GEOGACETA, 45, 2008

Quantitative tools for environmental reconstructions of the recent estuarine infill using benthic foraminifera

Herramientas cuantitativas para realizar reconstrucciones ambientales de los rellenos estuarinos recientes usando foraminíferos bentónicos

Alejandro Cearreta (1), Eduardo Leorri (1, 2), Iratxe Iriondo (3), María José González (4) and Oihana Aristondo (4)

(1) Departamento de Estratigrafía y Paleontología, Facultad de Ciencia y Tecnología, Universidad del País Vasco/EHU, Apartado 644, 48080 Bilbao, Spain. alejandro.cearreta@ehu.es.
(2) Sociedad de Ciencias Aranzadi, Calle Zorroagagaina, 11, 20014 Donostia-San Sebastián, Spain.
(3) Departamento de Ingeniería Minera y Metalúrgica, Ciencia de los Materiales, Escuela Universitaria de Ingeniería Técnica Minera, Universidad del País Vasco/EHU.
(4) Departamento de Matemática Aplicada, Escuela Universitaria de Ingeniería Técnica Minera, Universidad del País Vasco/EHU.

RESUMEN

Con la idea de evaluar la respuesta cuantitativa de los foraminíferos con respecto a la distancia relativa a la boca del estuario (RDEM) en los sistemas estuarinos del sur del Golfo de Vizcaya, se ha desarrollado una función de transferencia basada en un matriz de datos compuesta por 88 muestras y 41 especies obtenidas en seis estuarios del norte de España. La RDEM ha sido considerada como un indicador del gradiente de salinidad. La relación entre los resultados obtenidos e inferidos indica el óptimo funcionamiento de la función de transferencia (r^2_{jack} *= 0.76) y permiten llevar a cabo reconstrucciones precisas de la evolución reciente de la RDEM a partir del análisis del registro sedimentario.*

Key words: *benthic foraminifera; estuaries; transfer function; salinity gradient; Bay of Biscay.*

Geogaceta, 45 (2008), 67-70
ISSN: 0213683X

Introduction

Estuaries are located between the continental and oceanic end members, resulting in strong variations of salinity and all other parametres linked to the penetration of seawater into the estuary. An estuary could be defined most simply based on salinity, being an area where freshwater enters saline water and during at least some period of time, water is neither truly saline nor truly fresh. However, data over diurnal and longer time series are seldom available. On the other hand, benthic organisms are good ecological indicators, given their inherent ability to integrate sediment quality and changing environmental conditions, and therefore to provide an insight of the spatial variations derived from the salinity influence. Recently, advances in high-resolution studies have been made through the development of foraminifera-based transfer functions. This technique is an important palaeoecological tool that provides objective, quantitative and reproducible estimates of the environmental parametre studied, associated with explicitly stated error terms (Birks, 1995). Consequently, we hypothesize that transfer functions would provide an adequate method to quantify the assemblage turnover along the salinity gradient in the southern Bay of Biscay, using the relative distance to the estuary mouth (RDEM) as a proxy for salinity. In this paper we present a new transfer function based on the modern distributions of intertidal foraminifera recorded in six estuaries from the southern Bay of Biscay (Figure 1) and provide an improved quantitative assessment with defined error terms of the potential of regional intertidal foraminifera for salinity studies (in terms of RDEM).

Study area

Samples were recovered from six estuaries with similar mesotidal ranges (mean 2.5 m): San Vicente de la Barquera estuary (5.4 km long and 750 m wide), Santoña estuary (14 km long and 500 m wide), Barbadun estuary (5.5 km long and 5-10 m wide), Plentzia estuary (7.9 km long and 60 m wide), Urdaibai estuary (11.6 km long and 1 km wide), and Orio estuary (11.4 km long and 80 m wide).

Materials and methods

The data set analyzed here is composed by the dead foraminiferal assemblages of 88 sampling locations coming from six estuarine areas (Figure 1) and includes 41 species. Following Hayward et al. (2004) we have used here the distance of each sample to the estuarine mouth as a proxy for salinity. To allow for comparison among the different estuaries, we have standardized distances relative to the total length of each estuary defined as the distance between the head and the mouth: $RDEM_n = d_n / d_{MTL} \times 100$, where $RDEM_n$ is the standardized distance to the mouth for sample n, d_n the distance to the mouth of sample n (in metres), d_{MTL} the maximum tidal level (in metres). This produces a standardized distance (RDEM) for each modern sample with 100 representing maximum tidal distance

