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Trouble in Paradise? A comparison of 1953 and 2005 benthonic foraminiferal seafloor assemblages at the Ibis Field, offshore eastern Trinidad, West Indies

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ABSTRACT – Foraminiferal communities are not static, but change in response to environmental perturbations. Given sufficient time, the change will be recorded in the total (live+dead) seafloor assemblage, from which valuable information regarding environmental trends can be obtained by re-sampling assemblages at the decadal scale.

The seafloor assemblage in the 5 km × 6 km Ibis Field, off southeast Trinidad, first surveyed in 1953, was re-examined in 2005. The fauna had changed markedly between the surveys. Overall increases in the proportional abundances of *Uvigerina subperegrina*, *Ammonia pauciloculata*/*Rolhausenia rolhauseni* and *Pseudononion atlanticum* indicate an increase in nutrient supply that apparently killed off *Cibicidoides pseudoungerianus* and *Miliolinella subrotunda*, and reduced the relative abundance of *Hanzawaia concentrica*, but did not affect the relative abundance of *Cancris sagrai*. As shown by similar 1953 and 2005 planktonic/benthonic foraminiferal ratios, the increased nutrient supply impacted on both surface and bottom waters.

Of the six most abundant species in 2005, five showed the same general biogeographical distributions within the field in 1953 and 2005. However, whereas the proportional abundance of *Uvigerina subperegrina* in 1953 increased southwards, in 2005 it increased northwards.

Trinidad cannot be the source for the nutrient enrichment: the island lies down-current from the Ibis Field. Sources must therefore be sought up-current and to the southeast, in the Amazon, Essequibo and Orinoco river basins, or along the South American shoreline. It is speculated that the nutrient enrichment may be a consequence of increased phytoplankton primary production associated with nitrogen-rich run-off from South American sugarcane plantations, or from flushing of organic carbon from poorly regulated sewage systems or shrimp farms in South America. *J. Micropalaeontol.* **25**(2): 157–164, November 2006

KEYWORDS: *Caribbean, Uvigerina, Pseudononion, Amazon, Orinoco*

INTRODUCTION

Micropalaeontologists have been surveying contemporary foraminiferal seafloor assemblages for well over a century, and repeated examinations of some areas have formed datasets that can be used to determine environmental trends. Here, contemporary and older data are used to determine changes in foraminiferal seafloor assemblages over the last fifty years in a small area off Trinidad, southeast Caribbean. The changes are interpreted in terms of modern knowledge of foraminiferal ecology as summarized in, for example, Sen Gupta (1999).

The earliest studies documenting foraminiferal distributions gave only semi-quantitative records of abundance, using qualifiers such as Rare, Common or Abundant (e.g. Cushman, 1918–1931). Such qualifiers are of relatively limited use in determining environmental trends, although they continue to be used (e.g. Hofker, 1983; Mikhalevich, 1983). Commencing in the 1950s (e.g. Phleger, 1951), recording became so precisely quantitative that the data can be reinterpreted using modern statistical methods (e.g. Culver, 1988). Drooger & Kaasschieter (1958) examined foraminiferal seafloor assemblages around Trinidad and Tobago, and presented 36 maps showing the 1953 distributions of foraminiferal species on the Orinoco–Trinidad–Paria Shelf. Proportional abundances can be calculated readily from these because they indicate the number of specimens per species in samples of 200 foraminifera.

Should conditions at a locality change, some foraminiferal species will die out while others able to cope with the new conditions flourish (Scott *et al.*, 2001). Although the seafloor assemblage at a sample site frequently far outnumbers the live assemblage (e.g. Smith (1964) recorded live: dead ratios between 2:100 and 4:100 000 on the continental shelf off Honduras), given the short life-spans of foraminifera and sufficient time, the change in the live assemblage will eventually be reflected in a change in the seafloor assemblage, despite the possibility of mixing through bioturbation. Recent studies re-examining areas surveyed earlier have shown that changes in foraminiferal seafloor assemblages can occur within a few decades.

1. Stott *et al.* (1996) re-examined the impact of effluent 30 years after Bandy *et al.* (1964) found that outflow from a sewage outfall off Los Angeles was detrimental to the nearby foraminiferal fauna, and several decades after the introduction of stringent effluent treatment. Stott *et al.* (1996) concluded that the fauna was much recovered, numbers around the outfall differing little from those in other, unaffected parts of the Southern California continental shelf.
2. Gustafsson & Nordberg (2001) compared 1993–1994 foraminiferal taphocoenoses in the Gullmar Fjord, Sweden, with material collected in 1927, and found a trend towards a more opportunistic, low-oxygen tolerant fauna.

