrix are linked by the same relationships as the normal correlation and covariance matrices. Each table is projected onto the factorial plan obtained from the analysis and represented by an arrow, in order to establish the ordination of the different tables, which summarizes the global structure and the relationships between tables. This configuration (based upon the covariance matrix) allows an overall graphical comparison of the tables and shows proximities between the configurations of the same observations.

The second step of this method is analysis of the compromise, a fictitious table which is computed as the weighted mean of all the tables of the series, using the components of the first eigenvector of the interstructure as weights (i.e. issued from the eigenvalues of the vector covariance matrix) (Thioulouse et al. 2004). In other words, it consists in calculating a linear combination of the *k* initial tables with the aim of constructing a mean table of maximum inertia (Gaertner 2000):

$$\mathbf{X}_c = \sum_k \alpha_k \mathbf{X}_k \, , \qquad (2)$$

where $\mathbf{X}_c$ represents the compromise and captures (optimally) the similarities among the individual matrices. Once obtained, $\mathbf{X}_c$ (which has the same dimensions and the same structure and meaning as the tables of the series) is then analyzed by principal component analysis (PCA) and the rows and columns of the individual matrices are projected onto the analysis as supplementary individuals and supplementary variables, respectively. Thus analysis of the compromise gives a factor map that can be used to interpret the structures of this compromise. In other words, it gives a picture of the structures which are common to all the tables (Thioulouse et al. 2004).

The third step summarizes the variability of the succession of tables in comparison to the common structure defined by the compromise. The rows and columns of all the tables of the three dimensional array are projected onto the factor map of the PCA of the compromise as additional elements (Thioulouse et al. 2004) in order to summarize the reproducibility of the structure across the series of tables. Denote by $\mathbf{U}$ the matrix of the eigenvectors of the analysis of the compromise. The coordinates of the rows of the table $\mathbf{X}_k$ are:

$$\mathbf{R}_k = \mathbf{X}_k\mathbf{D}_p\mathbf{U}, \tag{3}$$

and the coordinates of its columns are

$$\mathbf{C}_k = \mathbf{X}_k^T\mathbf{D}_n\mathbf{X}_c\mathbf{D}_p\mathbf{U}\mathbf{\Lambda}^{-1/2}, \tag{4}$$

$\mathbf{\Lambda}^{-1/2}$ being the diagonal matrix of the inverses of the square root of the eigenvalues of the analysis of the compromise.

Each row of each table is represented by a point in the space of its p columns, and can be projected as a supplementary individual onto the principal axes of compromise. The same procedure is applied (similarly) for the columns (Simier et al. 1999). The points can then be linked, for example by lines, to underline their trajectories; their study constitutes the third step of the method.

For the dinoflagellates and environmental data studied in this work, PTA offered the possibility of studying these three-dimensional data in the way that Figure 1 shows, and studying the dynamic trajectories of the species and

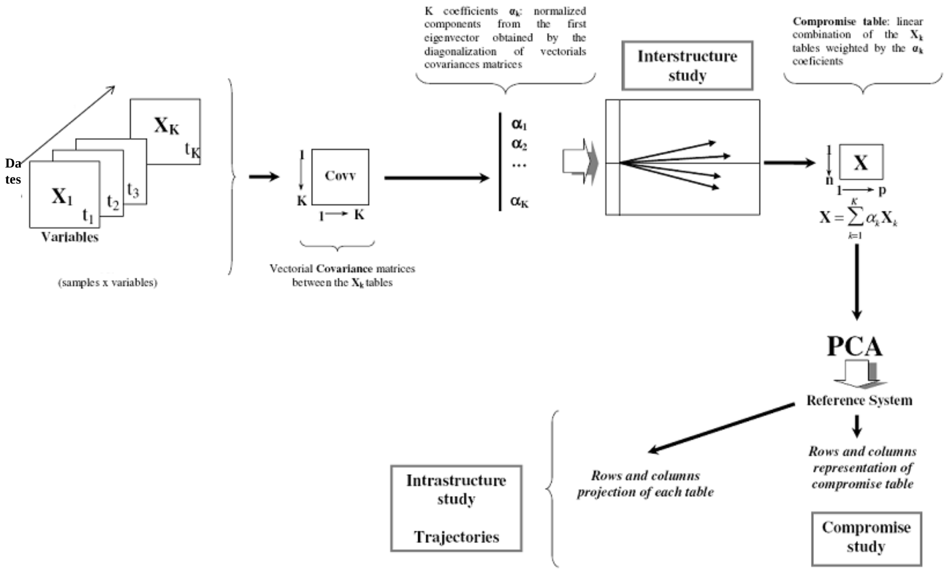

Figure 1. General scheme of the PTA: construction of the interstructure matrix and extraction of the compromise table.

environmental variables per site (each site considers one sampling station in one of the two conditions: high and low tide; data were considered as a series of tables for each site, i.e. table-site: dates in rows vs. variables/species in columns). The main aim in this study is to identify the common temporal structure derived from each station table. The calculations and graphs shown in this work were made using ADE-4 software (Thioulouse et al. 1997). This software is available free of charge from http://pbil.univ-lyon1.fr/ADE-4. Species abundances were transformed to *log(x + 1)* prior to the calculations, in order to minimize the dominant effect of exceptional catches.

