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A TEST APPLICATION OF THE SHE METHOD AS A BIOSTRATIGRAPHICAL PARAMETER

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With 6 figures and 1 table

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Abstract:

Biodiversity – the index "expressing the variety and variability of living organisms and of the ecological systems comprising them" (Ferrari, 2001) – is essential in the characterization and study of past and present biological systems, and is generally expressed by a number (the "biodiversity index"), statistically derived from empirical observations.

The SHE indexing method (Buzas & Hayek, 1996, Hayek & Buzas 1997), is expressed by the Shannon Index, H (a measure of the system's entropy) as the composition of two factors representing respectively the number of species in the sample (S) and the distribution uniformity (E).

The SHE index does not only describe in a thorough way the system's biodiversity, but, as a function of abundance and evenness, can be used to identify biofacies (SHEBI – SHE for Biofaces Identification) or to characterize the whole structure of the analysed community (SHECSI – SHE for Community Structure Identification).

SHE analysis, independently of its application purposes, appears to be highly flexible, does not require the adoption of specific computer packages beyond a common spreadsheet, and is based on a simple graphical analysis; widely adopted in botanics, SHEBI analysis in particular has been applied with satisfactory results to the study of benthic foraminiferal faunas from the Atlantic ocean (Buzas & Hayek,1998].

In this work, the SHEBI method has been applied to 87 samples from the Falconara section (Southern Sicily) – the purpose of the study is to verify the possibility of applying SHE/SHEBI to Messinian planktonic foraminiferal assemblages.

Our study has to face issues that are typical of planctonic faunas – such as the lower number of species and the ample variability in single taxa abundances; a further factor to be taken into account in setting up and executing the analysis is the progressive deterioration of the ecosystem as the peak of the Messinian crisis approaches. Biofacies identification through SHEBI in less than ideal conditions, but on such a widely studied and described section, offers an excellent opportunity to test the method and its limits, its application range and the reliability of its results.

1. Introduction – SHE and the measure of diversity

This work aims at identifying and evaluating the limits (if any) of the application of the SHE analysis to planktonic foraminiferal faunas, in order to simplify the application of this powerful diversity-based technique to the field of planktonic foraminiferal biostratigraphy.

Diversity is one of the defining factors in any study of an ecological system. A number of indices was developed through the years by different researchers, to quantitatively express diversity as observed in the field or in laboratory; among the more widely used indices are Fisher's α index (a measure of species richness), Simpson's λ index, Equitability (E, a measure of evenness) and

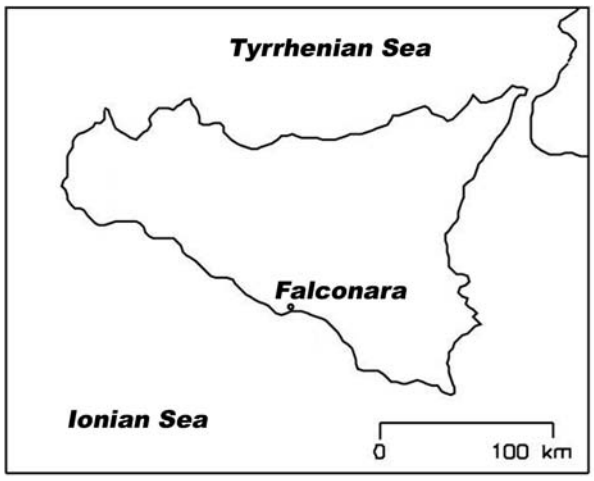

Fig. 1: Location map of the Falconara outcrop in Sicily.

Shannon's H index (a derivation of the information function) (Smart, 2002).

Species richness itself (expressed as S, total number of species) has been used in the past as a rough measure of diversity.

The recognition of the mathematical relation between Species Richness and Taxa Abundance, and its meaning in terms of Diversity and Dominance is the basis of the recent SHE approach to the study of biodiversity (Hayek & Buzas, 1997).

The mathematical expression summing up this relationship is

(1) **H = ln(S) + ln(E)**

in which

H is the Shannon Diversity Index

S is the Species Richness

E is the Dominance or Evenness of the distribution

Relation (1) is constant as long as species proportions are constant.

As a change of the proportions of species to each other is clearly a sign of change in diversity, the SHE relationship has to be interpreted as an expression of diversity.

