ISSN : 2395-647X
Vol. 1, No. 1, June 2015

International Journal of Geology and Earth Sciences

www.ijges.com

Email : editorijges@gmail.com or editor@ijges.com

Int. J. of Geology & Earth Sci., 2015

International Journal of Geology and Earth Sciences

ISSN 2395-647X www.ijges.com
Vol. 1, No. 1, June 2015

Case Study

POLLEN GRAIN PROPORTIONS AS A PALEOECOLOGICAL RECONSTRUCTION TOOL: THE CORRELATIVITY OF ZONOCOSTITES RAMONAE AND MONOPORITES ANNULATUS IN THE NIGER DELTA BASIN AS A CASE STUDY

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Zonocostites ramonae and *Monoporites annulatus* are the most abundant pollen in each of the wells M-1, 2 and 3. They constitute 82.4%, 90.0% and 91.5% of the total pollen respectively. The proportionality of the two taxa was considered for predicting the prevailing paleoecological condition during the deposition of sediments in the studied wells. The mean values of *Z. ramonae* in the wells were 88.8, 269 and 169 respectively; that of *M. annulatus* were 5.76, 11.7 and 16.1. The correlation coefficient (r_c) were 0.634, 0.666 and 0.189 respectively whilst the regression coefficient values were -0.883, 6.16 and 14.7. The coefficient of variation percent (CV%) were 52.3, 298 and 259 respectively for *Z. ramonae* and 107, 77.3 and 72.7 respectively for *M. annulatus*. The coefficient of alienation and index of forecasting efficiency ranged from 0.746 to 0.982 and 0.018 to 0.254 respectively. The percentage of the difference in the occurrence of the two taxa varied greatly; there were five samples with 100%, 96 dominated with >50.0% and one of the remaining two samples had a negative value whilst the other had 0.00%. The correlation coefficient indicated that the occurrence of *Z. ramonae* and *M. annulatus* in M-1 and M-2 was very significantly different but not significantly different in M-3 at $r_c = 0.05$. The cross correlation between *Z. ramonae* and *M. annulatus* showed that both spectra were generally not coherent which meant that these taxa only slightly shared their source area. This work inferred that whilst *Z. ramonae* always suggested a mangrove environment, however, using *M. annulatus* as a simple indicator of arid condition may overstate trends or boundary transitions and also disregard seasonal variation in swamp communities. Predicting the relationship of occurrence in these taxa might be difficult since the reduction in the error of prediction (IFE) ranged from low to very low (0.226, 0.254, 0.018).

Keywords: *Zonocostites ramonae*, Monoporites annulatus, Mangrove, Savannah, Paleoecology, Correlation

INTRODUCTION

There are many useful approaches to the reconstruction of the ecological and environmental settings of the past and the theory

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and methods used to reconstruct them overlap to a certain extent. The differences between them may be characterized as such: the science of paleoecology addresses the relationships between both plant and animal species and their environments whilst paleoenvironmental research tends to be more focused on the physical conditions of the surrounding area including terrain and vegetation structure, as well as characteristics such as temperature and rainfall. Paleoclimatology, a related discipline, is concerned with these sorts of characteristics and reconstructing broad, long-term records of them at a global or regional level (Kovarovic, 2012). Palaeoecological record is a natural laboratory to explore biotic responses under a range of past conditions. This record can be used to improve our ability to predict ecological responses to environmental changes using detailed biostratigraphical data of palynoecological groups of interest. Reconstructions of past environment is important in evaluating the extent of natural variabilities. Pollen grains and spores of vascular plants are some of the biotic proxies that provide evidence of the past occurrences, past populations, past communities, past ecosystems and landscapes, and past environments (Ivanor *et al*., 2007, Ige, 2009).