3. Application Example

Data

The example data set was extracted from Resende et al. (2007). The data used in this work was collected in Vila Praia de Âncora coast (Fig. 2), which is located on the north-western tip of Portugal (41º49.26’N; 8º51.50’W). Vila Praia de Âncora’s coast is characterized by a vast rocky shore and a small beach, which forms a sandy inlet. The beach receives the estuarine waters of the river Âncora (Resende et al. 2007).

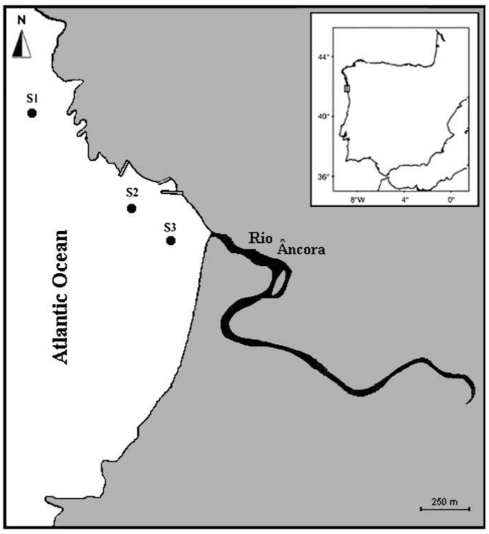

Figure 2. Map of the Northwest Portuguese coast and the study area with location of the three sampling sites (Resende et al. 2007)

Three sites were sampled near the shore (Fig. 2): S1, facing the rocky shore (41º49.26’N; 8º52.64’W); S2, adjacent to the fishing port (41º48.83’N; 8º52.24’W); and S3, opposite the Âncora estuary (41º48.27’N; 8º52.11’W). Sampling took place monthly, in daylight hours, always at full moon, at low tide (L) and high tide (H), from August 2002 to October 2003. A detailed description of the sampling sites is given by Resende et al. (2007). In total, 90 samples were collected between August 2002 and October 2003: 30 at S1, 30 at S2 and 30 at S3.

During the study period, the following environmental data were collected, in situ, for each site: pH, salinity, water temperature, dissolved oxygen and transparency (Secchi disc). Water samples for chemical analysis and chlorophyll *a* and volatile solids quantification were collected at the water subsurface. The concentrations of dissolved nutrients were also measured:

nitrate, nitrite, ammonia, phosphate. A more detailed description of the environmental methodologies and temporal variation of the environmental parameters can be found in Resende et al. (2007). The N:P ratio and the zooplankton biomass were also included. Zooplanktonic oblique tows were made at 1.5–2 km, and a detailed description of the sampling methodology is given by Azeiteiro et al. (2006).

Samples for taxonomic and quantitative dinoflagellates study were collected with a glass bottle (1 litre capacity) and immediately preserved with Lugol 1% (iodine/iodide potassium and distilled water). Only the armoured dinoflagellates were recorded and identified to the lowest possible taxon. The taxa selected for the investigation are listed in Table 1 (Resende et al. 2007).

Organization of matrices

The data were organized in two three-way tables: one for environmental factors (dates x variables x sites) and another one for the species abundances (dates x species x sites). Three sampling sites were considered in two conditions – high tide and low tide. Consequently, each multi-table was made up of six matrices. Fifteen dates were considered, from August 2002 to October 2003, being the same for each type of data matrix. All the species matrices had the same species, and all the environmental matrices had the same variables. Hence the data could be seen as "data cubes": a "species data cube" and an "environmental data cube", each one presented as a sequence of two-way tables.

4. Results

Interstructure analysis – similarity between different stations

The map of the interstructure analysis corresponds to a global representation, presents an ordination of the sampling sites and shows the vectors for individual stations on the plan made by the first and second axes, and consequently the similarities between stations tables. For environmental factors and dinoflagellates abundances the decreasing values of the eigenvalues (Fig. 3a,c)