3. Hallock *et al.* (2003) found that nutrient enrichment on coral-reefs kills larger foraminifera, leaving smaller opportunists to flourish and, eventually, dominate the seafloor assemblage.

In recent years British Petroleum of Trinidad and Tobago Limited (bpTT) has routinely conducted foraminiferal analyses around oil rigs southeast of Trinidad, off northeast South America. Comparison is made here between March 2005 foraminiferal assemblages at the bpTT Ibis oil field and the March–May 1953 thanatcoenosis recorded by Drooger & Kaasscheiter (1958).

STUDY AREA

Trinidad is situated northeast of the Orinoco Delta, Venezuela, and the 5 km × 6 km Ibis Field lies *c.* 37.5 km southeast of Galeota Point, Trinidad (Fig. 1), approximately midway between the northwestern ends of the transects DQ and DU of Drooger & Kaasscheiter's (1958) survey of foraminifera. To the east of Trinidad the continental shelf trends north–south. In the vicinity of the Ibis Field this trend is interrupted by the east–west-trending Columbus Channel, which separates southern Trinidad from the southern part of the Orinoco Delta (also known as the Delta Amacuro). However, water depths at the Ibis Field vary little (68–71 m).

The marine environment around the Ibis Field, and around Trinidad in general, is influenced by outflow from the Orinoco, Essequibo and Amazon Rivers of the South American mainland, which collectively account for *c.* 20% of the fresh water discharged into the world's oceans (Agard & Gobin, 2000; Dagg *et al.*, 2004). Discharge from the Amazon alone is so large that river/ocean water mixing occurs out on the continental shelf rather than in the estuary, as in many smaller rivers (DeMaster & Aller, 2001). The northwest-flowing Guyana Current carries water from all three rivers towards Trinidad.

The rate of fresh-water discharge from each river is variable but largely predictable, being climatically controlled by the Inter-Tropical Convergence Zone (ITCZ), migrations of which induce on Trinidad a monsoonal climate with pronounced rainy (June–December) and dry (January–May) seasons (Agard & Gobin, 2000). During Trinidad's rainy season, maximum discharge of the Orinoco River produces a low-salinity plume that extends from Venezuela to Puerto Rico (Hochman *et al.*, 1994), completely engulfs Trinidad (Agard & Gobin, 2000) and is rich in dissolved organic carbon from sources including decaying dead organisms, humic materials from the soil, and gelbstoff (dissolved organic material). During the Trinidad/Orinoco dry season, waters around the island are affected by fresh-water outflow from the River Amazon, which is at that time in flood. Lentz (1995) concluded that *c.* 30% of Amazon outflow is carried towards Trinidad by the Guyana Current, and Aslan *et al.* (2003) suggested that half the sediment forming the Orinoco Delta is derived from the Amazon. According to Agard & Gobin (2000) Amazon discharge forms a lens of low salinity water (<33.5 ppt) up to 50 m deep between Trinidad, Tobago and Barbados.

The nutrient-rich waters around Trinidad induce high phytoplankton primary productivity, with rates of carbon production exceeding 500 mg m^{-2} day^{-1} (Barnes & Hughes, 1999, fig. 1.22), and even attaining values as high as 2026 mg m^{-2} day^{-1} (Agard & Gobin, 2000). Barnes & Hughes (1999) suggested that the high values may be associated with upwelling around the island, but Agard & Gobin (2000) found little evidence of this. They instead ascribed high primary productivity to the intrusion of Amazon water, which they found to be associated with the diatom genera *Navicula* and *Coscinodiscus*.