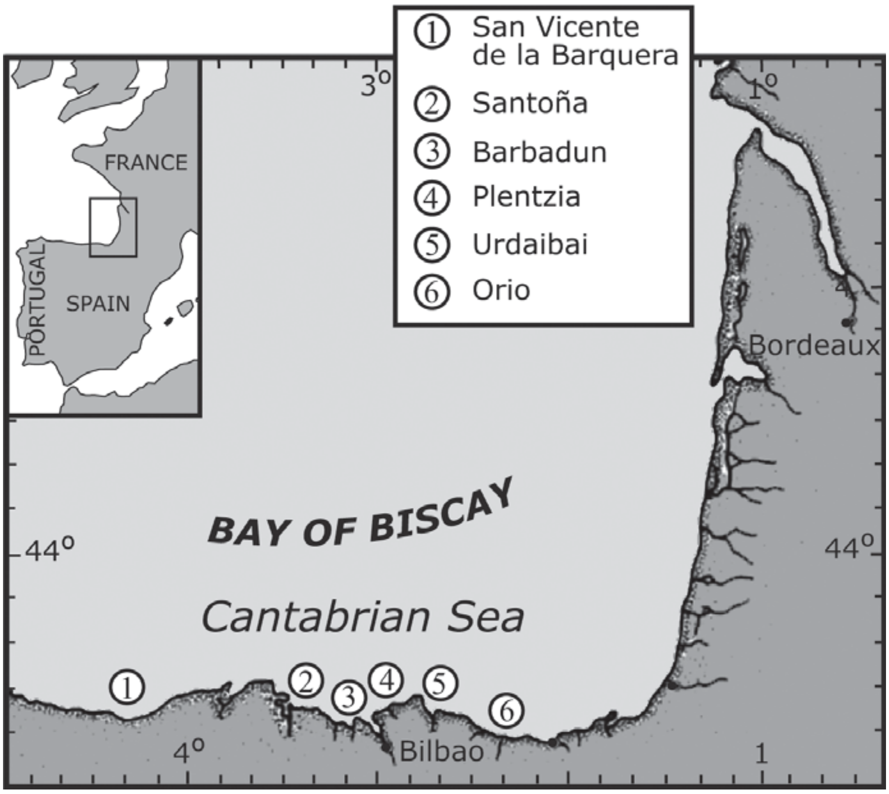

Fig. 1.- Geographical location of different estuarine areas in the southern Bay of Biscay. Key: 1-San Vicente de la Barquera; 2- Santoña; 3- Barbadun; 4- Plentzia; 5- Urdaibai; 6- Orio.

Fig. 1.- Localización geográfica de las diferentes zonas estuarinas en el sur del Golfo de Vizcaya. Clave: 1-San Vicente de la Barquera; 2- Santoña; 3- Barbadun; 4- Plentzia; 5- Urdaibai; 6- Orio.

and 0 for the samples placed at the mouth of the estuary.

A foraminifera-based transfer function: Numerous methods have been developed to quantitatively reconstruct palaeoenvironmental variables (see Birks, 1995 for a review of transfer function methods). Those methods differ in the numerical assumptions made on the data used, including whether the taxon-environment response is unimodal (Gaussian) or linear (Sejrup et al., 2004). In order to determine which of these model responses corresponds to our data, we used detrended correspondence analysis (DCA) and detrended canonical correspondence analysis (DCCA), since these techniques are valuable guides in detecting the species assemblage response (Sejrup et al., 2004). Modern foraminiferal percentages were transformed to square roots to maximise the "signal to noise" ratio, and DCA and DCCA involved detrending by segments, nonlinear rescaling, and down-weighting of rare taxa (Sejrup et al., 2004). DCCA provides an estimate (as the length of DCCA axis 1) of the gradient length in relation to x (environmental variable) in standard deviation (SD) units (Birks, 1995). If the gradient length is longer than 2 SD units several species will have their optima located within the gradient and unimodal-based methods of regression and calibration are appropriate (Birks, 1995). We used "weighted-averaging partial least squares" regression (WA-PLS) as the transfer function model. WA-PLS is an extension of the unimodal method "weighted averaging" (WA), which considers the variance along the environmental variable of interest (i.e., RDEM). As indicated above, other environmental variables (e.g., temperature) influence foraminiferal distributions, and this may distort the faunal–environment relationships. In WA-PLS, further components are calculated orthogonal to earlier components and they are obtained as WA of the residuals for the environmental variable, improving the predictions as it considers the combined influence of additional environmental variables.