Palynology can tell us more about upland areas outside basins of deposition than other paleontological discipline. At best, palynofloral data can be used to establish local and even worldwide datums of chronologic importance. Palynological data can be checked for sampling error; paleoecological bias, and statistical reliability, because the database typically contains hundreds of species and tens of thousands of records. One only has to understand floral and faunal diversity in our world today to appreciate the task of correlating ancient worlds where so much is unknown. Clearly, the paleontological method that has the greatest potential for accurate age determination and environmental deduction is the method that employs the most taxa, and palynologists commonly use more taxonomic data than any other specialty (Cornet, 1993). But with increasing amounts of data come complications, making reliance on a few diagnostic taxa a frequent practice (Cornet, 1993). Pollen is related numerically to vegetation. A record of past pollen rain preserved in sediment at several depths gives an idea of past vegetation at that time and that space.

Rhizophora, are known from the late Eocene and are represented morphogenerically by the fossil pollen species *Zonocostites ramonae* (Germeraad *et al.*, 1968). They are either trees or shrubs and live exclusively in mangrove habitats, pantropical, widely distributed along tropical coastalines and generally used as indicator of wet environment (Tobe and Raven, 1988; Schwarzbach and Ricklefs, 2000; Hoorn, 2005). *Monoporites annulatus* is also the morphogeneric name given to all the pollen species of Poaceae, a grass family. This is because all the pollen grains of Poaceae possess a pore surrounded by annulus, though with varying pore diameter, annulus shape and size (Joly *et al*., 2007, Schüler, 2011); they are well known to be very homogenous (Salgado-Labouriau and Rinaldi 1990a, b) which makes it easy to recognise them. Poaceae is one of the most widely distributed and abundant groups of plants on Earth. Grasses are found in every continent and are absent only from central Greenland and much of Antarctica (Sarandón, 1998). The persistence of grassland depends on the exclusion of competing woody species that would supplant the grass, hence all major habitats of grass are open and largely devoid of trees (Poacae, 2015). Increase in *M. annulatus* abundance is often used as indicator of large degree of landscape openness (Behre, 1981; Birks, 1990) and increased aridity (Simon and Alfonso, 2011, Bankole, *et al*., 2014).

The occurrence of *Zonocostites ramonae* and *Monoporites annulatus* in the three wells in the shallow offshore of the Niger Delta basin were subjected to statistical analysis in order to determine their correlativity. Both pollen types are anemophilous which when in atmosphere are well mixed and can be recovered in a wide variety of deposits. The scale of dispersal of both pollen type is regional. The methods and applications presented below are an example to clarify the benefits of correlating the occurrence of palynological data statistically rather than the semi-quantitative method usually adopted. The study is to determine whether it is possible to deduce a general inverse relationship between the taxa that can be used to predict the paleoecology of the environment of deposition of the sediments. Whether this will enable differentiating between humid and dry conditions.