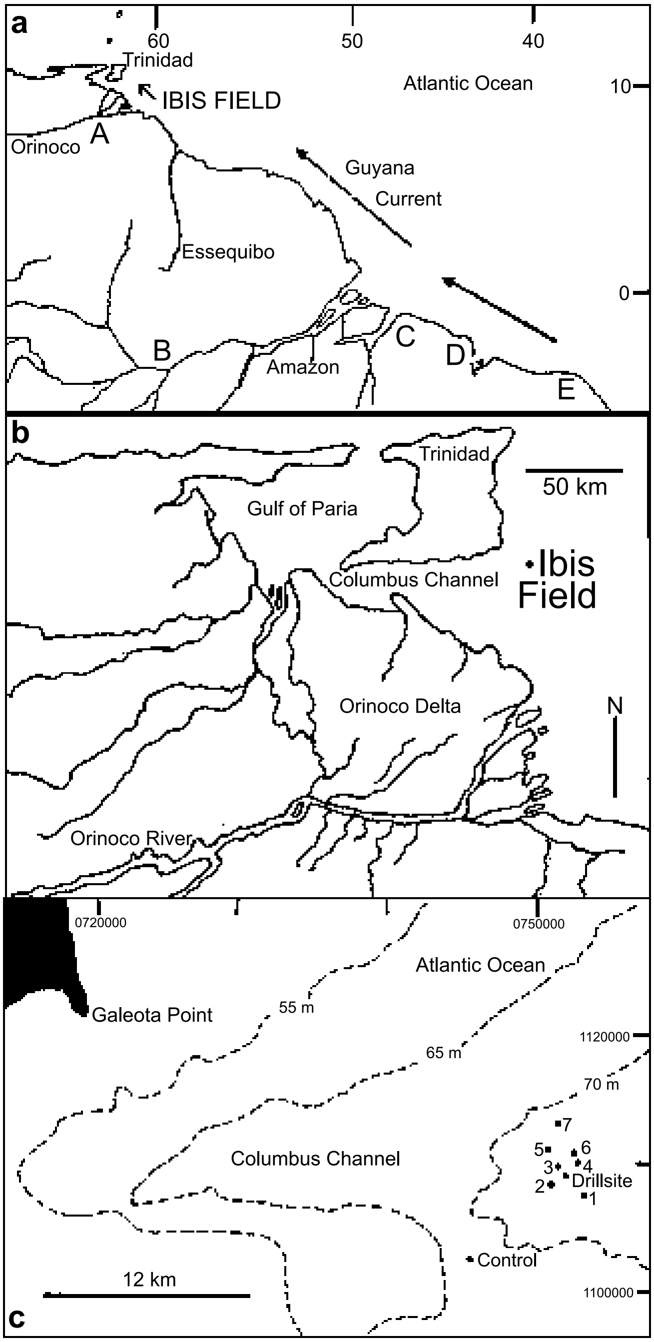

Fig. 1. (**a**) The general location of Trinidad, the Guyana Current and the Ibis Field. Letters indicate cities: A, Ciudad Guyana; B, Manaus; C, Belem; D, São Luis; E, Fortaleza. (**b**) Location of the Ibis Field relative to Trinidad, the Orinoco Delta and the Gulf of Paria. (**c**) Location of the Ibis Field stations.

Trinidad shelters the continental shelf east of the island from sedimentation from the Orinoco Delta (see Agard & Gobin, 2000, fig. 2). Furthermore, the dominant current directions are not towards eastern Trinidad, but westward, into the Gulf of Paria, which separates Trinidad from the northern Orinoco Delta (van Andel & Postma, 1954). Carr-Brown (1972, figs 2, 3) indicated that the seafloor east of the island comprises a relict, late Pleistocene transgressive facies of calcareous, skeletal debris with many *Quinqueloculina lamarckiana*. Further south, in the Ibis Field area, he recorded a thin (<2 m) sequence of bottomset clays associated with the Orinoco prodelta overlying delta-top Pleistocene, although Drooger & Kaasscheiter (1958, map 2) mapped the Ibis Field seafloor as comprising calcarenitic sandy pelite. In the present study fine quartz was recovered only from the most northerly part of the Ibis Field (Station 7), the remaining samples comprising grey-brown mud with small quantities of mollusc fragments.

FORAMINIFERA IN THE IBIS FIELD IN 1953

Drooger & Kaasscheiter (1958) recorded rapid lateral changes in the foraminiferal fauna in the Ibis Field. The proportion of the fauna comprising *Hanzawaia concentrica* increased rapidly northwards from *c.* 5% in the Ibis Field to >20% on relict sands in shallower water *c.* 10 km to the north. In contrast, the proportion of *Pseudononion atlanticum* increased southwards from *c.* 5% in the vicinity of the field to *c.* 20% a few tens of kilometres further south. Off southern Venezuela, and Guyana as far as the Essequibo River, Drooger & Kaasscheiter (1958) found the reverse pattern, *P. atlanticum* occurring mostly in shallower water than *H. concentrica*. Debenay *et al.* (2004) recorded *P. atlanticum* living on marine-influenced, shallow-water mudflats adjacent to mangrove swamps in French Guyana, but did not find *H. concentrica*. This suggests that *P. atlanticum* lives more proximal to rivers than does *H. concentrica*.

