# Economy and Environmental Problems in the Mexican Coastal States

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*Abstract:* A canonical correspondence analysis (CCA) for environmental and economic variables was performed for 17 Mexican coastal states. The ordination method allowed us to identify three groups, namely hydroelectric energy generation (I), pollution (II) and harbours (III), which were associated to different human activities. Furthermore, CCA is efficient to help us generate hypotheses for future research. It is therefore advised that CCA should be used for routine analyses into economics.
*Keywords:* Coastal States of Mexico, Canonical Correspondence Analysis, Diversity Index, Economic Development, Environmental Variables.

*Resumen:* Se realizó un análisis de correspondencia canónica sobre variables ambientales y económicas de 17 estados costeros de México. El método de ordenación nos permitió identificar tres grupos llamados generación de energía hidroeléctrica (I), contaminados (II) y portuarios (III), los cuales se asociaron a diferentes actividades humanas. El análisis de correspondencia canónica es una eficiente herramienta para generar hipótesis en investigaciones futuras y puede ser utilizado en análisis de rutina en economía.
*Palabras clave:* estados costeros, análisis de correspondencia canónica, índices de diversidad, desarrollo económico, variables ambientales.

JEL *Classification:* 0, 01, 013, 018.

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## Introduction

The development of canonical correspondence analysis (CCA) by ter Braak (1986) and its implementation in his computer program *Canoco* (along with other constrained ordination methods such as redundancy analysis (RDA), detrended canonical correspondence analysis and hybrid methods), have revolutionised quantitative community ecology and related subjects such as limnology. These multivariate techniques incorporate regression and ordination into a single extremely powerful method for multivariate direct gradient analysis called canonical or constrained ordination. Besides these direct gradient analysis techniques, *Canoco* also allows to perform analysis by which the effects of external variables are removed statistically, the statistical testing of the relationship between response variables (usually species) and environmental variables by means of several different types of Monte Carlo permutation tests, the reconstruction of environmental variables (e.g. lake-water pH or salinity) from biological data (e.g. fossil diatoms), statistical analysis of multivariate data from field experiments, etc.

*Canoco* has been used for data analysis in many topics such as economy (Beltrán *et al.*, 2003), paleolimnology (García *et al.,* 2004; García *et al*., 2002; Smol *et al.*, 1995), biogeography (Hill,1991; Birks, 1993), conservation (Brown *et al.,* 1993; Dzwonko, 1993), ecology (Allen & Peet, 1990; Adams *et al.,* 1992; Ainley *et al.,* 1993), landscape ecology (Stewart *et al.,*1993), management (Best, 1993; Dzwonko,1993), monitoring (Kremen, 1992; Johnson *et al.,* 1993), remote sensing (Frederiksen & Lawesson, 1992), and many others. Therefore, it represents an important tool to extracting information from multivariate data. This is so especially in ecology where hypotheses are often generated and tested with the aid of *Canoco* (Farrel *et al*., 1995). The goal of this paper is to perform CCA, by means of *Canoco*, to a set of economic information (response variables) and environmental variables as well as the calculation of economic diversity, for the Caribbean and Pacific coasts of Mexico.

