Application of fuzzy sets to the biometric evaluation of the species Nummulites millecaput

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***Abstract**: The goal of this paper is to demonstrate the ability of the fuzzy-set theory to contribute to the evaluation of paleontological problems. The species Nummulites millecaput has been chosen for the test calculation. One hundred specimens have been selected from the collection of the Museum of Natural History, Budapest from four localities: Arrimblar, Adel-holzen,Dudar and Mount –Kotuc, covering an east-west distance of about 3800 km. Equatorial sections have been prepared and internal and external characteristics were measured on each specimen. The traditional statistical evaluation was completed by membership functions. The results of the evaluations confirmed that the same species migrated eastward in the Tethys ocean during the Eocene period.*

Keywords: biometry, Nummulites, fuzzy sets, uncertainties

1 Introduction

The goal of this study is the demonstration that the fuzzy set theory can be successfully applied to the biometric evaluation of fossils. The species *Nummulites millecaput*, very common in the marine sediments of middle Eocene age, has been chosen for the test calculations. Four localities were selected from the collection of the Museum of Natural History, Budapest for the biometric measurements: Arrimblar in southwestern France, Adelholzen in Bavaria, Germany, Dudar in the Bakony Mountains, Hungary and the Mount Kotuc in Armenia. The four localities extend over a distance of 3800 km in west-east direction and are representative for this part of the Eocene ocean, called Téthys (see Figure 1).

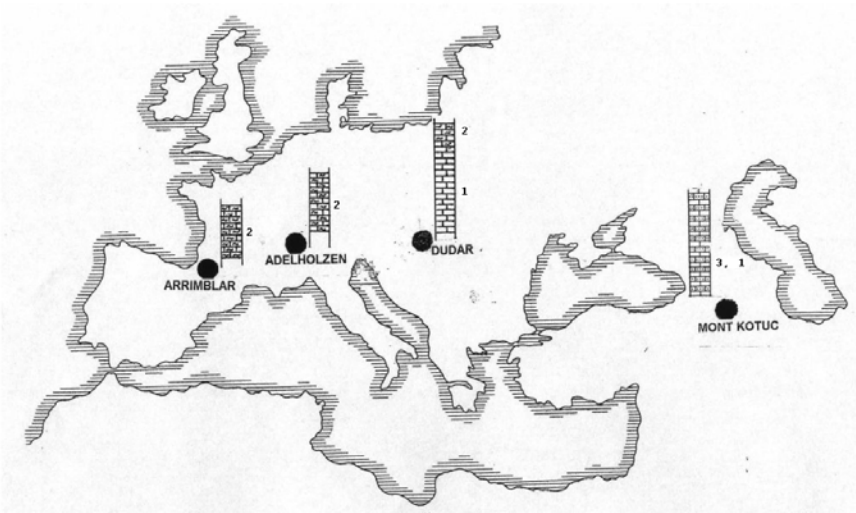

Figure 1. Four localities of occurrences of Nummulites millecaput

Altogether 100 specimens have been separated from the rock samples with the aim to carry out biometric measurements on their equatorial sections. The following external characteristics have been measured: diameter and the thickness of the house. From the internal characteristics the diameter of the protococh (the embrional chamber),the number of whorls in radial direction, the number of lamellae separating the chambers, the ratio of the spiral channels in two successive whorls of the house, the height and the length of the chambers and their ratio have been measured. These characteristics are illustrated in Figure 2.