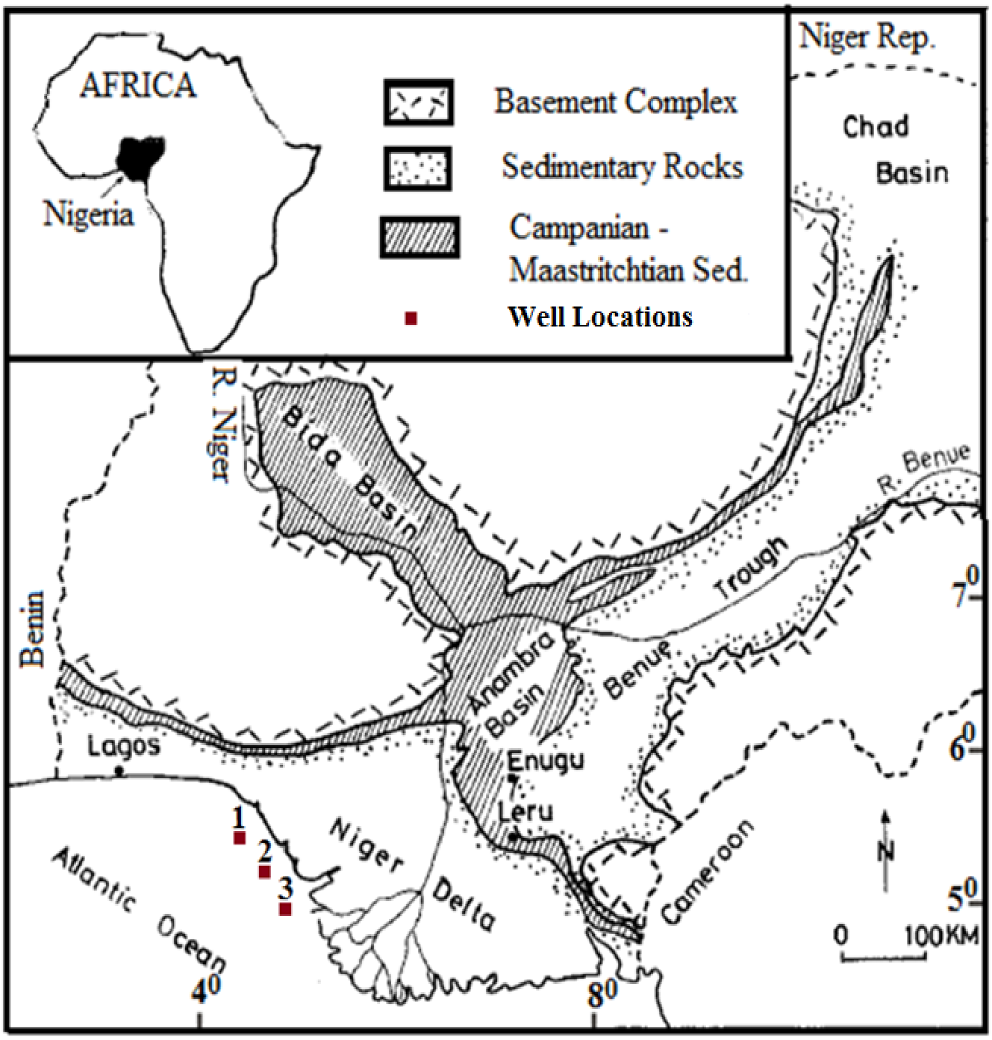
GEOLOGICAL SETTING

The present day Niger Delta Basin is located in the Gulf of Guinea in the southern part of Nigeria (Figure 1). Its geological setting is as described in Adebayo (2014) and Adebayo *et al.* (2015). It lies between longitudes 4^0E and 8.8^0E and latitudes 3^0N and 6^0N. It occupies the coastal oceanward part of the Benue-Abakaliki Trough; hence its evolution has been linked with that of this larger sedimentary complex (Murat, 1972; Reijers *et al*., 1997). Various authors have identified the Benue-Abakaliki Trough as the failed arm of the three radial rift systems that met at an R-R-R triple junction in the Gulf of Guinea that was active in early Cretaceous due to crustal doming (Burke *et al*., 1971; Burke, 1972; Burke and Whiteman, 1973; Lehner and De Ructer, 1977). Niger Delta now occupies the centre of the triple junction. The Niger Delta Basin represents the third cycle in the evolution of the trough and its associated basins. The first cycle (Aptian-Santonian) brought about the evolution of the trough as the failed arm of a rift triple junction (RRF-type) associated with the separation of South American and African plates (Burke and Whiteman, 1973; Mascle, 1976). Two platforms (Anambra and Ikpe) were formed on both sides of the trough during this period. The second cycle (Santonian-Eocene) began after the Campanian-Santonian folding episode. The Abakaliki Trough was uplifted to form Abakaliki Anticlinorium whilst the Anambra platform was downwarped to form the Anambra Basin (Murat, 1972; Weber and Daukoru, 1975) resulting in the westward displacement of the trough's depositional axis. During the Paleocene- Early Eocene, the upliftment of Benin and Calabar flanks initiated a major regressive phase. By the end of this cycle, rifting has diminished considerably. The third cycle (Eocene-Recent) brought about the development of the modern Niger Delta. The general agreement is that the present-day Niger Delta is built on oceanic crust. Evidence for this came from pre-drift continental reconstruction (Stoneley, 1966) which indicates an overlap of northeast Brazil on the present Niger Delta.

MATERIALS AND METHODS

A total of 103 samples from M-1, 2 and 3 wells from the shallow offshore section of the western Niger Delta, Nigeria (Table 1) were analyzed.