The final WA-PLS models were selected based on low root-mean square of the error of prediction (RMSEP), low maximum bias, high squared correlation (r^2) of observed versus predicted values, and the smallest number of "useful" components. The RMSEP indicates the systematic differences in prediction errors, whereas the r^2 measures the strength of the relationship of observed versus predicted values. These statistics were calculated as "apparent" measures in which the whole training set was used to generate the transfer function and assess the predictive ability, and the data were also jack-knifed (also known as 'leave-one-out' measures). Jack-knifing is a cross-validation method that provides more reliable measures of the overall predictive abilities of the dataset, at

DCCA				
Axes	**1**	**2**	**3**	**4**
Eigenvalues:	0.22	0.325	0.103	0.074
Lengths of gradient:	2.169	2.385	1.544	2.06
Species-environment correlations:	0.758	0	0	0
Cumulative percentage variance				
of species data:	13.5	33.4	39.7	44.2
of species-environment relation:	97.8	0	0	0
DCA				
Axes	**1**	**2**	**3**	**4**
Eigenvalues:	0.468	0.127	0.088	0.057
Lengths of gradient:	2.926	1.437	1.558	1.694
Cumulative percentage variance				
of species data:	28.7	36.5	41.9	45.3

Table I.- Statistics summary of detrended correspondence analysis (DCA) and detrended canonical correspondence analysis (DCCA) of the modern foraminifera-RDEM from the southern Bay of Biscay estuaries.

Tabla I.- Resumen estadístico de los análisis DCA y DCCA de la relación entre foraminíferos y RDEM en los estuarios del sur del Golfo de Vizcaya.

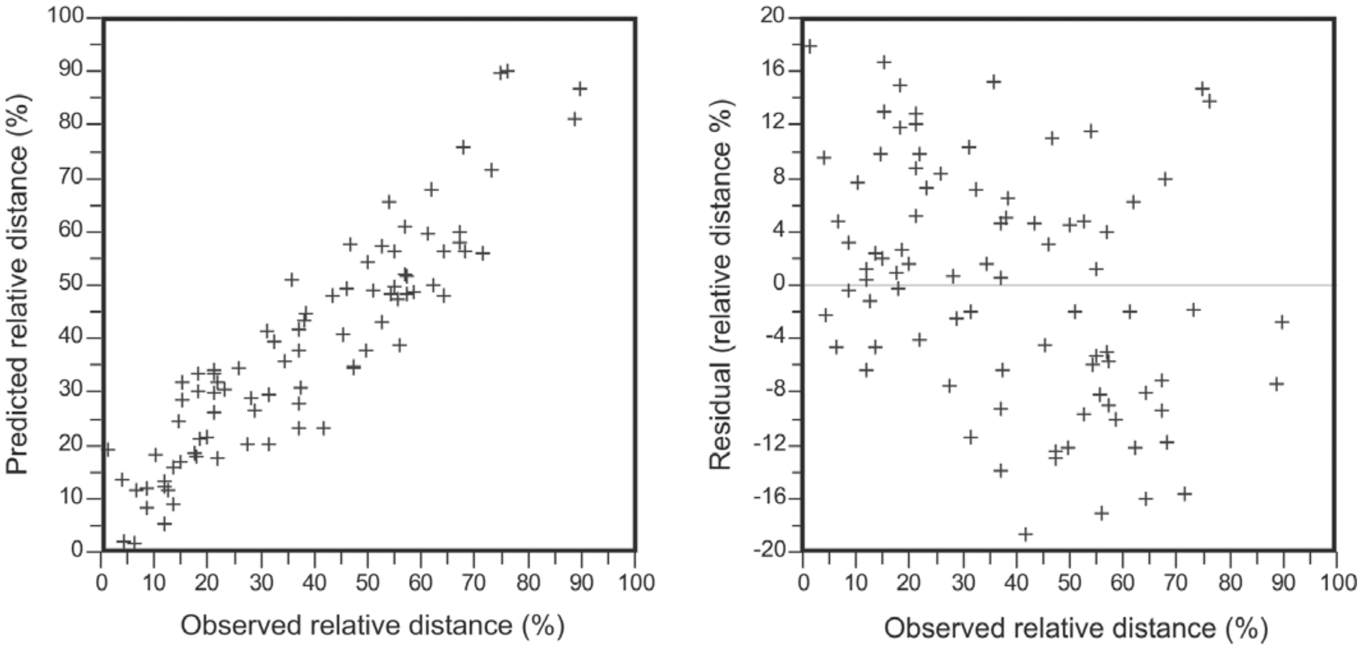

Fig. 2.- Observed and predicted values of the RDEM for Model 1 (component 4) of the foraminiferal transfer function and their residual errors.