This allows a simple graphical analysis of the variations of biodiversity: each of the three variables can in fact be plotted against the Abundance (N) of the sample; changes in proportions (and therefore in diversity) will be signalled by a change in the graphic line slope (a "slope break" in the "hollow curve" following Hayek & Buzas' terminology).

Operationally, the method is not as mathematically intensive as other well-established analysis procedures (i.e., Cluster Analysis), requiring simply a logarithmic transformation of the indices, and while specific software is easily available to calculate the values of H and E, given standard sample counts, the whole analysis can be carried out on a simple spreadsheet software (i.e., Microsoft Excell or OpenCalc) with a minimum of fuss.

Conceptually, the analysis can be carried out through time (i.e., vertically, comparing levels along a geological section) or through space (i.e. laterally, comparing sectors in a landscape).

Introduced in the late 1990s as a way to sidestep some perceived limits in more popular diversity indices (Shannon-Weiner in particular), SHE's field of application was later extended and redefined, with the introduction of SHEBI (SHE Analysis for Biofacies Identification) and SHECSI (SHE Analysis for Community Structure Identification) (Buzas and Hayek, 1996, 1998 ; Hayek and Buzas, 1997, 1998).

Examples of applications of the SHE approach to biodiversity have been published as part of botanical (Hayek and Buzas, 1996, 1997, Small and McCarthy 2002) and zoological studies (Leponce et al. 2004); closer to the concerns of this paper, SHE has been applied to the study of quaternary benthic foraminiferal faunas in what can be defined as a non-perturbed environmental setting (Buzas and Hayek, 1998, Osterman et al, 2002).

By all accounts, when applied to current or recent environments and populations, SHE appears to be a solid, easily applied method for describing diversity; in particular, it allows a high-resolution visualization of changes in diversity through time or space; the method allows researchers "to examine evenness separately from richness within a single multispecies system" (Buzas and Hayek, 1998) and it does not suffer from some of the limits signalled for other diversity-based indices (Hayek and Buzas, 1997).

Some doubts might still remain when SHE is to be applied to situations in which those factors the method takes into account (population density, specific richness, etc.) are subject to extreme or unpredictable variations – i.e. due to drastic changes in environmental conditions, or to other external causes.

To verify the viability of SHE analysis in such critical conditions, this study has been carried out on planktonic foraminiferal faunas from Messinian strata of the Mediterranean, which are normally characterized by lower species richness (S) than ben-

thic faunas. Proximity to the peak of the Messinian Salinity Crisis further weakens the species richness signal, due to increased environmental stress.

This paper briefly summarizes the study and its results.

2. The Falconara Section and the planktonic samples

The samples used for this study were collected in the alternating clay/diatomite cycles of the Tripoli formation (Upper Tortonian-Messinian) with an exposed thickness of one hundred meters in the Falconara Section.

Located on the southern face of Monte Caltagirone, on the southern coast of Sicily between Gela and Licata (see fig. 1), the Falconara Section (fig.2) was originally proposed as the type-section for the Messinian (Colalongo et al., 1979), and has been the object of continuing studies, criticism and revisions, due to its paramount importance for the comprehension of Mediterranean events; in more than thirty years, studies have shifted from bio-stratigraphical and chronostratigraphical concerns and techniques to cyclostratigraphical and astro-chronological methods. (summarized in Hilgen et al., 2000).

The abundance of previous studies and the detailed description of the Falconara faunas (Colalongo et al., 1979, Hilgen & Krijgsman, 1999, Hilgen et al., 2000) by previous authors provides an excellent background for our test-run of the SHE approach to planktonic foraminifera biostratigraphy. Our study does not mean to redefine in any way the stratigraphy of the Falconara section, but to use a well-studied section and its wealth of accumulated paleontological and stratigraphical knowledge as the consensus against which the results of the SHE test will be compared for validation.

The samples used in this study were collected from the Falconara Section in 1994 (fig. 3), as part of a wide-ranging campaign of studies on the Messinian Salinity Crisis in the Mediterranean; in the field, both clay and diatomite layers were sampled separately, and were later subjected to standard micropaleontological analysis and quantitative studies in the laboratories of the Università degli Studi, Torino.

Fig. 2: View of the Falconara outcrop.

The environmental information provided by the faunas contained in the sediments was presented and discussed in the author's graduation paper (Mana, 2001) concerning the same samples used in this study; in that work, a general biozonation based on a traditional method (Cluster Analysis), was proposed, identifying seven distinct biofacies, each connected with the progressive environmental crisis of the Messinian sea.