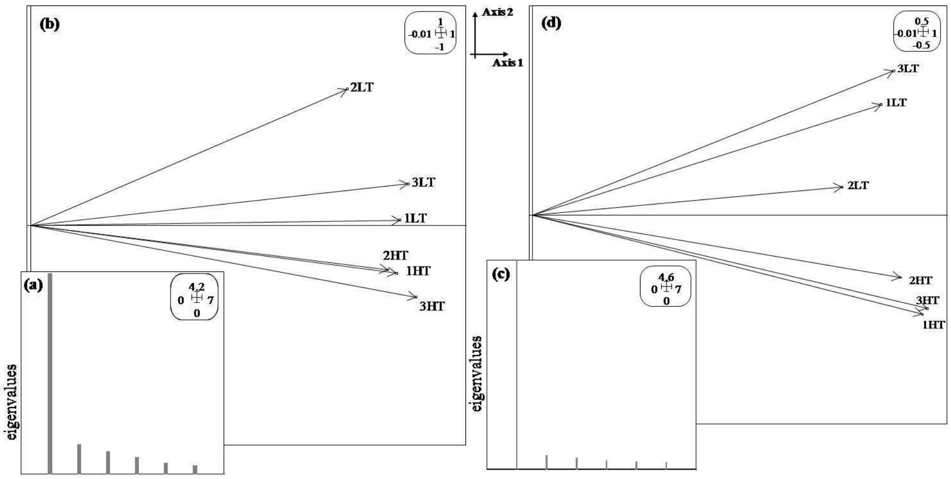

Figure 3. Interstructure analysis and eingenvalue diagrams: (a) Eingenvalue diagram of the series of environmental factors tables; (b) Interstructure factor map of the series of environmental factors tables; (c) Eingenvalue diagram of the series of dinoflagellates abundance tables; (d) Interstructure factor map of the series of dinoflagellates abundance tables. Axis 1 is the first principal component; Axis 2 is the second principal component. The scale of the graph is given by the box in the top right; 1HT – Station 1 at high tide; 1LT – Station 1 at low tide; 2HT – Station 2 at high tide; 2LT – Station 2 at low tide; 3HT – Station 3 at high tide; 3LT – Station 3 at low tide. Note the different scales.

allowed exploration of the first two factorial axes. Indeed, spatial variations of environmental factors and dinoflagellates are mainly projected on the first axis. All the sites display the same sign on the principal axis 1 (69% and 81% of the total inertia for environment and dinoflagellates, respectively), whilst axis 2 (10% and 6% of the total inertia for environment and dinoflagellates, respectively) presented two distinct groups: an opposition between low tide sampling stations and the high tide stations (Fig. 3b,d). All stations with the same sign had a positive correlation between the corresponding set of matrices (the stations' vectors on the first axis presented a uniform distribution) and indicates a relatively strong common sites structure, which indicates a large similarity among stations. The structure expressed through the first axis of the interstructure therefore corresponded to an environmental (Fig. 3b) and dinoflagellates (Fig. 3d) temporal pattern common at the different sampling stations. The only isolated site appeared to be 2LT (this environment appears with a high positive value on the second axis, Fig. 3b). Besides this, in the interstructure analysis of dinoflagellates three stations come out more closely than the others: 1, 2 and 3, at high tide, with negative values on the second axis. However, detailed description of spatial variations of environmental factors and dinoflagellates were not necessary and were omitted in the further analyses.

Compromise analysis

Figure 4a and Figure 6a shows the factor maps of the compromise, for the environmental variables (Fig. 4a) and for the dinoflagellates species (Fig. 6a). Additionally, Figure 5a and Figure 7a show the factor maps of the compromise, for the sampling dates related to environmental variables (Fig.5a) and to the dinoflagellates species (Fig. 7a).

Stable part of the environment and sampling dates

Analysis of the compromise for environmental variables was carried out to reveal the common temporal pattern and to better explain the differences/similarities among stations. The graphical illustration of the analysis of the compromise (Fig. 4a) shows the average position of each environmental parameter in respect to the first and second axes, and the projection onto the compromise plan of the fifteen sampling dates (Fig. 5a) shows the temporal dynamics of the environmental factors for a mean station.

The first two axes of the analysis of the compromise account for 52% of the cumulative inertia, hence providing a summary of the environment attributes' spatial dynamics. Interpretation of this figure provides a good summary of the spatial environmental dynamics. The length of the arrows on the factor map of the compromise in the PTA analysis indicates that the most relevant environmental variables (variables with long arrows contributed more to the definition of the axes, compared with the variables with short arrows) are temperature, pH and volatile solids followed by, in decreasing order, nitrates,