Figure 1: Simplified Geologic Map of Nigeria and Well Locations



Standard maceration technique (Faegri and Inversen, 1989; Wood *et al.*, 1966) was followed in the preparation of these samples. Samples were treated with HF and HCl to remove calcareous and siliceous materials respectively; heavy liquid separation using zinc chloride and hydrochloric acid solution (specific gravity 2.0) and finally acetolysis to dissolve cellulose for easy identification of palynomorphs. Minor modifications such as varying the percentage of hydrochloric acid (30-36%) used, staining of some residues and excluding acetolysis step for older samples with no cellulose. After treatment, samples were mounted on slides and studied under x40 and x100 objectives using an Olympus CH30, camera-attached microscope. Photomicrographs Photographs of the most important pollen were taken with an X100 objective using oil immersion (see Adebayo, 2013).

The results of the data obtained for *Z. ramonae* and *M. annulatus*, the dominant taxa in the wells with relative abundances of 82.4%, 90.0% and

91.5% respectively, were subjected to statistical analysis. Statistical analyses used were the determination of mean, standard variation and coefficient of variation percent. Others were correlation coefficient (r_{xy}), coefficient of alienation (C_A), index of forecasting efficiency (IFE), regression coefficient (R_{xy}) and coefficient of determination or variance $(r_{xy})^2$. The r_{xy} was converted to Table value to see if significant differences existed among the sample results at t =0.05 (Oloyo, 2001).

RESULTS AND DISCUSSION

Table 1 showed the results of the counting of *Zonocostites ramonae* and *Monoporites annulatus* in the three wells whilst Figures 1 a, b

Table 1: The Counts of *Z. ramonae* and *M. annulatus* in the Three Wells

M-1 Well			M-2 Well			M-3 Well		
Depth (ft)	Zoncostites ramonae A	Monoporites annulatus B	Depth (ft)	Zoncostites ramonae C	Monoporites annulatus D	Depth (ft)	Zoncostites ramonae E	Monoporites annulatus F
3130-3160	116	8	4240-4270	4	2	4140-4170	54	10
3250-3280	119	1	4360-4390	30	10	4260-4290	189	12
3370-3400	75	1	4480-4510	22	6	4380-4410	241	13
3490-3520	93	3	4600-4630	33	14	4500-4530	1596	24
3610-3640	21	0	4720-4750	95	12	4620-4650	403	11
3730-3760	109	19	4840-4870	385	16	4740-4770	231	9
38503880	65	4	4960-4990	1018	21	4860-4890	106	19
3970-4000	21	1	5080-5110	103	5	4980-5010	40	7
4090-4120	201	23	5200-5230	207	7	5100-5130	79	14
4210-4240	47	13	5320-5350	25	5	5220-5250	110	6
4330-4360	12	3	5440-5470	25	3	5340-5370	54	9
4450-4480	70	6	5560-559-	199	12	5460-5490	11	11
4570-4600	111	5	5680-5710	84	7	5580-5610	86	7
4690-4720	137	7	5800-5830	71	5	5700-5730	144	7
4810-4840	140	4	5920-5950	86	5	5820-5850	441	16
4930-4960	87	7	6040-6070	172	8	5940-5970	192	9
5050-5080	73	0	6160-6190	908	32	6060-6090	21	9
5170-5200	104	7	6280-6310	151	8	6180-6210	144	32
5290-5320	205	17	6400-6430	369	6	6300-6330	100	6
5410-5440	150	3	6520-6550	45	2	6420-6450	58	13

Table 1 (Cont.)

M-1 Well			M-2 Well			M-3 Well		
Depth (ft)	Zoncostites ramonae A	Monoporites annulatus B	Depth (ft)	Zoncostites ramonae C	Monoporites annulatus D	Depth (ft)	Zoncostites ramonae E	Monoporites annulatus F
5530-5560	55	5	6640-6670	311	18	6540-6570	47	4
5650-5680	100	6	6760-6790	396	31	6660-6690	62	7
5770-5800	20	0	6880-6910	101	6	6780-6810	51	48
5890-5920	40	1	7000-7030	85	8	6900-6930	24	28
6010-6040	50	0	7120-7150	34	3	7020-7050	164	15
	2221	144	7240-7270	28	8	7140-7170	203	17
			7360-7390	47	8	7260-7290	126	26
			7480-7510	180	28	7380-7410	142	24
			7600-7630	11	0	7500-7530	62	6
			7720-7750	540	33	7620-7650	113	10
			7840-7870	199	8	7740-7770	136	45
			7960-7990	518	13	7860-7890	79	7
			8080-8110	612	3	7980-8010	307	30
			8200-8230	1147	23	8100-8130	217	20
			8320-8350	854	30	8220-8250	50	14
			8440-8470	289	14	8340-8370	43	11
			8560-8590	454	19	8460-8490	19	8
			8680-8710	181	15	8580-8610	276	48
			8800-8830	37	3		6421	612
			8920-8950	373	7			
				10429	464			