A: 1 - diameter; 2 – thickness

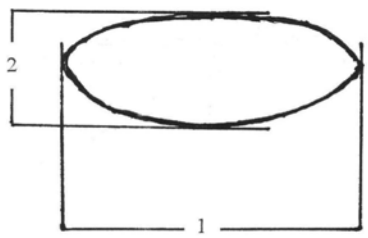

Figure 2A: Morphological parameters of Nummulites millecaput

B: Equational section. 1 - spiral lamella, 2 - whorl, 3 - septum, 4 - chamber, 5 - protoconch, 6 - height of the chamber, 7 - length of the chambers

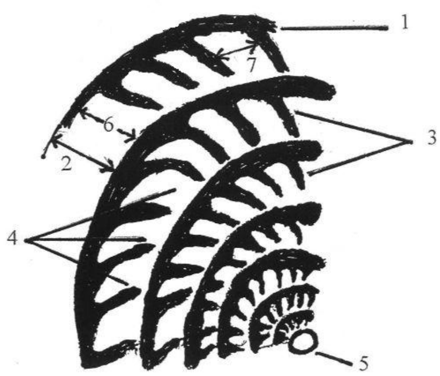

Figure 2B. Morphological parameters of Nummulites millecaput

2 Statistical evaluations

The results of the measurements have been evaluated first by traditional statistical methods and are presented in Table 1. This indicates gradual changes of the measured characteristics in west-east direction. Note that according to paleogeographic studies, the Téthys ocean expanded in the middle Eocene from west to the east. The species Nummulites millecaput followed this expansion (called transgression) by a slow migration in the waters of the sea.

The *diameter of the house* shows a gradual diminution parallel to the direction of the migration and the standard deviation also diminishes in this direction. These changes are illustrated on the box-plots of the Figure 3. Note the outliers at the Dudar locality.

The *thickness of the house* did not follow this trend, it remained unchanged along the entire studied area, only the specimens of the above mentioned Dudar locality are thinner than those of the other three localities. These diffe-rences can be explained by local paleogeographic conditions, e.g. shallower marine conditions.

The *protoconch* is one of the most important taxonomic features. According to our measurements the diameter of the protococh slightly increases from the west to the east, as confirmed by the confidence intervals taken at 95 % level of confidence (see Table 1). The variability of the diameter does not show any significant differences and is relatively small.

Diameter of the house

Locality	M mm	CI mm	SD mm	CV %	Min mm	Max mm	R mm
Arrimblar	5.5	5.1 – 5.9 (0.8)	± 0.8	± 14.3	4.6	7.1	2.5
Adelholzen	5.1	4.9 – 5.3 (0.4)	± 0.5	± 10.7	4.3	6.7	2.4
Dudar	5.0	4.7 – 5.2 (0.5)	± 0.6	± 12.5	3.9	6.7	2.8
Mont Kotuc	4.6	4.4 – 4.8 (0.4)	± 0.4	± 9.1	3.9	5.6	1.7

Thickness of the house

Arrimblar	2.7	2.5 – 2.9 (0.4)	± 0.4	± 14.2	2.0	3.4	1.4
Adelholzen	2.8	2.6 – 2.9 (0.3)	± 0.4	± 14.9	2.3	4.2	1.9
Dudar	2.1	2.0 – 2.3 (0.3)	± 0.5	± 24.7	1.4	3.8	2.4
Mont Kotuc	2.9	2.6 – 3.2 (0.6)	± 0.6	± 19.9	2.2	4.2	2.0

Table 1. Statistical evaluation of the external characteristics. M = mean; CI = Confidence interval (95% level of confidence); SD = Standard deviation; CV = Coefficient of variation; R = range

The average of the *number of the whorls* is practically the same in all the four localities, but the individual numbers are quite different. The *number of the lamellae* separating the chambers („septa") has been counted by us separately for each whorl, and then rounded averages have been calculated. The results are presented on Figure 4. The four localities are very similar in this respect: the number of septa increases with the number of whorls.

The *ratio of spiral chambers* in two successive whorls increases regularly in radial direction (called „step"). Again each whorl has been measured separately and averages were calculated for them. The results are presented in Figure 5. Two groups can be distinguished in this respect: In the first group – Arrimblar and Dudar – the step first increases and then decreases. In the second group – Adelholzen and Mount Kotuc – the step is increasing all the way until the last whorl.