The 1953 distributions of *Ammonia pauciloculata*/*Rolhausenia rolhauseni* and *Uvigerina subperegrina* [=*U. peregrina* of Drooger & Kaasscheiter, 1958] match those of *Pseudononion atlanticum*, increasing rapidly south of the field to attain frequencies of *c.* 5% each.

MATERIALS AND METHODS

Two replicates were recovered from each of eight stations around the Ibis Field (Stations 1 to 7 and Drillsite) using a grab designed to preserve the sediment–water interface. Another two were taken from a site called Control *c.* 7 km to the southwest (i.e. 18 replicates in all). Smith & Buzas (1986) have shown that the foraminiferal taphocoenosis can be distributed patchily at the small scale: replicates were taken from the Ibis Field to overcome this by sampling from adjacent patches. The grid references of the stations, all in UTM Zone 20P, were recorded using a GPS (Table 1).

Although foraminifera can live infaunally to depths of >10 cm (Jorissen, 1999), only the top 1 cm of sediment was recovered for study. The replicates were stained with rose Bengal, which distinguishes live specimens from dead; however, because the results were to be compared with Drooger & Kaasscheiter's (1958) data, the entire (live+dead) fauna was picked. There was an overwhelming abundance of dead specimens. The replicates were split using a microsplitter into aliquots yielding *c.* 300 benthonic foraminifera, then picked in two stages:

1. all foraminifera (benthonic and planktonic) were picked to a total of 200 benthonics and these data used to calculate the percentage of planktonics (%*P*), the value of which is positively correlated with water depth (e.g. de Rijk *et al.*, 1999);
2. a further *c.* 100 benthonic foraminifera were picked to give a total per replicate of *c.* 300 benthonics.

The specimens were mounted onto card slides, sorted into species and identified using Phleger & Parker (1951), Todd & Bronnimann (1957), Drooger & Kaasscheiter (1958), Andersen (1961), Mikhalevich (1983) and Hofker (1983). The data from replicates from each site were pooled to give a total count of *c.* 600 benthonics from each station. To facilitate comparison with Drooger & Kaasscheiter (1958), data for *Ammonia pauciloculata* and *Rolhausenia rolhauseni* were combined. Drooger & Kaasscheiter (1958) presented two maps for the genus *Quinqueloculina* (map 24, all *Quinqueloculina* spp.; map 25, *Q. lamarckiana*+*Q. bicostata*). Here, only *Q. lamarckiana* and *Q. bicostata* are compared.

The number of species per site was recorded. However, because species richness is a poor measure of diversity, giving equal weight to rare and abundant species (Magurran, 1988), diversity was also measured using the Information Function:

$$H' = -\Sigma p_i \ln p_i \qquad (1)$$

where p_i is the proportional abundance of the *i*th species. To check for geographical trends, relationships between (a) species' proportional abundances, (b) H', (c) %*P* and (d) grid reference northings and eastings were examined using Pearson's Product Moment Correlations, using a confidence limit of $p<05$. In view of the narrow depth range of the stations, no attempt was made to correlate species abundances with depth.

RESULTS

A total of 5451 specimens were picked, belonging to 49 species or species groups (Table 1). However, only 12 each formed >1% of the recovery from any one station. These comprise the subject of the remainder of this paper. Correlations between species percentage abundances, H', northings and eastings are shown in Table 2.

The percentage of the foraminiferal taphocoenoses comprising planktonics (%*P*) varies little (mean 28.7%, standard deviation 2.47%) and showed no geographical trend, correlations with both eastings and northings being insignificant (Table 2). This is to be expected, as water depths in the Ibis Field vary little.

Species richness ranged between S=14 and 28 (mean 20.1), but is not positively correlated with either northings or eastings. In contrast, the Information Function (H') is positively correlated with northings but not eastings, indicating a northward increase in diversity. The values are generally low (mean H'=1.65, s.d.=0.17).