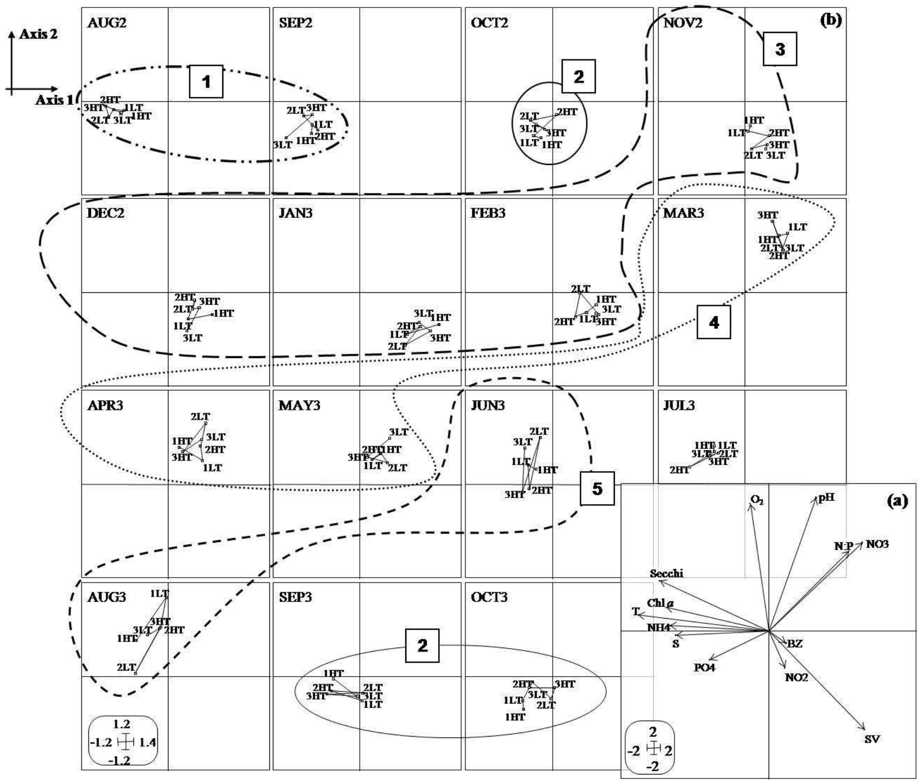

Figure 4. Compromise and trajectories factor maps of the PTA analysis: (a) Compromise factor map of the PTA analysis: environmental variables. This map shows the stable part of the environment relationships on plan 1-2. The scale of the graph is given by the box in bottom left. T – water temperature; O2 – dissolved oxygen; S – salinity; NP – N:P ratio; NH4 – ammonia; Chl a – chlorophyll *a*; PO4 – phosphate; NO2 – nitrite; NO3 – nitrate; Secchi – water transparency; BZ – zooplankton biomass; SV – volatile solids; (b) Trajectories factor maps of the PTA analysis: row-dates projection of each table-site in plan 1-2 of the compromise. The scale of the graph is given by the box in the bottom left. Station codes as Fig. 3. Each date is identified by the three first letters of the month followed by a number: 2 for the year 2002 and 3 for the year 2003 (e.g. AUG2 – August 2002). Axis 1 is the first principal component; Axis 2 is the second principal component. Note the different scales.

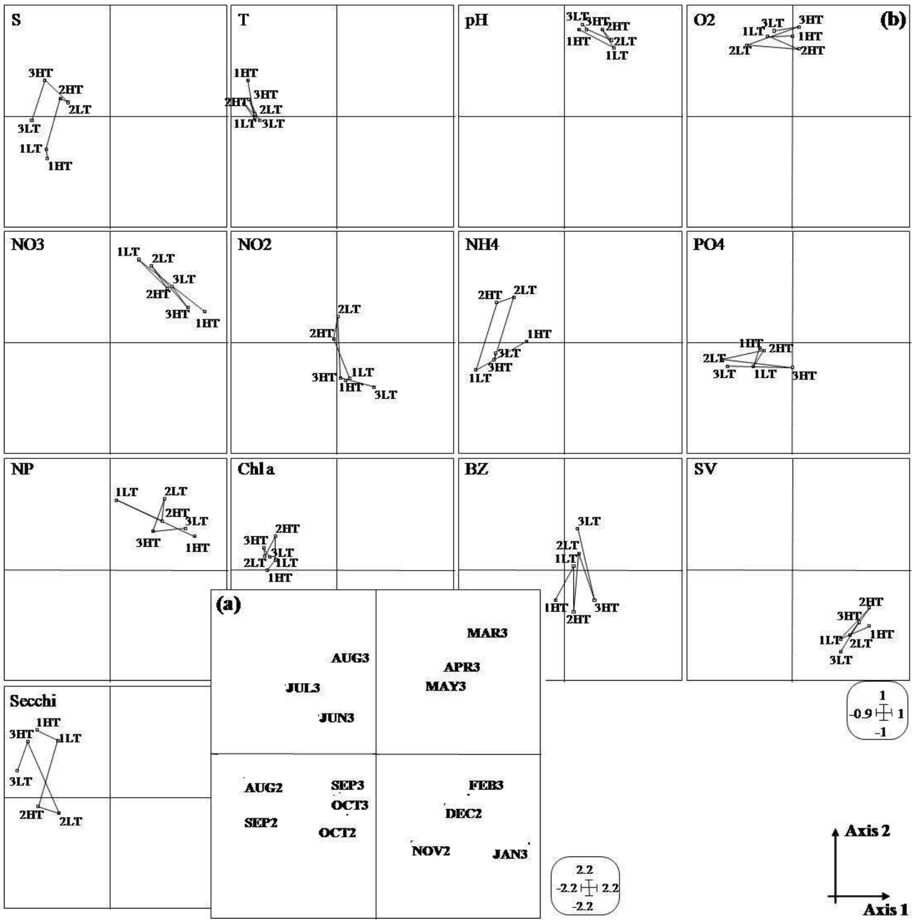

Figure 5. Compromise and trajectories factor maps of the PTA analysis: (a) Compromise factor map of the PTA analysis: sampling dates. This map shows the stable part of the date relationships. The scale of the graph is given by the box in the bottom right. Month codes as Fig. 4; (b) Trajectories factor map of the PTA analysis: variables-environmental factors projection of each table-site in plan 1-2 of the compromise. The scale of the graph is given by the box in the bottom right. Station codes as Fig. 3; Environmental codes as Fig. 4. Axis 1 is the first principal component; Axis 2 is the second principal component. Note the different scales.