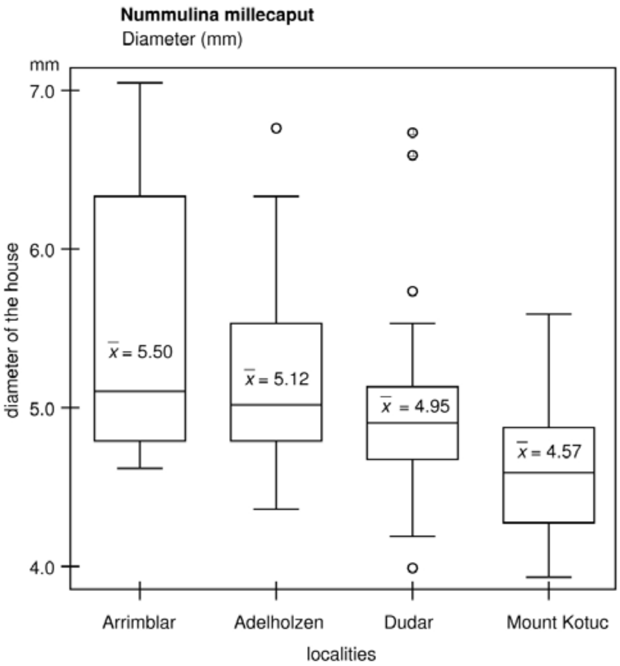

Figure 3. Box-plot diagram for diameters of the house at different localities. Small circles denote outliers, x is the mean of the sample at the given location.

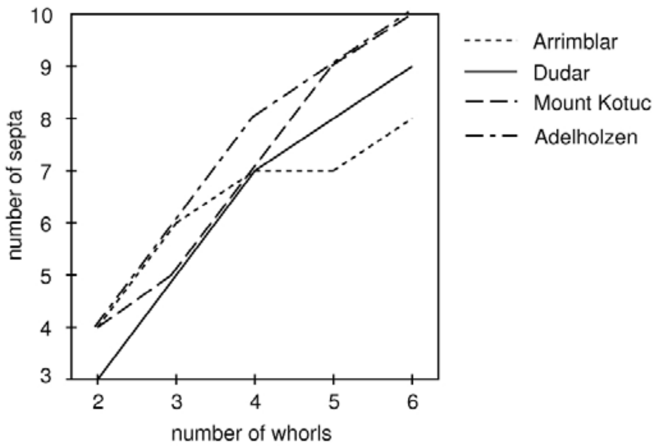

Figure 4. Relation of the numbers of septa to the whorls (mean values)