Significant positive correlations between northings and the percentage abundances of *Hanzawaia concentrica* and *Uvigerina subperegrina* reflect overall northward increases in their relative abundance, while significant negative correlations between

Species	Control	1	2	3	4	5	6	7	Drillsite
Ammonia pauciloculata/*Rolhausenia rolhauseni*	160	149	139	128	149	106	120	70	113
Amphicoryna catesbyi	0	0	1	0	0	0	0	0	0
Bombulina spinata	0	0	0	0	0	0	1	1	0
Brizalina barbata	0	0	0	0	0	0	2	0	0
Brizalina spathulata	3	0	0	0	0	0	0	0	0
Brizalina striatula	0	1	0	0	2	2	3	3	4
Bulimina marginata	0	3	0	4	3	4	0	1	2
Cancris sagrai	36	12	20	10	25	38	24	34	21
Cibicides indet.	0	1	1	1	0	0	0	0	0
Cibicidoides io	0	0	0	0	0	0	0	7	0
Cibicidoides mollis	0	0	0	0	0	0	1	9	0
Cibicidoides pseudoungerianus	2	1	1	0	1	4	0	0	1
Dentalina cf. *D. subemaciata*	0	0	0	0	1	0	4	0	0
Elphidium advenum	0	0	0	0	0	0	1	0	0
Elphidium discoidale	0	0	0	1	1	0	3	2	1
Epistominella decorata	0	0	0	0	0	0	0	2	1
Eponides antillarum	0	1	1	0	2	1	0	4	0
Fursenkoina pontoni	7	1	4	0	0	1	2	1	1
Glandulina surinamensis	0	0	0	0	0	2	0	1	0
Globocassidulina subcalifornica	0	0	0	0	0	0	2	0	0
Globocassidulina subglobosa	0	0	1	0	0	2	0	0	0
Hanzawaia concentrica	1	5	9	8	8	11	10	30	10
Lagena ex gr. *striata*	0	0	0	0	0	2	0	2	1
Lenticulina iota	0	0	0	0	0	0	2	3	0
Lenticulina lowmanni	5	4	5	4	4	7	1	3	6
Lenticulina peregrina	0	0	0	2	1	0	0	0	0
Lenticulina rotulata	0	0	0	1	0	0	1	0	0
Lenticulina sp. B	0	0	0	0	1	0	0	0	0
Marginulinopsis planata	0	0	0	0	0	1	0	0	0
Pseudononion atlanticum	283	167	285	237	249	237	267	171	269
Pseudononion grateloupi	0	0	0	1	1	0	2	4	1
Quinqueloculina bicostata/*Q. lamarckiana*	17	12	19	14	5	36	32	49	17
Quinqueloculina polygona	0	2	0	0	0	0	0	0	0
Quinqueloculina seminula	0	2	0	2	1	2	0	2	4
Quinqueloculina sp.	0	0	0	0	0	0	1	0	0
Quinqueloculina sp. A	3	1	5	5	7	11	11	4	6
Rectobolivina advena	4	8	5	3	6	4	2	12	4
Reophax guttifer	0	0	0	0	0	0	1	0	0
Reussella atlantica	0	0	0	0	1	0	0	0	0
Sagrina antilleana	0	0	0	0	0	0	0	1	0
Siphonaperta horrida	2	1	1	0	1	2	0	3	0
Siphonina reticulata	0	1	0	0	0	0	1	1	0
Siphotextularia rolhausenia	0	0	0	0	1	1	0	1	1
Textularia candeiana	0	0	0	1	0	0	0	0	0
Trifarina bradyi	0	0	0	0	0	0	1	0	0
Triloculina tricarinata	0	0	2	0	0	5	0	1	0
Triloculina trigonula	1	0	0	2	0	1	0	0	2
Uvigerina subperegrina	94	114	115	185	117	152	166	201	155
Valvulineria sp.	0	0	0	0	0	0	1	0	0
N	618	486	614	609	587	632	662	623	620
S	14	26	19	17	28	18	14	23	22
H'	1.49	1.59	1.52	1.51	1.57	1.83	1.70	2.01	1.60
northings (m)	1102425	1107521	110836	1109779	1109908	1110811	1110811	1112811	1109085
eastings (m)	0745716	0753140	0751010	0751462	0752688	0750880	0752494	0751332	0751904
%*P*	28.4	26.7	27.1	26.9	27.8	30.7	27.5	34.4	28.3
Depth	69	70	70	71	71	71	71	71	70

N, number of specimens per sample; S, species richness; H', Information Function; %*P*, percentage of planktonics.