That work, and the excellent synthesis by Hilgen and Krijgsman (1999) will be our two chief references for comparison.

3. SHE Analysis

For the purposes of this study, 87 samples were observed, and 300 individuals counted according to standard statistical data-gathering practices; seventeen planktonic taxa were recognized (see below) and counted; to these, a class labelled "others" was added to include the few non-planktonic individuals (mostly *Bulimina echinata*). For the species *Neogloboquadrina acostaensis*, sinistral coiling individuals were counted separately from dextral coiling individuals.

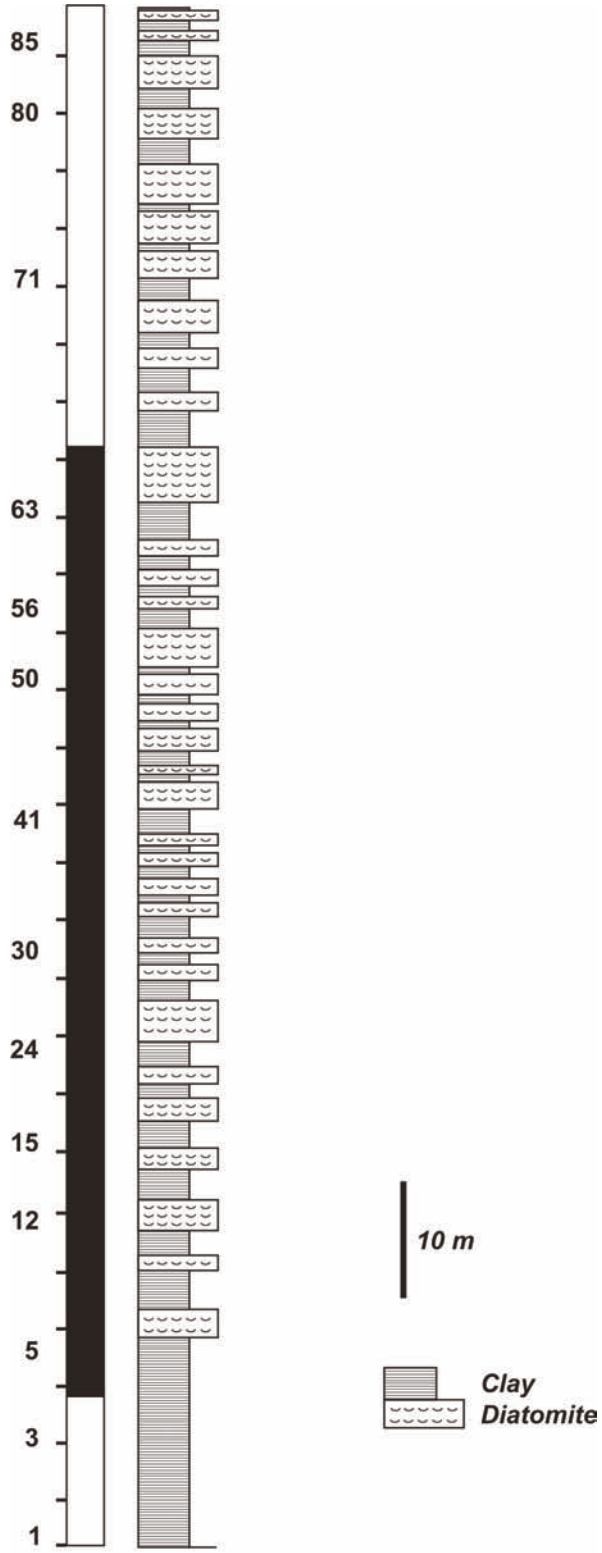

Fig. 3: Summary sketch of the Falconara Section, with sample numbers.

The taxa used in this study are:

Globigerina angustiumbilicata
Globigerina sp
Globigerinoides ruber
Globigerinoides sp
Turborotalita multiloba
Turborotalita sp
Globorotalia conoidea
Globorotalia praemenardi
Globorotalia sp
Neogloboquadrina continuosa
Neogloboquadrina acostaensis sin.
Neogloboquadrina acostaensis dex.
Orbulina universa
Globigerinella obesa
Globigerinella praesiphoniphera
Globigerinella sp
Sphaeroidinellopsis
Other

As described in Buzas and Hayek (1998), from the species counts, the cumulative values of N (number of individuals in sample), S (number of species in sample or Specific Richness), H (Shannon's Index) and E (Evenness) were calculated using an Excell spreadsheet, and the natural logarithms extracted for each value (Table 1).