and c showed the plots of the abundance of the two taxa in each well. The trends in the abundance indicated an inverse relationship at some depths (Figures 1a and b), i.e. as there were increase in the abundance of the mangrove and wet conditions indicator (*Z. ramonae*), the open and arid conditions indicator (*M. annulatus*) decreased (Macphail, 1983) . Figure 1c and parts of Figure 1b generally showed that the taxa depicted a coherent occurrence (in phase).

The percentage difference in the occurrence of the two taxa in all the wells (M-1, 2 and 3) varied greatly as seen in Table 2. In Table 2 where M-1 well represents the values of *Z. ramonae* minus *M. annulatus* (A-B in percentage), 100 %

Figure 2: Plots of the Abundance of *Z. ramonae* and *M. annulatus* in the Three Wells

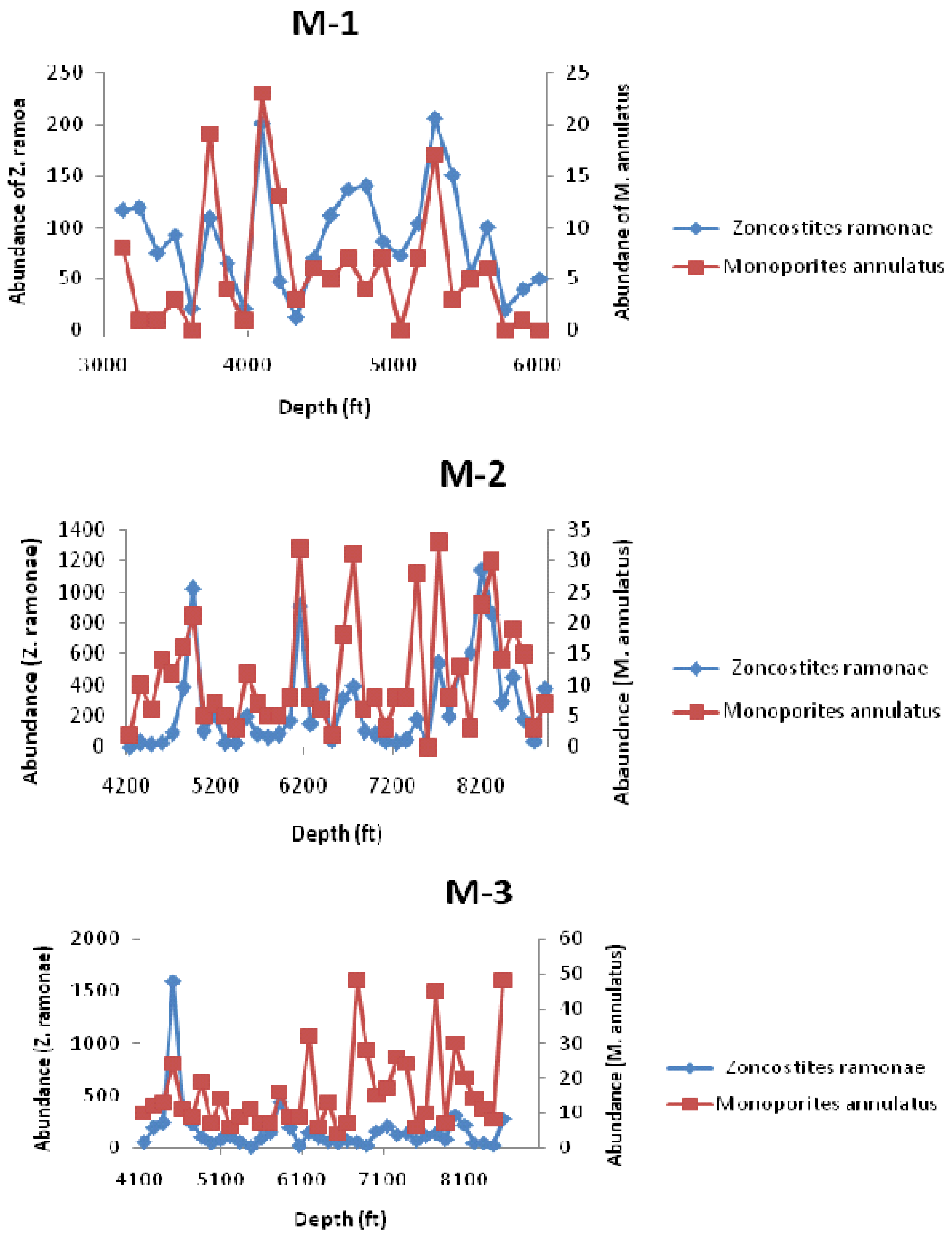


Table 2: Percentage Difference between *Z. ramonae* and *M. annulatus* in the Three Wells

M-1 Well		M-2 Well		M-3 Well	
Depth (ft)	Difference (A-B)%	Depth (ft)	Difference (C-D)%	Depth (ft)	Difference (E-F)%
3130-3160	+108 (93.1%)	4240-4270	+2 (50%)	4140-4170	+44 (81.5%)
3250-3280	+118 (99.2%)	4360-4390	+20 (66.7%)	4260-4290	+177 (93.7%)
3370-3400	+74 (98.7%)	4480-4510	+16 (72.7%)	4380-4410	+228 (94.6%)
3490-3520	+90 (96.8%)	4600-4630	+19 (57.6%)	4500-4530	+1572 (98.5%)
3610-3640	+21 (100%)	4720-4750	+83 (87.4%)	4620-4650	+392 (97.3%)
3730-3760	+90 (82.6%)	4840-4870	+369 (95.8)	4740-4770	+222 (96.1%)