dissolved oxygen, transparency, N:P ratio, chlorophyll *a*, ammonia and salinity. In the fourth quadrant, volatile solids appeared isolated. Although nitrite and biomass appear in the same direction, the arrows that represent them have a small length. This means a poor representation on the plan 1-2 and probably does not reflect the proper position. The first axis of this analysis is mainly characterised by temperature, transparency, chlorophyll *a*, ammonia and salinity. Therefore this axis is marked for the left side with higher values of those variables (normally a summer characteristic, see Fig. 5a). Additionally the angles among them were small, which denoted that the variables were strongly correlated. Therefore the opposite side of this axis (on the right side) is where the months that are normally characterised by lower values of temperature, transparency, chlorophyll *a*, ammonia and salinity (usually a winter characteristic, see Fig. 5a) were located. Axis 2 appeared mainly characterised by dissolved oxygen and pH and, in decreasing measure, by nitrates, N:P ratio and volatile solids. In fact, these three variables are variables from the factor plan, although marking different positions. Besides this, the pH and dissolved oxygen have higher values in the months located in the superior part of axis 2 (spring/summer season, see Fig. 5a). The opposite situation occurs at the inferior extreme. Overall the first axis mainly separates spring and winter months from summer and autumn months, while the second axis separates spring and summer months winter and autumn ones (Fig. 5a).

The stable part of dinoflagellates and sampling dates

For dinoflagellates the compromise was performed on the six tables for each site. This gave an average picture of the dinoflagellates abundances (see Table 1 for species codes) which best explained the variations of the species pattern at the fifteen dates for each site (Fig. 6a). The first two axes represented, respectively, 80% and 8% of the total variability. A large abundance of *Prorocentrum micans, Ceratium fusus var fusus, Dinophysis acuminate* and *Ceratium furca* was observed. These were strongly correlated with the positive part of axis 1 (species from axis 1) and therefore characterized the temporal

Table 1. List of the 17 dinoflagellates species, with codes and category [adapted from Resende et al. (2007)]

Code	*Taxa*
ACIP	*Actiniscus pentasterias*
CEFS	*Ceratium fusus var. fusus*
CEFU	*Ceratium furca*
CEHO	*Ceratium horridum*
CEKO	*Ceratium kofoidii*
DIAC	*Dinophysis acuminata*
DIAT	*Dinophysis acuta*
DICA	*Dinophysis caudata*
GONS	*Gonyaulax spinifera*
PHRO	*Phalacroma rotundatum*
PRDB	*Protoperidinium diabolus*
PRDE	*Protoperidinium depressum*
PRDI	*Protoperidinium divergens*
PRMI	*Prorocentrum micans*
PRPE	*Protoperidinium pellucidum*
PRPT	*Protoperidinium pentagonum*
PYHO	*Pyrophacus horologium*

organizational pattern of the described dinoflagellates. Along axis 2, *Ceratium kofoidii* was opposed to *C. furca. Dinophysis acuta* was strongly correlated with the positive part of axis 2 (species from axis 2). The remainder were considered less abundant (within these, species which are near the origin are slightly abundant).

The analysis of the compromise for sampling dates (Fig. 7a) showed the temporal dynamics of the dinoflagellates assemblage for a mean station and the stable part of the dates' relationships. The two major gradients were determined by the interpretation of the first two axes of the compromise. Axis 2 mainly opposed the dates of September 2002 to August and July 2003. October 2002 and 2003 are strongly correlated with axis 2, while March 2003 has an opposed position and is an axis 1 date. The remaining dates were considered less significant (within these, months which are near the origin, like January and February 2003, are weakly important).