Cumulative values (a stepwise addition of values) were used so that S will be steadily increasing through the sequence.

Considering now equation

(1) **H = ln(S) + ln(E)**

as we have already stated, this relation remains constant as long as species proportions remain constant. More to the point, if – as in the case of our analysis – the value of S increases steadily due to the cumulative process, two possibilities can become apparent: if, as S increases, H remains constant, this will mean a progressive decrease in the value of the samples' cumulative Evenness; should instead the value of ln(E) remain constant, this would mean a progressive variation in the value of H.

Plotting linear graphics for

ln(S) vs ln(N)
H vs ln(N)
ln(E) vs ln(N)

allows us to pinpoint biofacies changes, represented by slope breaks on the graphs (fig. 4).

SAMPLE	N	(N)	ln(N)	(S)	ln(S)	H	(E)	LN(E)	SAMPLE	N	(N)	ln(N)	(S)	ln(S)	H	(E)	LN(E)
1	307	307	5,73	7	1,95	0,97	0,38	-0,97	**45**	316	10913	9,30	54	3,99	0,14	0,02	-3,85
2	288	595	6,39	11	2,40	1,00	0,25	-1,40	**47**	304	11217	9,33	54	3,99	0,11	0,02	-3,88
3	329	924	6,83	20	3,00	0,86	0,12	-2,14	**48**	341	11558	9,36	54	3,99	0,11	0,02	-3,87
4	302	1226	7,11	22	3,09	0,62	0,08	-2,47	**49**	343	11901	9,38	54	3,99	0,15	0,02	-3,84
5	315	1541	7,34	26	3,26	0,62	0,07	-2,64	**50**	337	12238	9,41	54	3,99	0,10	0,02	-3,89
6	303	1844	7,52	31	3,43	0,53	0,05	-2,91	**51**	396	12634	9,44	54	3,99	0,14	0,02	-3,85
7	300	2144	7,67	31	3,43	0,43	0,05	-3,01	**52**	347	12981	9,47	56	4,03	0,13	0,02	-3,90
8	327	2471	7,81	32	3,47	0,38	0,05	-3,09	**53**	317	13298	9,50	56	4,03	0,11	0,02	-3,91
9	329	2800	7,94	34	3,53	0,34	0,04	-3,18	**54**	354	13652	9,52	57	4,04	0,12	0,02	-3,93
10	396	3196	8,07	35	3,56	0,40	0,04	-3,16	**55**	326	13978	9,55	57	4,04	0,11	0,02	-3,93
11	285	3481	8,16	37	3,61	0,31	0,04	-3,30	**56**	300	14278	9,57	57	4,04	0,11	0,02	-3,93
12	319	3800	8,24	37	3,61	0,27	0,04	-3,34	**57**	307	14585	9,59	57	4,04	0,11	0,02	-3,93
13	286	4086	8,32	38	3,64	0,29	0,04	-3,34	**58**	198	14783	9,60	57	4,04	0,07	0,02	-3,98
14	296	4382	8,39	39	3,66	0,28	0,03	-3,39	**59**	327	15110	9,62	57	4,04	0,12	0,02	-3,93
15	323	4705	8,46	45	3,81	0,30	0,03	-3,51	**61**	331	15441	9,64	58	4,06	0,12	0,02	-3,94
16	312	5017	8,52	46	3,83	0,26	0,03	-3,57	**62**	350	15791	9,67	58	4,06	0,10	0,02	-3,97
17	328	5345	8,58	48	3,87	0,21	0,03	-3,66	**64**	349	16140	9,69	60	4,09	0,11	0,02	-3,98
20	303	5648	8,64	48	3,87	0,23	0,03	-3,64	**65**	287	16427	9,71	60	4,09	0,09	0,02	-4,00
22	305	5953	8,69	49	3,89	0,22	0,03	-3,67	**67**	344	16771	9,73	60	4,09	0,11	0,02	-3,99
24	172	6125	8,72	50	3,91	0,13	0,02	-3,78	**68**	311	17082	9,75	60	4,09	0,10	0,02	-3,99
25	313	6438	8,77	50	3,91	0,20	0,02	-3,72	**70**	314	17396	9,76	60	4,09	0,10	0,02	-4,00
26	293	6731	8,81	50	3,91	0,19	0,02	-3,72	**72**	320	17716	9,78	60	4,09	0,10	0,02	-3,99
27	209	6940	8,85	50	3,91	0,13	0,02	-3,78	**73**	72	17788	9,79	60	4,09	0,03	0,02	-4,06
29	303	7243	8,89	51	3,93	0,20	0,02	-3,73	**74**	347	18135	9,81	60	4,09	0,10	0,02	-4,00
31	289	7532	8,93	52	3,95	0,19	0,02	-3,77	**75**	332	18467	9,82	60	4,09	0,08	0,02	-4,01
33	300	7832	8,97	53	3,97	0,17	0,02	-3,80	**76**	350	18817	9,84	60	4,09	0,08	0,02	-4,01
34	309	8141	9,00	53	3,97	0,17	0,02	-3,80	**77**	304	19121	9,86	60	4,09	0,07	0,02	-4,03
35	304	8445	9,04	54	3,99	0,16	0,02	-3,83	**78**	197	19318	9,87	60	4,09	0,06	0,02	-4,03
37	321	8766	9,08	54	3,99	0,17	0,02	-3,82	**79**	300	19618	9,88	60	4,09	0,08	0,02	-4,01
38	304	9070	9,11	54	3,99	0,15	0,02	-3,84	**80**	370	19988	9,90	60	4,09	0,08	0,02	-4,01
39	291	9361	9,14	54	3,99	0,14	0,02	-3,85	**81**	338	20326	9,92	60	4,09	0,08	0,02	-4,02
40	316	9677	9,18	54	3,99	0,14	0,02	-3,85	**82**	345	20671	9,94	60	4,09	0,09	0,02	-4,01
42	302	9979	9,21	54	3,99	0,14	0,02	-3,85	**84**	201	20872	9,95	60	4,09	0,05	0,02	-4,04
43	300	10279	9,24	54	3,99	0,13	0,02	-3,85	**85**	267	21139	9,96	60	4,09	0,06	0,02	-4,04
44	318	10597	9,27	54	3,99	0,14	0,02	-3,85	**87**	332	21471	9,97	60	4,09	0,07	0,02	-4,02