3850-3880	+61 (93.8%)	4960-4990	+997 (97.9%)	4860-4890	+87 (82.1%)
3970-4000	+20 (95.2%)	5080-5110	+98 (95.1%)	4980-5010	+33 (82.5%)
4090-4120	+178 (88.6%)	5200-5230	+200 (96.6%)	5100-5130	+65 (82.3%)
4210-4240	+34 (72.3%)	5320-5350	+20 (80.0%)	5220-5250	+104 (94.5%)
4330-4360	+9 (75.0%)	5440-5470	+22 (88.0%)	5340-5370	+45 (83.3%)
44504480	+64 (91.4%)	5560-5590	+187 (94.0%)	5460-5490	+0 (0.00%)
4570-4600	+106 (95.5%)	5680-5710	+77 (91.7%)	5580-5610	+79 (91.9%)
4690-4720	+130 (94.9%)	5800-5830	+66 (93.0%)	5700-5730	+137 (95.1%)
4810-4840	+136 (97.1%)	5920-5950	+81 (94.2%)	5820-5850	+425 (96.4%)
4930-4960	+80 (92.0%)	6040-6070	+164 (93.3%)	5940-5970	+183 (95.3%)
5050-5080	+73 (100%)	6160-6190	+66 (96.5%)	6060-6090	+12 (57.1%)
5170-5200	+97 (93.3%)	6280-6310	+143 (94.7%)	6180-6210	+112 (77.8%)
5290-5320	+188 (91.7%)	6400-6430	+363 (99.2%)	6300-6330	+94 (94.0%)
5410-5440	+147 (98.0%)	6520-6550	+43 (95.6%)	6420-6450	+45 (77.6%)
5530-5560	+50 (90.9%)	6640-6670	+293 (94.2%)	6540-6570	+43 (91.5%)
5650-5680	+94 (94.0%)	6760-6790	+365 (92.2%)	6660-6690	+55 (88.7%)
5770-5800	+20 (100%)	6880-6910	+95 (94.1%)	6780-6810	+3 (5.88%)
5890-5920	+39 (97.5%)	7000-7030	+77 (90.6%)	6900-6930	-4 (-16.7%)
6010-6040	+50 (100%)	7120-7150	+31 (91.2%)	7020-7050	+149 (90.9%)
		7240-7270	+20 (71.4%)	7140-7170	+186 (91.6%)
		7360-7390	+39 (83.0%)	7260-7290	+100 (79.4%)
		7480-7510	+152 (84.4%)	7380-7410	+118 (83.1%)

Table 2 (Cont.)