Table 1. Benthonic foraminifera of the Ibis Field area, Trinidad, in March 2005.

Ammonia pauciloculata/*Rolhausenia rolhauseni* and *Fursenkoina pontoni* and northings reflect southward increases in relative abundance. The only significant correlation between eastings and any species was with *Fursenkoina pontoni*, but the correlation was negative, indicating greater relative abundance to the west.

Species	Northings	Eastings
Ammonia pauciloculata/Rolhausenia rolhauseni	**−0.7009**	−0.0381
Cancis sagrai	−0.0671	−0.5205
Fursekoina pontoni	**−0.8096**	**−0.8450**
Hanzawaia concentrica	**0.7473**	0.3123
Lenticulina lowmani	−0.2795	−0.1611
Pseudononion atlanticum	−0.4493	−0.2158
Quinqueloculina lamarckiana/Q. bicostata	0.4868	0.2510
Quinqueloculina sp. A	0.5338	−0.0118
Rectobolivina advenca	0.2184	0.2474
Uvigerina subperegrina	**0.6885**	0.4901
%P	0.4617	−0.1290
H'	**0.7016**	0.2120

Correlations significant at $p<0.05$ in bold. %P, percentage of planktonics; H', Information Function

Table 2. Correlations between the 12 species forming >1% of recovery at any one station in the Ibis Field area, Trinidad, percentage of planktonics (%P), the Information Function (H'), and eastings and northings.

DISCUSSION

Diversity

Gibson & Buzas (1973) noted that values of the diversity measures S and H' are depressed in the vicinity of the Mississippi delta compared with the remainder of the Gulf of Mexico. The manner in which Drooger & Kaasscheiter (1958) presented their results precludes calculation of 1953 values of S and H'. The 2005 values of S and H' at the Ibis Field compare with those reported by Gibson & Buzas (1973, fig. 12) off the Mississippi delta: the mean S (=20.1) is comparable with that off the delta at depths of *c.* 100–200 m, while the low value of mean H' (=1.65) is comparable with that around the delta at depths of *c.* 110 m. Elsewhere in the Gulf of Mexico values of H' at the same depth as the Ibis Field are typically *c.* 2.7. Thus, it seems that 2005 diversities reflect the impacts of the Orinoco, Essequibo and Amazon Rivers.

The percentage of planktonics

Previous work has shown that the percentage of planktonics (%P) is generally positively correlated with depth. De Rijk *et al.* (1999) calculated that water depth and %P in the eastern Mediterranean, including around the Nile Delta, are related through:

$$\text{Depth} = e^{((81.9 + \%P)/24)} \qquad (2)$$

When applied to the mean value of %P=28.7 in the Ibis Field, de Rijk *et al.*'s (1999) expression indicates a depth of *c.* 100 m, considerably greater than the actual depth of *c.* 69–71 m. Differences in the values of %P between the Mediterranean and southeast Caribbean may be related to either high phytoplankton primary productivity in the latter compared with the former (cf. Barnes & Hughes, 1999), or differences in the sieve mesh size used (this study, 63 μm; de Rijk *et al.*, 1999, 125 μm).

There was no apparent change in %P at the Ibis Field between 1953 and 2005 (Table 2: see also Drooger & Kaasscheiter, 1958, map 38).

Comparison: 1953 and 2005

Six of the distribution/abundance maps published by Drooger & Kaasscheiter (1958) show the 1953 distributions of species abundant in 2005 [see Table 3 – this also lists *Miliolinella subrotunda* and *Cibicidoides pseudoungerianus* which, although recorded as abundant by Drooger & Kaasscheiter (1958), were either rare or absent in 2005]. Application of simultaneous confidence intervals (Lamboy & Lesnikowska, 1988), using a population size of 200 individuals for Drooger & Kaasscheiter's (1958) data, show that the overall percentage abundances of *Ammonia pauciloculata/Rolhausenia rolhauseni*, *Pseudononion atlanticum* and *Uvigerina subperegrina* increased significantly between 1953 and 2005, while those of *Hanzawaia concentrica*, *Quinqueloculina bicostata/Q. lamarckiana*, *Cibicidoides pseudoungerianus* and *Miliolinella subrotunda* declined. The percentage abundance of *Cancris sagrai* remained unchanged. The biogeographical distribution of *U. subperegrina* changed between the two surveys: in 1953 its proportional abundance increased southwards across the field, whereas in 2005 it increased northwards.