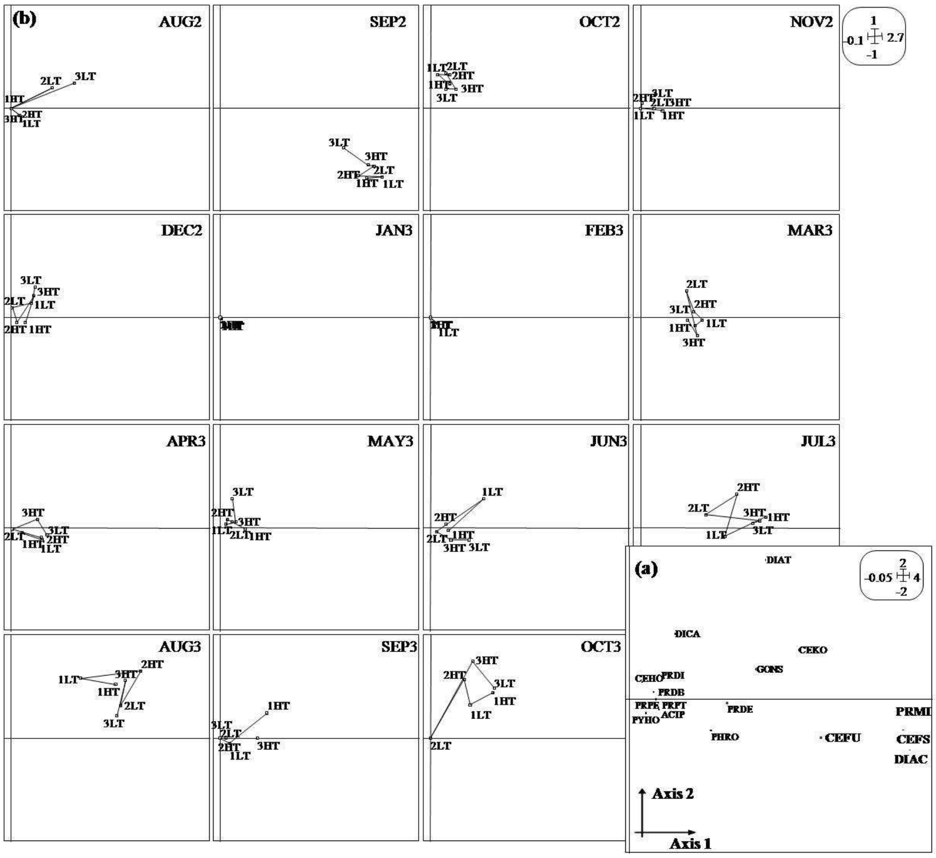

Figure 6. Compromise and trajectories factor maps of the PTA analysis: (a) Compromise factor map of the PTA analysis: the dinoflagellates. The scale of the graph is given by the box in the top right. See Table 1 for species codes. (b) Trajectories factor maps of the PTA analysis: row-dates projection of each table-site in plan 1-2 of the compromise. The scale of the graph is given by the box in the top right. Station codes as Fig. 3. Month codes as Fig. 4. Axis 1 is the first principal component; Axis 2 is the second principal component. Note the different scales.

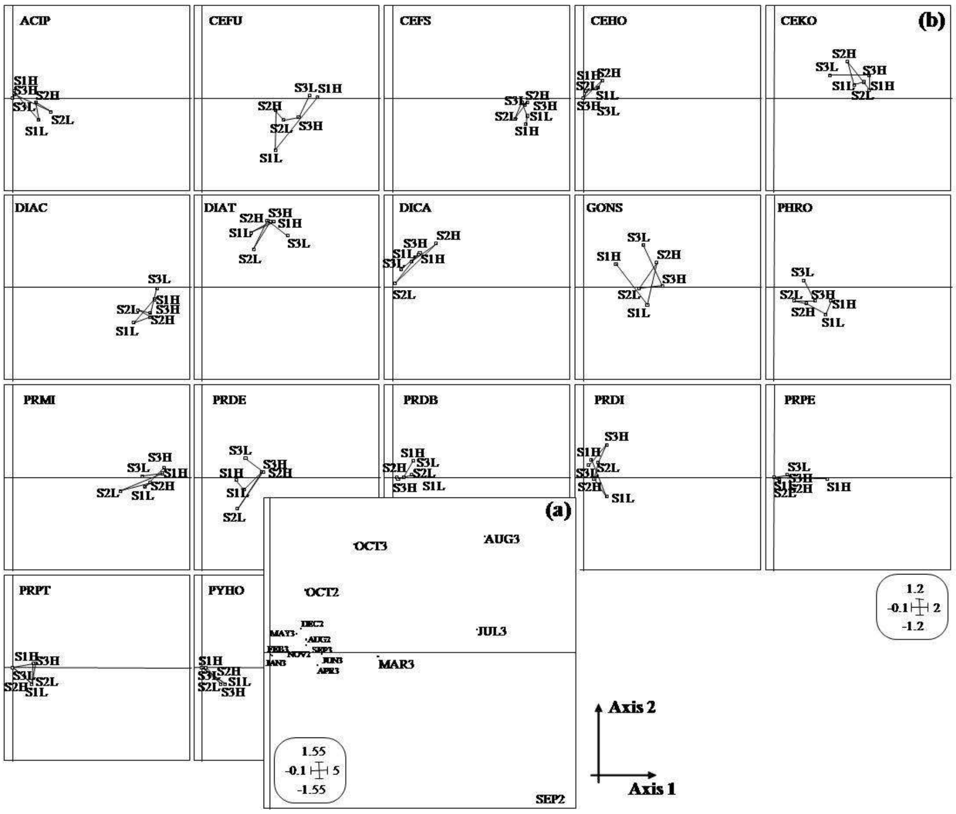

Figure 7. Compromise and trajectories factor maps of the PTA analysis: (a) Compromise factor maps of the PTA analysis: sampling dates. The scale of the graph is given by the box in the bottom left. Month codes as Fig. 4. (b) Trajectories factor map of the PTA analysis: variables-species projection of each table-site in plan 1-2 of the compromise. The scale of the graph is given by the box in the bottom right. Station codes as Fig. 3. See Table 1 for species codes. Axis 1 is the first principal component; Axis 2 is the second principal component. Note the different scales.