M-1 Well		M-2 Well		M-3 Well	
Depth (ft)	**Difference (A-B)%**	**Depth (ft)**	**Difference (C-D)%**	**Depth (ft)**	**Difference (E-F)%**
		7600-7630	+11 (100%)	7500-7530	+56 (90.3%)
		7720-7750	+507 (93.9%)	7620-7650	+103 (91.2%)
		7840-7870	+191 (96.0%)	7740-7770	+91 (68.4%)
		7960-7990	+505 (97.5%)	7860-7890	+72 (91.1%)
		8080-8110	+609 (99.5%)	7980-8010	+277 (90.2%)
		82008230	+1124 (98.0%)	8100-8130	+197 (90.8%)
		8320-8350	+824 (96.5%)	8220-8250	+36 (72.0%)
		8440-8470	+275 (95.2%)	8340-837-	+32 (74.4%)
		8560-8590	+435 (95.8%)	8460-8490	+11 (57.9%)
		8680-8710	+166 (91.7%)	8580-8610	+228 (82.6%)
		8800-8830	+34 (91.9%)		
		8920-8950	+366 (98.1%)		

Table 3: The Statistical Parameters of M-1, M-2 and M-3 Wells

	M-1	M-2	M-1
r_{xy}	0.634*	0.666*	0.189
r_t	o.396	0.304	0.325
R_{xy}	-0.883	6.16	14.7
$\bar{x}$	88.8	269	169
sd_x	52.3	293	259
$CV_x\%$	58.9	109	153
$\bar{y}$	5.76	11.7	16.1
sd_y	6.17	9.04	11.7
$CV_y\%$	107	77.3	72.7
C_A	0.774	0.746	0.982
IFE	0.226	0.254	0.018

Note: r_{xy} = Correlation of *Z. ramonae* and *M. annulatus*, r_t = Table value at $\alpha = 0.05$; $\bar{x}$ = Mean of *Z. ramonae*, sd_x = Standard deviation of *Z. ramonae*; $\bar{y}$ = Mean of *M. annulatus*, sd_y = Standard deviation of *M. annulatus*; CV% = Coefficient of variation percent, C_A = Coeeficient of alienation; IFE = Index of forecasting efficiency, * = Significant.

difference were noticed in four depths (3610-3640 ft, 5050-5080 ft, 5770-5800 ft and 6010-6040 ft) respectively. Furthermore, percentage values between 50 % and above 99 % but less than 100 % were noticed for other 21 depths. All percentage values were positive. This meant that the A (*Z. ramonae*) values were all greater than the corresponding values in B (*M. annulatus*). In well M-2 where the taxa were represented by C (*Z. ramonae*) and D (*M. annulatus*), all percentage difference values were positive but greatly varied. In contrast to M-1 only one value of 100% was recorded in depth 7600-7630 ft. Percentage values with 90 % and above but less than 100 % were recorded in 29 samples forming an overall percentage of 72.5 % forming the largest overall difference. Other percentage values ranged between 50 % and 88.0 %. Again, like in well M-1, C (*Z. ramonae*) was greater than D (*M. annulatus*) for each depth determined. The observations in M-3 were much different from the observations made for M-1 and M-2. For examples, values of 0.00%, negative percent and positive percent were all recorded in M-3. In more detailed form, one depth (5460-5490 ft) recorded 0.00 % showing that equivalent values existed in E (*Z. ramonae*) and F (*M. annulatus*). Negative difference of -16.7 % was observed for depth 6900-6930 ft meaning that F value (28 counts) was greater than E value (24 counts) giving a difference of -4 or -16.7 %. All other values were positive and ranged between 57.1 % and 98.5 %.