Species names (this report)	Species names (Drooger & Kaasscheiter, 1958)	1953	2005
Ammonia pauciloculata/Rolhausenia rolhauseni	*Rotalia pauciloculata/Rotalia rolhauseni*	2–5	11.2–30.6
Cancris sagrai	*Cancris sagra*	2–5	1.6–6.0
Hanzawaia concentrica	*Hanzawaia concentrica*	5–10	0.16–4.8
Pseudononion atlanticum	*Nonionella atlantica*	5–10	27.4–55.3
Quiqnueloculina bicostata/Q. lamarckiana	*Quiqnueloculina bicostata/Q. lamarckiana*	5–10	0.85–5.7
Uvigerina subperegrina	*Uvigerina peregrina*	2–5	15.2–32.2
Cibicidoides pseudoungerianus	*Cibicidoides pseudoungerianus*	5–10	n/a
Miliolinella subrotunda	*Miliolinella subrotunda*	5–10	n/a

Table 3. Percentage abundances of selected species in the Ibis Field area in 1953 and 2005.

The increase in the overall proportional abundance of *Uvigerina subperegrina* from *c.* 2–5% in 1953 to *c.* 15–32% in 2003 suggests that the nutrient flux to the Trinidad Shelf has increased: although Kaiho (1994) suggested species of *Uvigerina* to be indicative of dysoxic waters, Rathburn & Corliss (1994) found *Uvigerina* only rarely at sites with <1.76 ml l^{-1} dissolved oxygen in the Sulu Sea, and concluded that this genus is typical not of dysoxic waters, but of areas with a high nutrient flux. The notion of an increased nutrient flux to the Ibis Field is supported by the increased proportional abundance of *Pseudononion atlanticum* from 5–10% in 1953 to *c.* 27–55% in 2005. *Pseudononion atlanticum* is an opportunist associated with nutrient-rich environments and tolerant of low oxygen and high sedimentation rates (Ernst & van der Zwaan, 2004; Osterman *et al.*, 2005).

Possible sources of nutrient enrichment

At present it is only possible to speculate about the nutrient source, although an anthropogenic cause seems most likely. Trinidad (population *c.* 1 million) has sugar and petrochemical industries, but these can be ruled out: the Guyana current at all times flows through the Ibis Field towards Trinidad. Likewise, changes at the upstream control site rule out the oil production facilities at the Ibis Field as a source. Causes of nutrient enrichment must, therefore, be sought to the southeast, in the Amazon, Essequibo and Orinoco River basins of South America and the adjacent sea. The River Amazon at least significantly influences the flux of nutrients for hundreds of kilometres northwest along the continental shelf and slope (Smith & Demaster, 1996), and DeMaster & Aller (2001) noted that anthropogenic activities are beginning to impact on biogeochemical processes in the Amazon Basin.

Foraminifera use labile carbon as a food source (Loubere & Fariduddin, 1999). Increased supplies of labile carbon might be associated with deforestation in the Amazon, Essequibo and Orinoco basins, the effects of which are being felt worldwide (Werth & Avissar, 2002). Much of Guyana's coastal plane around the Essequibo River has been cleared for sugar cultivation. In terms of absolute area, however, deforestation in the Amazon Basin, Brazil, has been more severe: 1.55% (78 000 km^2) of Brazil's 5×10^6 km^2 of rainforest had been cleared by 1978, rising to 4.6% (230 000 km^2) by 1988 (Skole & Tucker, 1993). About 10% of this land is used for cultivating annual crops, and *c.* 90% for pastures (Wood, 2002) linked to a growing demand for beef (Faminow, 1998). McClain (2001) recorded that the burning of trees felled during land clearance liberates nutrients that are washed out by the first rains and removed by surface runoff or through groundwater. However, carbon released through this is unlikely to be the cause of nutrient enrichment on the continental shelf: Houghton *et al.* (2000) found that it is re-absorbed either by crops or pasture, or during re-growth of deforested areas.

The increased nutrient flux might instead reflect increased phytoplankton primary production associated with application of nitrogen-rich fertilizers on cleared land. In the USA, farmers apply *c.* 25–40% more fertilizers than crops need (Puckett, 1995). Osterman *et al.* (2005) found that, on the Louisiana continental shelf, a six-fold increase in the use of nitrogen-rich fertilizer since 1950 is correlated positively with increased proportions of *Pseudononion atlanticum*, *Epistominella vitrea* and *Buliminella morgani*.