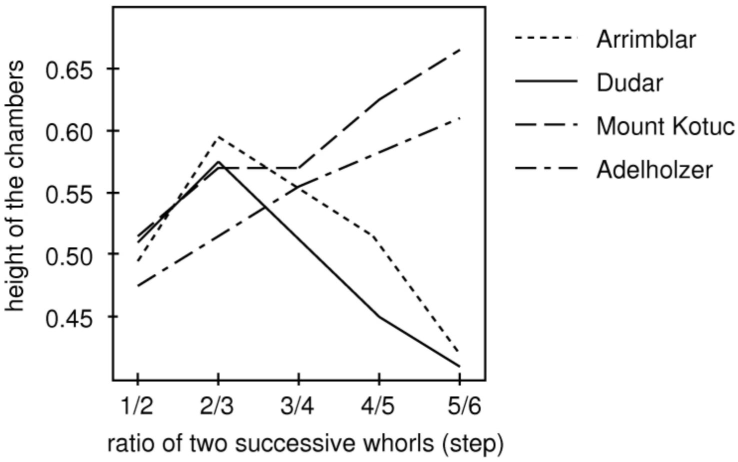

Figure 5. The ratio of spiral chambers in the successive whorls of the house

The *height of the chambers* shows exactly the same changes as the „step".When relating the averages of the height of the chambers to their length a surprisingly structured development was detected, as illustrated in Figure 6. In the figure the four localities are represented separately. The averages of the successive whorls are numbered from the center in outward direction and are connected by straight lines. This type of presentation depicts the evolution of the species at each locality. At Arrimblar, on the western end of the study area, only the length of the chambers increases in the first three whorls. After the fourth whorl an abrupt change occurs: the hight of the chambers rapidly decreases, accompanied by a slight increase of the length of the chambers. At Adelholzen and Dudar localities the direction of the diagram gradually changes, the left turn of the direction becomes less pronounced. Finally, at Mount Kotuc locality, at the eastern end of the study area, the length of the chambers increases much more intensely than their height. The left turn of the evolution is here the least pronounced.

Altogether a gradual change of the evolution of the species has been detected, having a clear west-east trend. This change is so regular that it cannot be considered a random phenomenon. It is interpreted by us as a gradual change that occurred parallel to the eastward migration of the species in the Téthys ocean.

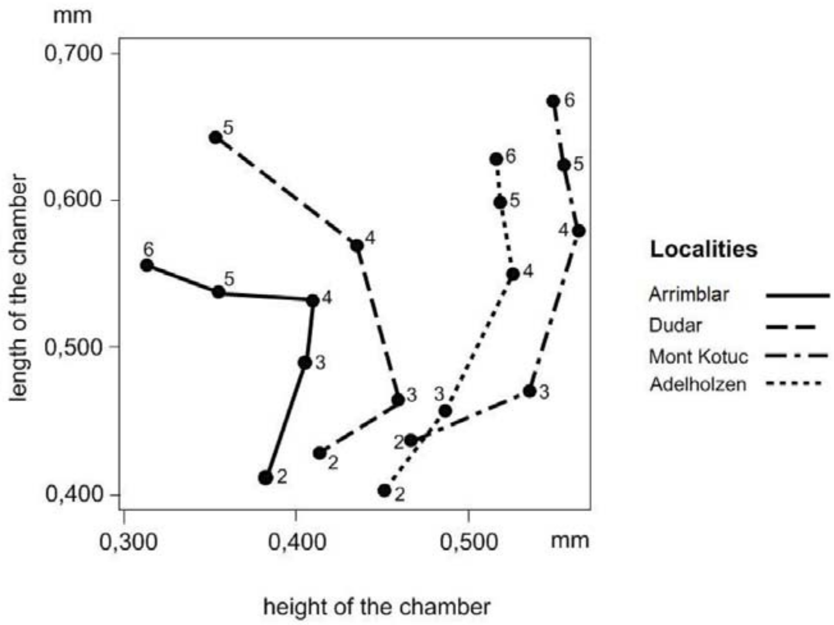

Figure 6. Relation of the height of the chambers to their length. The numbers indicate the successions of the whorls

3 Application of the fuzzy set theory

The above outlined statistical evaluation revealed a number of previously unknown facts and relationships of the species Nummulites millecaput. The most important were the gradual changes that occurred during the eastward migration of the species. In the case of our study some researchers pretended that during this eastward migration a new species was formed, that they called Nummulites maximus. It has been described from Armenia. This presumption is strongly discussed up to the present, but it could neither be confirmed, nor rejected by the traditional paleontological methods.

Dubois and Prade (1997) stressed that the fuzzy numbers express not only the degree of uncertainty of the data, but they can be applied to the expression of the degree of membership as well. In other words *transitions* can be evaluated by them and can be represented also in graphic form.

Fuzzy numbers were constructed by us for the averages of each locality for the external characteristics. The smallest value of the specimens of the given population was chosen as the minimum value of the *support* of the fuzzy number and the largest one as the maximum. To express the uncertainty the measurement error was also taken into account. The middle of the *core* corresponds to the average of the given locality. On both sides of this value follows the measurement error, plus the confidence interval at 95 % level of confidence. Thus the shape of the fuzzy numbers is trapezoidal.