Table 1: List of Falconara samples showing calculated values of indexes for SHE analysis. Missing samples were found to be sterile. Abbreviations: N, counted individuals; (N), cumulated N; (S), cumulated species richness; H, Shannon's Index; (E), Evenness.

In fig. 4 the three "hollow curves" (Hayek & Buzas, 1997, 1998) are plotted in a single graph in the same order in which we introduced them above; as our fig. 4 shows, a number of breaks are evident, each of them potentially marking a change in association, and therefore in biofacies.

It is important at this point to notice that matters of scale, and the high number of individuals projected, might distort the curve plot, causing a loss of definition and actually masking some significant slope breaks. To avoid this distortion effect, the suggested practice consists in breaking the sequence into smaller intervals – which is achieved in practice by stepwise deleting the samples whose trend has already been analysed, recalculating all the values in the system.

The stepwise deletion procedure also corrects another important distortion which may present the single-plot SHE model in fig. 4 – the one caused by the disappearance of certain taxa as the sequence develops. Cumulative addition of Specific Richness alone, does account for the appearance of new species, but not for the loss of those species that, while present in the earlier levels of the sequence, disappear later. By stepwise deleting earlier data-points from the plot as the analysis progresses, and recalculating the values of S, N, E and H, disappearances are now computed into the model.

For the purposes of this work, the SHE analysis procedure was applied six times (fig. 5) in order to heighten the definition of the hollow curve.

The resulting graphs appear choppy and uneven, especially when compared to similar plots for benthic faunas (Buzas and Hayek, 1998]; this is an effect most likely caused by the characters of the planktonic assemblage (low Specific Richness, sudden disappearances) and the time interval considered (wide and sudden variations in environmental conditions as the situation evolves towards the crisis). The operator has also to take into account the very low values of the indices, a product of the generally low Species Richness and of the scarcity of biological remains in some samples (fifteen of which lack fossils).