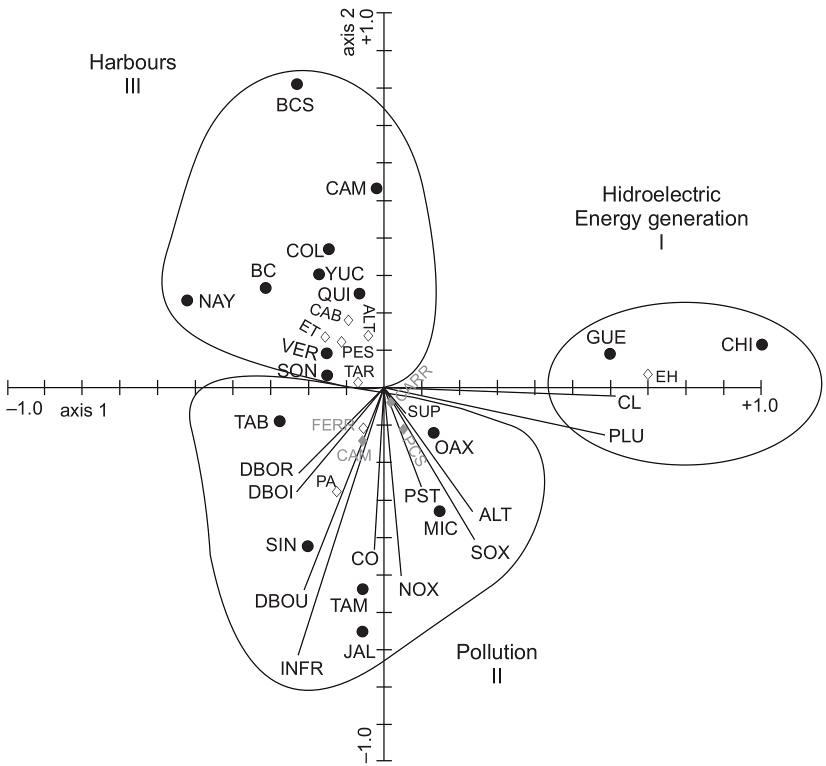
## Methods

The study area is shown in Figure 3. Information about all coastal states of Mexico was taken from the National Institute of Statistics, Geography and Computer Science of Mexico (INEGI, 1999). Selected variables and states are shown in the symbology of figures 1, 2 and 3. The final data base was a 17 states $\times$ 11 economic indicators matrix, and a $17 \times 12$ environmental variables matrix (number of occurrences 163 and 204, respectively).

CCA was performed with the aid of the computer program *Canoco* (version 3.21) (ter Braak, 1990). A complete explanation of CCA can be found in ter Braak (1986). Briefly, CCA is an extension of correspondence analysis (CA), an ordination technique of common use in ecology that extracts continuous axes of variation from a number of response variables (usually species). Such ordination axes are interpreted with the help of data or knowledge on environmental variables. This is a two-step (or indirect) analysis in which the reduction of the variation by ordination is performed, and then relationship between the ordination axis and environmental variables is established by multiple regression (ter Braak, 1986). CCA is a more powerful technique than CA because the ordination axis of response variables and their correlation with environmental variables are simultaneously estimated, thus turning the technique into a one-step (or direct) gradient analysis. The percentage of variance accounted for by ordination axes, are calculated from their eigenvalues ($\lambda$). The technique leads to an ordination diagram where response variables and sites are represented by points and environmental variables by solid lines. We used economic indicators as response variables, Mexican states as sites, and mainly human contamination as environmental variables. Such diagram effectively shows the relationship between the response variables and environmental data. Data were transformed to relative percentages prior to statistical analysis. The significance of the ordination diagram ($p < 0.05$) was assessed by performing Monte Carlo permutation test using 1000 unrestricted permutations.

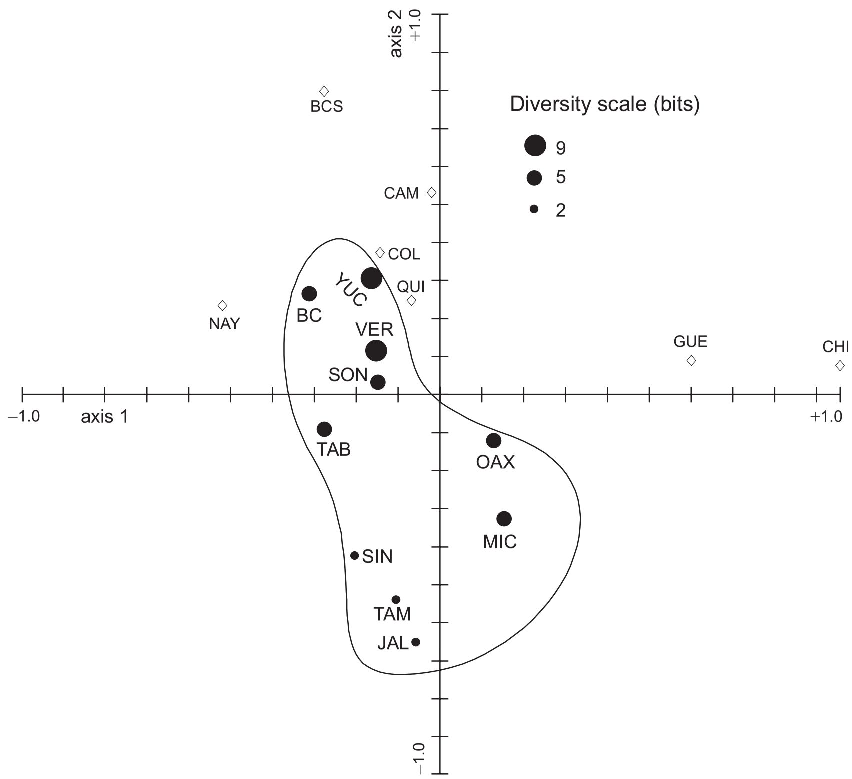
Diversity index of Shannon & Wiener was calculated and plotted with the aid of Canodraw (version 2.10, Smilauer, 1990), available in *Canoco* (ter Braak, 1990), for response variables according to the equation: $S = -\sum_{i=1}^{n} P_i \log_2(P_i)$, where $S$ is the diversity index and $P_i$ is abundance of the $i^{\text{th}}$ species (in our case economic indicators).