For the external features a very complete overlap of the membership functions was obtained, as shown in Figure 7. Moreover the gradual decrease of the diameter of the house in eastward direction is also conspicuous.(Figure 7A). The thickness of the house, represented on Figure 7B is almost identical and the overlap complete. The fuzzy numbers of these two morphologic features are clearly in favour of the assumption that all over the studied region the same taxon is present.

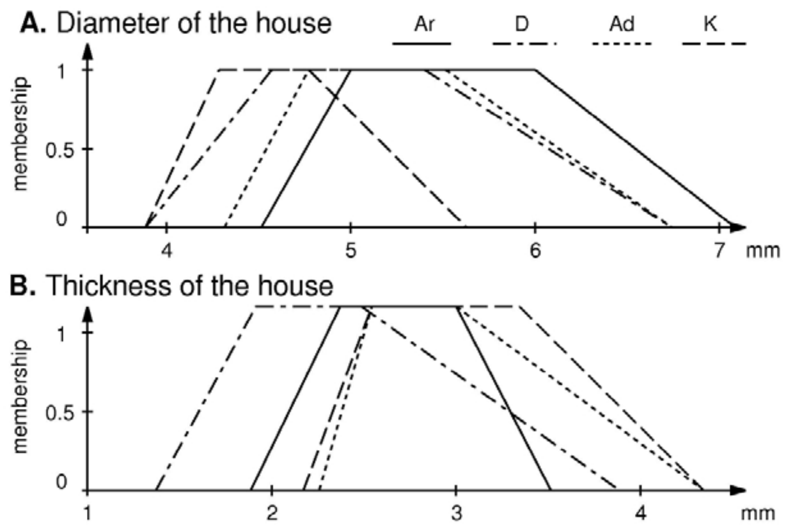

Figure 7. A: Diameter of the house. B: Thickness of the house.
Localities: Ar = Arrimblar; Ad = Adelholzen; D = Dudar; K = Mount Kotuc

Similar results were obtained for the diameter of the protococh, as illustrated in Figure 8. The populations of three localities – Adelholzen, Dudar and Mount Kotuc - are almost completely overlapping and even their varia-bility is similar, as expressed by the fuzzy numbers. Only the population of the Arrimblar locality is characterized by a slightly smaller diameter and variability. The difference is so small that it cannot be interpreted even as a different subspecies.

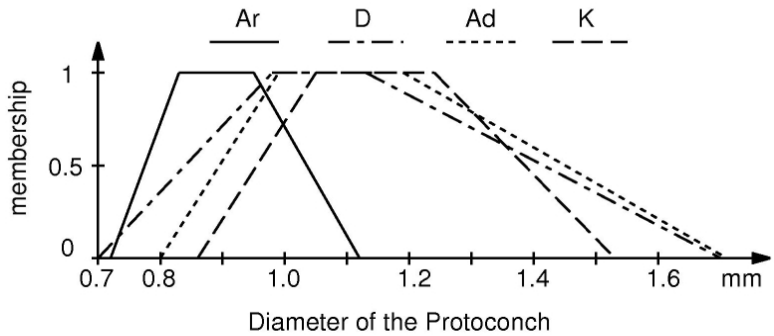

Figure 8. Diameter of the Protoconch.
Localities: Ar = Arrimblar; Ad = Adelholzen; D = Dudar; K = Mount Kotuc

For the remaining internal characteristics fuzzy numbers were constructed by us separately for each whorl, as a complete averageing of all whorls would be paleontologically meaningless. This type of evaluation resulted in several fuzzy numbers. The limited extent of this paper allows only the presentation of the most characteristic results. Figures 9A and 9B represent the length of the chambers at the second and fifth whorls. The fuzzy numbers of the second whorl are almost identical. Even the averages overlap within the range of the measurement error. Only the variability is slightly different. The fuzzy numbers of the fifth whorl are also overlapping but their variability is more different.