5. Trajectories

Time and space effect

For environmental factors, the projection of each date at the six sampling stations on plan 1–2 of the compromise (Fig. 4b) allowed us to visualize the trajectory of each sampling date. Each site (at low and high tides) is represented by a point. The graphical illustration shows the positions of the six stations on the compromise plan connected in the form of trajectories for each date. The trajectories factor maps revealed the possible distortion of the temporal structure of the sampling sites during the study period, that is to say, the diverse shapes of trajectories indicate deviations of single dates from the general pattern. On the whole, although stations followed a chronological scenario, changes of pattern with time can be seen. The main evidence was observed in August and June 2003. Five other distributional patterns of dates can be observed reflecting changes in the system. These patterns fall into distinct date groups: (1) August and September 2002, determined by the information given by the environmental variables transparency, chlorophyll *a*, water temperature, ammonia and salinity (Fig. 4a), which means that these sampling sites within those dates had higher values of these parameters in contrast to the other ones; (2) October 2002, September and October 2003, presented a clearly intermediate pattern between spring/summer and autumn; (3) November and December 2002, January and February 2003 were characterised by volatile solids (Fig. 4a) and evidenced, for the sampling sites, the passage to the autumn/winter season; (4) March, April and May 2003 represents the spring season, with higher values of pH, N:P ratio and nitrates (Fig. 4a), for the majority of the sampling sites; (5) June and August 2003 presented the most different shapes of trajectories when compared to the other ones. Here the trajectories of the stations are dispersed, meaning that their dynamics varied from station to station. At these two dates, variations at stations are determined by the information that was obtained mainly from higher values of pH and dissolved oxygen (Fig. 4a). However, the two dates do not present the same variations. In June 2003 axis 1 separated stations 2 and 3 at high tide from the others, while in August 2003 all stations were in the upper part of axis 2, and station 2 at low tide had lower values of pH and dissolved oxygen (Fig. 4a) when compared to the other stations. July 2003 appeared as an isolated date pattern, which is characterised by higher values of dissolved oxygen (Fig. 4a) and 2HT was mainly determined by higher observations of transparency, chlorophyll *a*, temperature, ammonia and salinity (Fig. 4a).

It is also possible to project the six sampling sites at the fifteen dates onto the factor map of the compromise and relate it to the dinoflagellates community. Figure 6b allowed us to study this, i.e. the positions of the six sampling sites on the compromise plan connected in the form of “trajectories” for each study date. The dynamics between the sites (at low and high tide) varied according to the sampling dates, and this shows the dynamics between those.

September 2002, October 2002 and August 2003 have a constant occurrence over the selected sites as their trajectories are concentrated on one part of the compromise map, while trajectories of the other dates are dispersed, meaning that their dynamics varied from site to site. In March 2003, axis 1 contrasted station 2 at high and low tide with the other stations. This resulted in a general increase of *P. micans, C. fusus var fusus, D. acuminate* and *C. furca* (Fig. 6a). March, June and July 2003 presented the most variant shapes, which means, in this scenario, more fluctuations across the information given by axis 2. From October 2002 to May 2003 (with the exception of March 2003), the dynamics were similar, corresponding to winter/spring dynamics, while summer dates (August, September 2002 and June to September 2003) have an opposite pattern. Some of the station points are positioned at the origin of the factor map (0, 0); probably in none of these stations was there any observation for the sampling date or the number of observations was too low (France and Mozetic 2006). This is the case with January, February 2003, which corresponds to a winter period.

Environment and space effect

Figure 5b shows the projections of the thirteen environmental factors at the six stations (represented by points) onto the factor map of the PCA of the compromise. This presents the stability of the dynamics of the environmental parameters, where the positions of each parameter through the study sites are connected in trajectories as well. Overall, obvious changes of variation patterns at any date can be seen through the sites, with the exception of pH, chlorophyll *a* and volatile solids. These are the factors that presented constant values over the selected sites, as their trajectories are mainly concentrated on one part of the compromise map. This stable distribution pattern means that these parameters do not have large fluctuations in the dates across the stations. Salinity, temperature, ammonia, chlorophyll *a*, transparency and phosphate are mainly determined by the information given by the spring and autumn seasons (Fig. 5a). Dissolved oxygen had higher concentrations in the summer/spring season (Fig. 5a), for all study sites. For nitrite concentration, the separation between station 2 (both tides) and the others is clear. Stations 3 and 1 (at the two tides) were mainly characterised by the conditions of winter/autumn season (Fig. 5a), while station 2 (at the two tides) are mainly determined by the spring/summer season (Fig. 5a). Another clear separation was observed between the three stations at low tide and at high tide for the zooplankton biomass: the low tide is determined by spring/summer, while high tide is defined by the winter season (Fig. 5a).

The species and space effect

Figure 7b shows the variables-species projection of each table-site in plan 1-2 of the compromise. Generally, the more irregular shapes were for *C. furca*, *Gonyaulax spinifera*, *Phalacroma rotundatum*, *P. micans*, *Protoperidinium pellucidum* and *Protoperidinium divergens*. *C. fusus var fusus*, *C. kofoidii*, *D. acuminata*, *D. acuta* and *Dinophysis caudata* have a constant occurrence over the selected sites as their trajectories are concentrated on one part of the compromise map, while trajectories of the other species are dispersed, meaning that their dynamics varied from site to site. For *P. rotundatum*, axis 1 contrasted station 3 at low tide with the other stations (Fig. 7b). This resulted in a general abundance increase in March, July August 2003 and September 2002 (a spring/summer period) (Fig. 7a). In a same way and for *G. spinifera*, axis 1 contrasted stations 1 and 2 (at low tide) with the other stations. An increase of *P. micans* abundances was observed in the summer period (July 2003, August 2003 and September 2002), mostly at stations 1 and 3 (at high tide) (Fig. 7a, b). *C. fusus var fusus* and *D. acuminata* were quite stable at the six sampling stations and for all summer periods (July and August 2003 and September 2002). Some of the station points are positioned at the origin of the factor map (0, 0); probably at none of these stations was any observation from the species detected in water samples or the number of findings was too low (France and Mozetic 2006). This is the case with *Ceratium horridum*, *Protoperidinium depressum*, *P. pellucidum*, *Protoperidinium pentagonum* and *Pyrophacus horologium.*