**Figure 1.** Canonical Correspondence Analysis (CCA) for economic and environmental indicators for 17 Mexican states




*Source:* INEGI (1995).

**Figure 2.** Shannon and Weaver diversity index calculated for economic data




*Source:* INEGI (1995).

## Results

Figure 1 shows the CCA ordination plot for economic and environmental data for 17 Mexican coastal states. Sites are ordered according to economic indicators (represented by dots), while environmental variables are represented by solid lines. The length and orientation of environmental variables reflect their relative importance and their approximate correlation to the ordination axes. The position of economic indicators and states approximates to the relationship (as weighted-averaged optimum), between them and the environmental gradient (Wilson *et al.*, 1994). CCA axis 1 (Figure 1) was a gradient of cholera (CL) and pluviosity (PL) (inter-set correlations 0.6 and 0.57 respectively), with an eigenvalue of $\lambda_1 = 0.37$ ($p < 0.05$), which accounted for 57% of the total variance, being hydroelectric energy generation (EH), the economic indicator associated to axis 1. Chiapas (CHI) and Guerrero (GUE) (group I) were the most representative states of this ordination axis.

Axis 2 (Figure 1) was mainly a gradient of respiratory infections (INFR), urban biochemical demand (DBOU), nitrogen dioxide (NOX) and carbon monoxide (NO) (inter-set correlations –0.68, –0.57, –0.52 and –0.50, respectively), being population (POB), drinking water production (PA), lorries/trailers (CAM), railroads (FERR) and highways (CARR), the economic indicators ordered in group II. This axis showed an eigenvalue of $l_2 = 0.134$ ($p < 0.05$) which accounted for 21% of the total variance.

Finally, group III (Figure 1) consisted of Baja California Sur (BCS), Baja California (BC), Campeche (CAM), Colima (COL), Yucatán (YUC), Nayarit (NAY), Quintana Roo (QUI), Veracruz (VER) and Sonora (SON), being sewage treatment plants (TAR), thermoelectric energy generation (ET), harbours of trade (CAB), harbours of call (ALT) and total fish caught (PES) the economic indicators ordered in this group. None of the environmental variables was associated to this group.

The ordination diagram from Figure 1 was translated to units of diversity (bits) for economic indicators (Figure 2). The sizes of open/solid bubbles approximate to diversity values. Higher diversity values (solid bubbles) were observed in all sites of group II, but also in those states of group III placed closer to the axes origin. Lower diversity (open bubbles) was observed closer to the axes end.