Our biofacies analysis is based chiefly on the joint observation of both ln(S) and ln(E) plots; the latter is considered to be most sensitive to specific assemblage changes by most authors, but considering the scarcity of species represented in the samples, and the low abundances, using the former as a control and as a support in the definition of biofacies

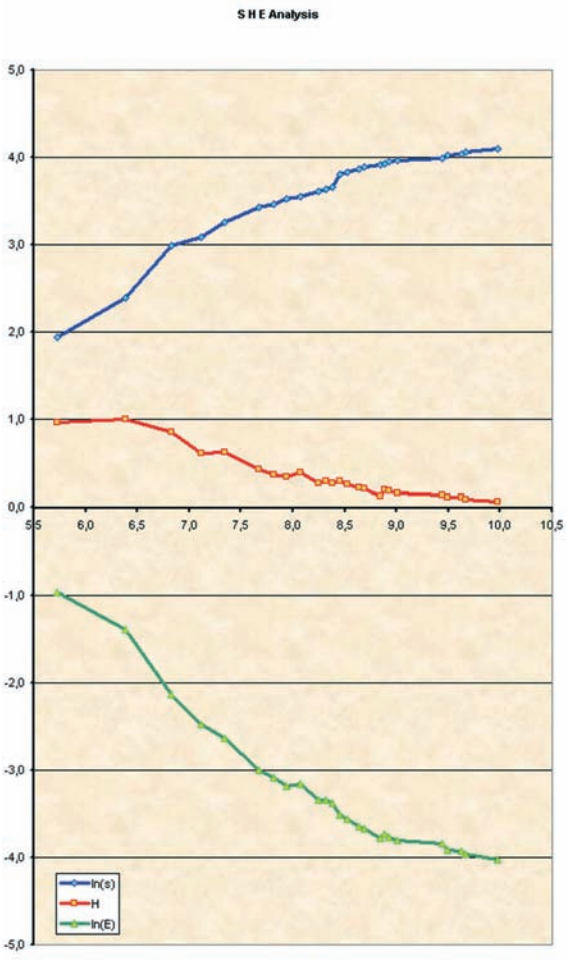

Fig. 4: SHE Analysis of Falconara samples, summary graph. Data-points (samples) have been thinned to improve readability.

breaks appears as an advisable line of conduct. The analysis leads to the definition of 21 intervals which can be considered each characterized by stable or near-stable conditions, their assemblages being therefore distinct biofacies.

Packing so many biofacies in a stretch of about one hundred meters could be considered embarrassing by someone – especially when compared to the seven biofacies intervals identified using the same samples and a more traditional discrimination approach (Cluster Analysis) in a previous work (Mana, 2001); and yet the intervals as identified by the method are undeniably a result of the observed species and counted abundances. And the fine subdivision of the Falconara sequence also reflects the rhythmic cycles of clays and diatomites, of which over forty couples can be observed in the field – and which were used as a basis for sampling in this study, and by many other authors (Hilgen and Krijgsman, 1999).

The definition of the SHEBI method is excellent, resolving in some cases changes in population balance (and therefore, in diversity) that occur at the scale of the single clay/diatomite couple; these were not considered in this work, as each should deserve a much more detailed analysis and assessment, but are shown in the plots collected in fig. 5, in which they appear as brief breaks in the slope of the hollow curve.

4. Conclusions and future developments

The SHE/SHEBI method is as reliable as more traditional approaches when applied to planctonic faunas, and does not require any ad hoc modification. In particular, the differences between planctonic and benthic faunas do not seem to hinder the application of the method, but simply require a higher degree of attention on the part of the researcher.

Similarly, conditions of progressive environmental crisis do not seem to compromise the method's functionality, and are easily recorded by the "hollow curve". By working on Species Richness S and Evenness E, SHEBI seems to compensate the progressive loss of data due to thinning of the association through time.

The biozonation obtained from the application of the SHE method appears to be consistent with previous zonations obtained through different analytical approaches (such as Cluster Analysis), but shows a higher sensitivity to minute changes in population balance, and therefore a higher resolution. Also, the method leaves a higher degree of freedom to the operator, who is allowed to fine-tune his interpretation of the graphs based on his knowledge of local peculiarities.