Fig. 2.- Valores de RDEM observados y calculados con el Modelo 1 (componente 4) de la función de transferencia y sus errores residuales.

least when applied to the modern assemblages (Sejrup et al., 2004). In general terms, we considered a "useful" component when improved the previous component performance by at least 5% of the component 1 (Birks, 1995).

Results and Discussion

DCA of the modern data (Table 1) shows that only axis 1 (one gradient) captures over 10 % of the total variance of the faunal composition (eigenvalue = 0.47, gradient length = 2.92 SD, 28.7 of the total variance). Subsequent axes have low eigenvalues (axis 2 = 0.13, axis 3 = 0.09, and axis 4 = 0.06) and only capture 7.8 %, 5.4 %, and 3.4 % of the total variance, respectively. DCCA of the training set with RDEM as the only environmental variable has produced a gradient length of 2.17 SD and capture over 13 % of the total variance in the microfaunal data. The results obtained by DCA and DCCA approximate those obtained for bottom waters summer salinity by Sejrup et al. (2004), and indicate a unimodal nature of the foraminiferal abundance data with respect to RDEM (Table 2). Thus, unimodal-based methods of regression and calibration were used.

Preliminary analysis demonstrated that WA-PLS method performed best in terms of maximum bias, r^2 and a smaller RMSEP (see Sejrup et al., 2004 for the advantages of using WA-PLS). No sample or species was screened from the dataset. The WA-PLS transfer function produces results for five components. The choice of component depends upon the prediction statistics (RMSEP and r^2) and the principle of parsimony, i.e. choosing the lowest component that gives an acceptable model. Using component four, the relationship between observed and foraminiferal-predicted RDEM was very strong (Table 1; Figure 1), a result that illustrated the robust performance of the WA-PLS transfer function (r^2_{jack} = 0.76). These results indicated that reconstructions of former salinity gradients based on foraminiferal assemblages from the sedimentary record are possible ($RMSEP_{jack}$ = 11.1).

The precision of the transfer function, expressed as a percentage of the range of the modern environmental gradient sampled, is comparable to other foraminifera-based transfer functions developed from the northern Atlantic Ocean. The obtained Model has a precision of ±11.1 %. This value is in the low range of error compared with bottom water summer salinity transfer functions, marine transfer functions based on planktonic foraminifera, limnological and terrestial transfer functions (see Sejrup et al., 2004) and sea-level transfer functions from salt marsh foraminifera, which typically range between 8 and 20 % in terms of percentage of the gradient analyzed.

	Component 1	Component 2	Component 3	Component 4	Component 5
RMSE	15.16	11.22	9.48	8.81	8.33
r^2	0.55	0.76	0.83	0.85	0.86
Max_Bias	36.71	16.66	9.20	7.95	9.95
r^2_{jack}	0.48	0.61	0.71	**0.76**	0.77
Max_Bias $_{jack}$	40.70	26.43	20.08	**15.42**	17.94
RMSEP $_{jack}$	16.44	14.28	12.21	**11.09**	10.81

Table II.- Statistics summary of the performance of Weighted Averaging-Partial Least Squares (WA-PLS) for the foraminiferal assemblages from the southeastern Bay of Biscay.

Tabla II.- Resumen estadístico de los resultados de WA-PLS obtenidos para las asociaciones de foraminíferos del sureste del Golfo de Vizcaya.

The technique developed here is aimed to provide a quantitative tool for both monitoring programmes of impacted areas and palaeoenvironmental reconstructions in estuarine areas using benthic foraminiferal assemblages that so far have been based mainly on qualitative assessments. This tool will allow a quantitative approach to both purposes and it will particularly improve the ongoing research in the southern Bay of Biscay providing specifically baseline data to assess environmental pollution as well as modern analogues to quantitatively reconstruct the Holocene estuarine sequences.

Acknowledgements

We thank Nieves González for digitalizing the data set. This work has been partially funded by the UNESCO06/08 and GIC07/32-IT-332-07 research contracts. It represents a contribution to IGCP project # 495.

References

Birks, H.J.B. (1995). In: *Statistical modelling of Quaternary science data, Technical Guide 5* (D. Maddy and J.S. Brew, Eds.). Quaternary Research Association, Cambridge, 161-254.

Hayward, B.W., Scott, G.C., Grenfell, H.R., Carter, R. and Lipps, J.H. (2004). *The Holocene*, 14, 218-232.

Sejrup, H.P., Birks, H.P.B., Klitgaard Kristensen, D. and Madsen, H. (2004). *Marine Micropaleontology*, 53, 197-226.