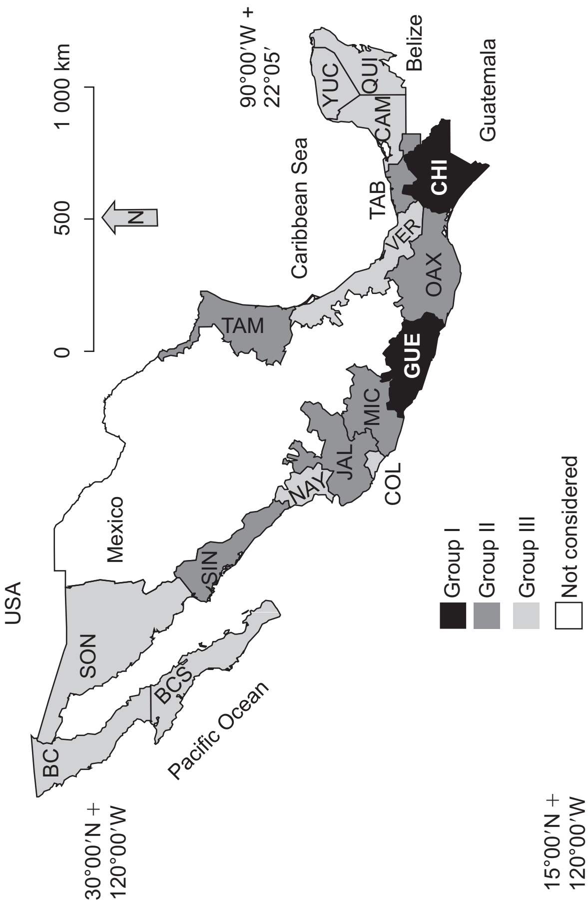
## Discussion

As expected, the use of CCA as exploratory analysis of environmental and economic data turned out a satisfactory tool, as it provided us an integrated view of the study area. Mexican states were ordered into three classes with different economic-environmental characteristics (Figure 1) which were mapped in Figure 3. Group I could be labelled as hydroelectric energy generation (Figure 1). This is because Chiapas and Guerrero generated respectively 23% and 56% of the hydroelectricity. These states also showed high precipitation values. Thus, one could conclude that pluviosity is a positive environmental factor as it induces to an increase in energy generation. However, pluviosity could also be causing cholera to increase, so investments in medical health would be necessary to keep good standards of life quality. This group showed low diversity values (Figure 2) because the economic indicators considered here showed low percentage values (except for hydroelectric energy generation as above mentioned). More economic indicators should therefore be added, as Chiapas and Guerrero are thought to be touristic states. Thus, hotel trade, historic ruins, climate, landscape ecology and recreation activities should be included into future analyses, to reliably assess environmental quality for the study area.

Group II could be referred to as pollution, since most of human contamination activities were associated to it (Figure 1). Thus, it could be hypothesised that the states ordered in group II have lower environmental quality levels than the other groups. The high diversity values observed in this group would support the former, thus economic diversity could be used as an index of environmental quality. High diversity values were also observed in those states of group III placed close to the origin of Figure 2. These states showed high percentage values of fisheries, harbours, sewage treatment plants and thermoelectric energy generation. On the other hand, states of group III (Figure 1), placed at the far upper left hand of the plot, exhibited low diversity values and are the least associated to environmental variables. Therefore the latter states would have the highest levels of environmental quality. Group III was characterised by fisheries and harbours. This implies that trade and smuggling should be included into further analyses as they might account for high percentages of variance.

If the results (Figures 1, 2 and 3) are analysed from an integral viewpoint (i.e. holistic rather than reductionist), one could conclude that the ordination might not be representative for the whole country,

**Figure 3.** Map of the study area




*Source*: INEGI (1995).

Simbology

| States (●) | |
|---|---|
| BC | Baja California |
| BCS | Baja California Sur |
| SON | Sonora |
| SIN | Sinaloa |
| NAY | Nayarit |
| JAL | Jalisco |
| COL | Colima |
| GUE | Guerrero |
| CHI | Chiapas |
| MIC | Michoacán |
| OAX | Oaxaca |
| VER | Veracruz |
| TAB | Tabasco |
| YUC | Yucatán |
| QUI | Quintana Roo |
| TAM | Tamaulipas |

| Environmental Indicators (__________) | |
|---|---|
| CL | Cólera |
| PLU | Pluviosidad |
| ALT | Altitud |
| PST | Suspensión total de partículas sólidas |
| SOX | Dióxido de sulfuro |
| NOX | Monóxido de nitrógeno |
| CO | Monóxido de carbono |
| SUP | Surface |
| INFR | Infecciones respiratorias |
| DBOU | Demanda urbana de oxígeno bioquímico |
| DBOR | BOD sewage |
| DBOI | BOD industrial |

| Economics Indicators (◇) | |
|---|---|
| EH | Generación de energía hidroeléctrica |
| ET | Generación de energía termoeléctrica |
| CAB | Harbour of Trade |
| TAR | Plantas de tratamiento Sewage |
| ALT | Harbour of Call |
| FERR | Vías de tren |
| CAR | Carreteras |
| PES | Total fish cought |
| CAM | Lorries/tráilers |
| PA | Producción de agua potable |
| POB | Población |

as only 17 states were selected from a total of 32. Moreover, the central region of the country presents the most populated cities (e.g. Mexico City), the lowest environmental quality standards, and most of the anthropic activities. Hence future studies should consider the whole country and more economic and environmental information of that selected here.

This study has also shown that CCA represents an objective approach to treat variables expressed in different units (e.g. cholera cases and DBO), so it is an appropriate tool for routine analyses of environmental, economic and social research. It is proposed therefore that CCA, by means of *Canoco*, should be used by other researchers in other countries because it will reliably compare environmental, economic and social information. The CCA on environmental and socioeconomic variables can be of great help to solve problems in regional development, and seems to be a satisfactory tool as it provided us an integrated and significant geographical analysis.

## Conclusion

The ordination method allowed us to identify three groups, namely hydroelectric energy generation (I), pollution (II) and harbours (III), which were associated to different human activities. As expected, the use of CCA as exploratory analysis of environmental and economic data was a satisfactory tool, as it provided us an integrated view of the study area. The CCA, by means of *Canoco*, should be used by other researchers in other countries because it will reliably compare environmental, economic and social information.

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