The mean, the correlation coefficient (r_c), the coefficient of variation percent (CV %), the coefficient of alienation (C_A) and index of forecasting efficiency (IFE) were all calculated and the results were shown in Table 3. The mean values of *Z. ramonae* in the wells M-1, 2 and 3 were 88.8, 269, 169 respectively; that of *M. annulatus* were 5.76, 11.7 and 16.1. The standard deviation were 52.3, 293 and 259, and the coefficient of variation percent 107, 77.3 and 72.7 respectively. The regression coefficient values were respectively -0.883, 6.16 and 14.7; the coefficient of alienation and index of forecasting efficiency ranged from 0.746 to 0.982 and 0.018 to 0.254 respectively. For M-1, the Table (critical) value at 0.05 is 0.396, since $r_c > r_t$, then the occurrence of the two taxa was very significantly different. The critical value at 0.05 for M-2 is 0.304, this result was also very significantly different, since 0.666 (r_c) is more than double 0.304 (r_t). The r_t in M-3 is 0.325 which is greater than 0.189 (r_c), hence the result is not significantly different. The CV_x % for the three wells were 52.3, 298 and 259 respectively whilst CV_y % were 107, 77.3 and 72.7 respectively; this meant that the occurrence of *Z. ramonae* was more homogenous in M-1 than *M. annulatus* but vice versa in M-2 and M-3 (i.e. more heterogenous).

The reduction in the error of predicting the relationship between *Z. ramnae* and *M. annulatus* ranged from low in M-2 to very low in M-3 (0.254, 0.226 and 0.180 in M-2, M-1 and M-3 respectively). Since the reduction in error of prediction ranged from low to very low in all the samples, there is difficulty in predicting the relationship of occurrence of the two taxa in the studied wells.

In view of the fact that the patterns of occurrence and association are influenced by the pollination strategy, pollen grain size, degree of pollen production, and effectiveness of pollen dispersal (Di-Giovanni *et al*., 1995; Jackson *et al*., 1999; Culley *et al*., 2002), it is expected that occurrence of *Z. ramnae* and *M. annulatus* in the same deposit will give a predictable relationship. But the very high pollen productivity (Sowunmi, 2004), the coastal origin and being an anemophilous tree might had made *Z. ramonae* to mask the contribution of Poaceae (Bush, 2002). Therefore the cross correlation between *Z*. r*amonae* and *M*. a*nnulatus* showed that both spectra were generally not coherent (an out-of-phase correlation) which meant that these taxa only slightly shared their source area. Bush (2002) suggests that very high (50-90 %) abundances of Poaceae pollen provide a strong indicator of savanna habitats, but trying to determine transitional vegetation types between savanna and wet forest is best determined using other taxa. Indeed, reliance on Poaceae abundance as an indicator of paleoprecipitation is potentially very misleading when it is in the fossil record at moderate abundances.

CONCLUSION

The correlativity of *Z. ramonae* and *M annulatus* had been assessed using some statistical analyses. Both constitute 82.4%, 90.0% and 91.5% of the total pollen in the three wells analyzed respectively. The cross correlation between *Z*. r*amonae* and *M*. a*nnulatus* showed that both spectra were generally not coherent. This work inferred that whilst *Z*. r*amonae* always suggested a mangrove environment, however, using *M*. a*nnulatus* as a simple indicator of arid condition may overstate trends or boundary transitions and also disregard seasonal variation in swamp communities. Predicting the relationship of occurrence in these taxa might be difficult since the reduction in the error of prediction (IFE) ranged from low to very low (0.226, 0.254, 0.018).

ACKNOWLEDGMENT

I acknowledged Prof E. I. Adeyeye of the Department of Chemistry, Ekiti State University, Ado Ekiti for supporting this study logistically; his contribution toward the improvement of the manuscript is significant and this is highly appreciated.

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International Journal of Geology and Earth Sciences
Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
E-mail: editorijges@gmail.com or editor@ijges.com
Website: www.ijges.com

ISSN 2395-647X
9 772395 647009 01