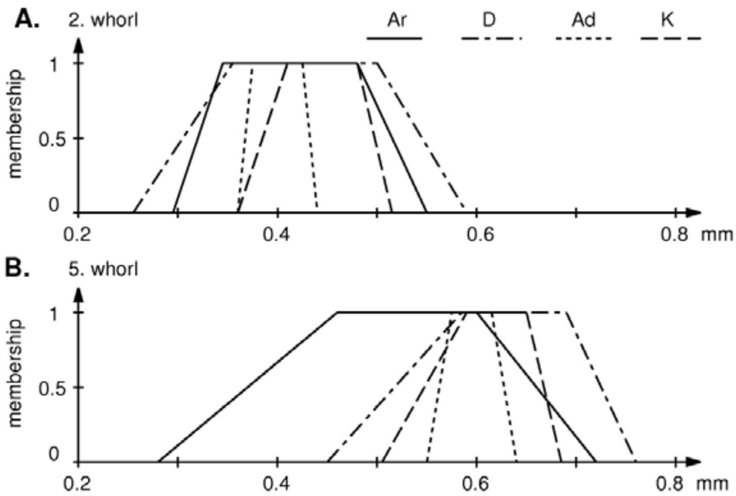

Figure 9. Length of the chambers (2. and 5. whorls). Localities: Ar = Arrimblar; Ad = Adelholzen; D = Dudar; K = Mount Kotuc

Figures 10A and 10B illustrate the fuzzy numbers of the height of the chambers at the second and the fifth whorls. In the second whorl the overlap is almost complete, but in the fifth whorl two groups can be distinguished.. The populations of the Adelholzen and Mount Kotuc localities have higher chambers as in the other two localities. For this last morphological characteristic one could raise the question of two different subspecies. However the structured, gradual changes in the relation between the height and the length of the chambers, discussed above, are in favour of one species migrating eastward, accompanied by gradual changes of some internal morphologic features.

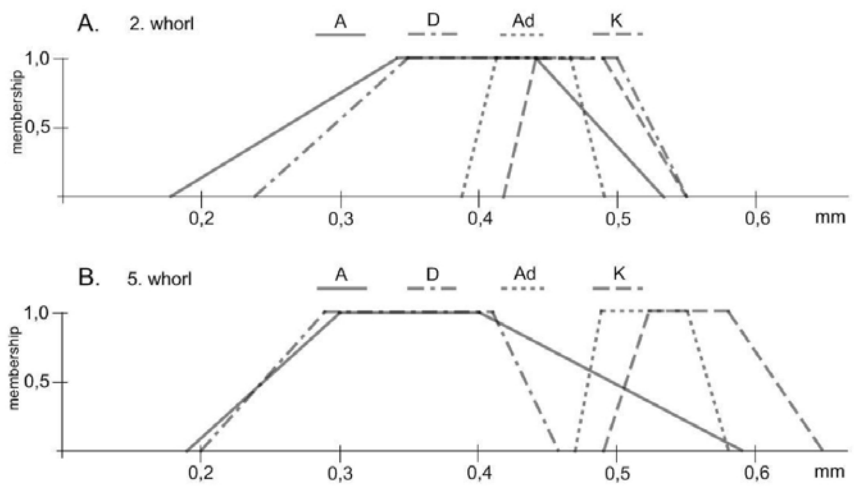

Figure 10. Membership functions representing the height of the chambers (2. and 5. whorls). Localities: Ar = Arrimblar; Ad = Adelholzen; D = Dudar; K = Mount Kotuc

Our results confirm that the traditional statistic evaluation of the morphological characteristics of fossils can be significantly completed by the application of fuzzy numbers and fuzzy logic. Relationships can be detected this way that would remain concealed without adequate biometric measurements and without a proper geomathematical evaluation of the results. In our opinion this methodology can be applied to other taxonomical problems of paleontology with success.

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