6. Discussion

This example shows that the PTA method can be used as a useful tool to analyse three-way table species and/or environmental data, interpreting the results in a direct way. This benefit results from the fact that it works with original data instead of operators. Besides this, along with the results interpretation it is possible to summarize the global structure and the relationships between the tables (by means of the interstructure analysis), provide a picture of the structures common to all the tables (by the compromise analysis), and summarize the variability of the series of tables around the common structure defined by the compromise (with the trajectories). The only constraints from PTA are that all the cross-tables must have the same rows and the same columns (i.e. that the species and environmental variables must be the same in all the pairs of tables).

In this work, analysis of the results from two PTA analyses allowed us to group the sites together in terms of their environment attributes or species and their trajectories–histories. Our results showed that: (1) sites may have similar temporal features and exhibit different trajectories; (2) sites may have similar trajectories but different temporal features; and (3) sites may be congruent for both temporal features and trajectories. Nevertheless, a general pattern of species abundance and environmental factors that persists through space (derived from different sampling stations) was recognized by applying PTA analysis and was demonstrated by the results given from interstructure and compromise analysis, which are not far from what really happens for all stations.

The interstructure analysis (similarity between stations) of the environment factors and dinoflagellates community reveals a relatively strong common sites structure (which indicates a large similarity among stations) and two distinct groups: low tide and high tide. Indeed, the contribution of the six sampling sites was well-balanced, indicating that no site was either favoured or ignored in the constitution of the average matrix. Only the second station at low tide was positioned separately from the main group of sites, indicating a different spatial dynamic, which means that their structure was not as well reflected by the compromise as the other five sampling stations.

The projection of the thirteen environmental variables onto the compromise axes when compared to the projection on the same axes of the fifteen sampling dates provided a good summary of the temporal pattern of the environment variables shared by the six sampling sites. In fact, the compromise matrix provided a good approximation of the time organizational pattern of the environment over the six sampling sites. In addition, the projection of the fifteen sampling dates onto the compromise axes was compared to the projection on the same axes of the thirteen environmental variables, in order to summarize the environmental pattern in the sampling months shared by the six sampling sites. Furthermore, the compromise analysis of dinoflagellates (the stable part of species) revealed an independent pattern between the most abundant dinoflagellates. Those, when well represented (species *P. micans, C. fusus var fusus, D. acuminate, C. furca, C. kofoidii, D. acuta, G. spinifera, P. depressum, P. rotundatum* and *D. caudata*), are mainly associated with warm months (summer and early autumn) and the distribution is forced by volatile solids, nitrates and N:P ratio (which appears with a plan position and were negatively related with temperature, transparency, ammonia, salinity, dissolved oxygen and pH). The projection of the species onto the compromise axes and its association with the projection on the same axes of the fifteen sampling dates summarized the temporal pattern of the dinoflagellates abundances shared by the six sampling sites. In reality, this work has shown that the spatial organization patterns of dinoflagellates assemblage in the Âncora coastal zone were persistent during the course of the considered seasons. The variations among sites of each species around the reference structure were generally low. Only a very limited number of species exhibited a strong variation of their abundance in space at this scale. The reported temporal distributions are similar to what is known from published papers (Resende et al. 2007). There, the relationship between dinoflagellates assemblage and the environmental parameters governing their composition and structure was performed with the Canonical Correspondence Analysis (CCA) (ter Braak, Verdonschot 1995). With this technique CCA extracts synthetic gradients from the biotic and environmental matrices, which are quantitatively represented by arrows in graphical biplots. The results obtained from the PTA method have been a successful approach in evaluating the prevailing inter-space and intra-space structure of the species, which with the CCA technique cannot be observed (the same applies to the environment). This becomes a significant problem when we are working with phytoplankton ecological studies. In this case, results may be insignificant and do not represent the reality of this assemblage. On the other hand, spatial stability has been weakly explained to date. The inclusion of PTA in ecology may be important for revealing that behind an overall stability of environmental gradients over the study period, the spatial changes are important and thus may have an impact on local communities. Besides this, it allows researchers to take into account more biological information, to use methods more adapted to the data, and to produce more accurate statistical results.

Our study analysed both dinoflagellates composition and structure (species abundances and environmental factors), which was likely to capture changes that may not be detected by several traditional methods alone. At this stage we will refer to the importance of dinoflagellates changes at both levels of biodiversity.

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