However, it is unclear whether nitrogen-rich fertilizers applied to South American croplands are responsible for increase phytoplankton productivity around Trinidad. Justić *et al.* (1995) found that the Amazon is a nitrogen-deficient river, while Ometo *et al.* (2000) suggested that agricultural crops in Brazil receive less fertilizer than they require, and so are net sinks for nitrogen. Conversely, sugar cane cultivation practises may play a role. Sugar cane is grown in Brazil, Surinam and Guyana, receives 80–100 kg ha^{-1} of nitrogen fertilizer per year, and is a high-impact crop that is burned annually. Plants are replaced every five years, at which time cultivated soil is exposed for months, and at which time nitrogen from fertilizers applied to sugar cane may be delivered to the South American continental shelf either in solution, or after being sorbed by clays (Kaiser & Zech, 2000) that are eroded from cleared land and carried downstream by rivers.

Alternatively, nutrients may be derived from sewage delivered either via rivers or directly into seas. Bandy *et al.* (1964) documented how dumping of raw sewage at sea can kill off the fauna immediately adjacent to the outlet, and modify species composition at more distal sites. It is possible that poorly treated sewage from South American cities is being transported to the continental shelf by the rivers. Cities adjacent to rivers include Cuidad Guyana, Venezuela (2002 population, 629 000) and Manaus and Belem, Brazil (2002 populations, 1.5 million and 1.3 million, respectively). Shores adjacent to the Brazilian cities of Fortaleza and São Luis (2002 populations, 2 256 000 and 889 000 respectively) are flushed by the Guyana current. IDBAmerica (1999) recorded that sanitary conditions in Fortaleza, Brazil's seventh largest city, are at best poor, particularly for the residents of >300 *favelas* (slums) scattered through the city. *Favelas* in Fortaleza in 1999 housed *c.* 541 000 people, and were serviced primarily by open-air sewers.

Faecal matter may also be derived from effluent from saltwater shrimp farms. Previous workers have documented the impact of finfish and shellfish farming on foraminiferal populations (e.g. Scott *et al.*, 1995; Angel, 2000): the author is unaware of any studies of the impact of shrimp ponds. However, Moles & Bunge (2002) estimated that shrimp production, launched in Brazil in 1974, would by the year 2000 amount to 25 000 metric tons, rising to 105 000 metric tons by 2003. They projected that 2000 production would require 6250 ha of shrimp ponds, of which *c.* 3300 ha along coastline washed by the Guyana Current would produce *c.* 53.4% of the total output. Moles & Bunge (2002) further noted that, due to a lack of planning control, some shrimp farms are sources of effluent.

The above factors are all chronic, but there is one other, acute but transient factor to consider. On August 24, 1995, 825 million gallons of cyanide-treated wastewater used in gold refining was released into the Essequibo River when a dam associated with mine tailings broke (Carson, 1995). Carson (1995) reported dead birds, hogs and shoals of fish floating downstream. However, no quantitative studies were undertaken to document the damage caused (Ramessar, 2003) and it is unclear how this event impacted on the marine community.

SUMMARY AND CONCLUSIONS

Foraminiferal communities are not static entities, but change in response to environmental perturbations. Given sufficient time, such a signal will become incorporated into the dead assemblages on the seafloor. The seafloor assemblage in the Ibis Field, off southeast Trinidad, which was first examined in 1953, was re-examined in 2005. Differences in assemblages in the two surveys indicate an increase in nutrient supply over time. However, the change has not impacted on the planktonic/benthonic foraminiferal ratio, and must therefore affect both the surface and bottom waters. Trinidad cannot be the source for the nutrient enrichment; the current flowing over the Ibis Field trends towards Trinidad, not away from it. Sources must, therefore, be sought to the southeast, from either the Amazon, Essequibo or Orinoco River basins. It is speculated that the nutrient enrichment may be a consequence of nitrogen-rich runoff from South American sugarcane plantations, or flushing of organic carbon from poorly-regulated sewage systems or shrimp farms in South America.

The results presented here show that environmental information of value may be obtained by re-sampling of seafloor assemblages at the decadal scale, and that even tropical islands, regarded in the popular imagination as paradisiacal, are not immune to environmental problems.

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