While probably regionally restricted due to the probability of sudden changes in planctonic associations, SHEBI zonation still appears to be an excellent correlation tool when used on different sections – and indeed this seems to be one of the more promising directions in which future investigation about the applications of SHE to Messinian faunas might expand; similarly, the possibility of coupling the biozonation tool offered by SHEBI with

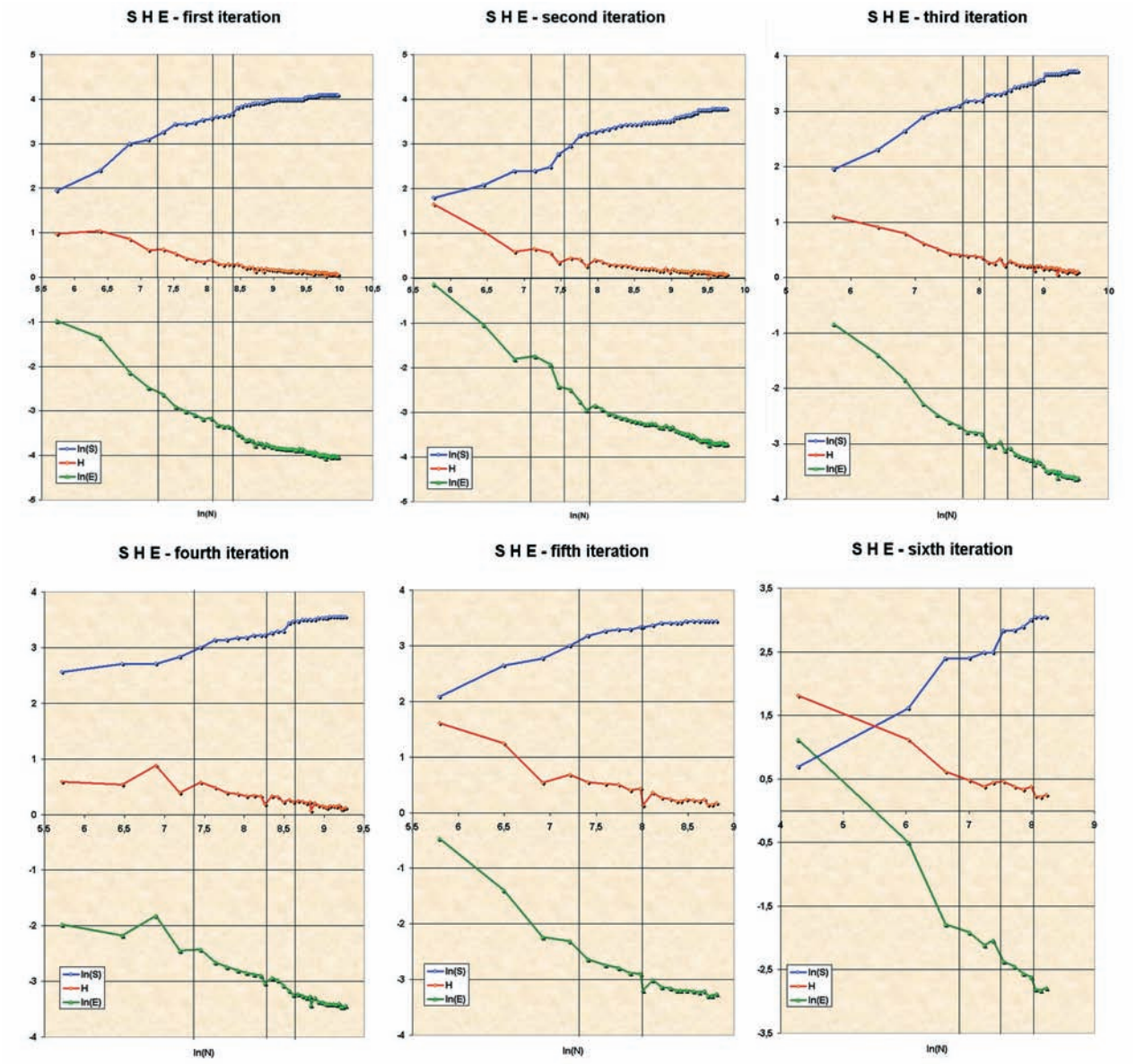

Fig. 5: SHE Analysis of the Falconara faunas; stepwise deletion of samples examined earlier with each new iteration. Vertical lines show the position of biofacies breaks.

palaeoecological assessing tools such as ordination methods (PCA, DCA) might hold great promise for future developments (Mana, 2004].

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Fig. 6: Schematic comparison of the biozonation based on Cluster Analysis [Mana, 2001], and the SHE biozonation (this work). Colors are purely indicative and have no stratigraphical meaning.

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