Trouble in Paradise? A comparison of 1953 and 2005 bentonic 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 x 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/Rolhaesenia rolhaeseni 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/bentonic 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

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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 & Kaasscheiter (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 opportunist 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 thanatocones 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*.
Comparison of benthonic foraminiferal assemblages

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 calcarceous, skeletal debris with many Quinqueloculina lamareckiiana. 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/Rolhaesenia 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.

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 (%) 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
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.

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

| Species | Control | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Drillsite |
|---------|---------|---|---|---|---|---|---|---|----------|
| **Ammonia pauciloculata Rolhausenia rolhauseni** | 160 | 149 | 139 | 128 | 149 | 106 | 120 | 70 | 113 |
| **Amphiocoryna 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 | 4 | 0 |
| **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 |
| **Cibicides io** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 |
| **Cibicides mollis** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 9 | 0 |
| **Cibicides pseudoungerianus** | 2 | 1 | 1 | 0 | 1 | 4 | 0 | 1 | 1 |
| **Dentalina cf. D. subenuciata** | 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 | 0 |
| **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 | 2 | 0 | 1 | 0 |
| **Globocassidulina subglobosa** | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 |
| **Hanzawaia concentrica** | 1 | 5 | 9 | 8 | 8 | 11 | 10 | 30 | 10 |
| **Lagenax gr. striata** | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 |
| **Lenticulina iota** | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 |
| **Lenticulina lovmani** | 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 |
| **Marginalinopsis planata** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **Pseudononion atlanticum** | 283 | 167 | 285 | 237 | 249 | 237 | 267 | 171 | 269 |
| **Pseudononion grateolae** | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 4 | 1 |
| **Quinqueloculina bicostata Q. lamarkiana** | 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. A** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Quinqueloculina sp. A** | 3 | 1 | 5 | 5 | 7 | 11 | 11 | 4 | 6 |
| **Rectobolivia 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 | 0 | 1 | 0 | 0 | 0 |
| **Sagrina antillea** | 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 rolhaussenia** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| **Textularia candeiann** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **Trifarina bradyi** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Triloculina tricolorata** | 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 | 1.53 | 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.

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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.

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| Species                                      | Northings | Eastings |
|----------------------------------------------|-----------|----------|
| Ammonia pauciloculata/Rolhausenia rolhausi  | 0.7009    | -0.0381  |
| Cancis sagrai                                | -0.0671   | -0.5205  |
| Furseolina pontoni                           | -0.8096   | -0.8450  |
| Hanzawaia concentrica                        | 0.7473    | 0.3123   |
| Lenticulina loveni                           | -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 advensca                       | 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:

\[ \text{Depth} = e^{(81.9 + \%P/24)} \]  

(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 rolhausi, 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 Cancis 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.

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 2–5% in 1953 to 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 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 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. Justic 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. IDB America (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 fishfod 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 (Ramasar, 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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REFERENCES

Agard, J.B.R. & Gobin, J.F. 2000. The Lesser Antilles, Trinidad and Tobago. In: Sheppard, C.R.C. (Ed.), Seas at the Millennium: An Environmental Evaluation, 1. Pergamon, Amsterdam, Holland, 627–641.

Andersen, H.V. 1961. Genesis and paleontology of the Mississippi River mudlumps, lower Mississippi River Delta, Louisiana. Louisiana Geological Survey, Bulletin, 35: 1–208.

Angel, D.L., Verghese, S., Lee, J.J., Saleh, A.M., Zuber, D., Lindell, D. & Symons, A. 2000. Impact of a Net Cage Fish Farm on the Distribution of Benthic Foraminifera in the Northern Gulf of Elat (Aqaba, Red Sea). Journal of Foraminiferal Research, 30: 54–65.

Aslan, A., White, W.A., Warne, A.G. & Guevara, E.H. 2003. Holocene evolution of the western Orinoco Delta, Venezuela. Geological Society of America Bulletin, 115: 479–498.

Bandy, O.L., Ingle, J.C. & Resig, J.M. 1964. Foraminifera, Los Angeles County Oufall area, California. Limnology and Oceanography, 9: 124–137.

Barnes, R.S.K. & Hughes, R.N. 1999. Introduction to Marine Ecology. Blackwell Publishing Limited, England, 296 pp.

Carr-Brown, B. 1972. The Holocene/Plenistocene contact in the offshore area east of Galeota Point, Trinidad, West Indies. 1°1 Conferencia Geologica Del Caribe: Margarita, Venezuela. Cromotip, Caracas, Venezuela, 381–397.

Carson, R. S. 1995. Cyanide River Disaster in Guyana. Albion Monitor/News. Available online at http://www.monitor.net/monitor/9-2-95/guyana.html (date accessed: May, 2005).

Culver, S.J. 1988. New Foraminiferal Depth Zonation of the Northwestern Gulf of Mexico. Palaios, 3: 69–85.

Cushman, J.A. 1918–1931. Foraminifera of the Atlantic Ocean. Bulletin of the United States National Museum, 104(1–8).

Dagg, M., Bennerb, R., Lohrenzc, S. & Lawrence, D. 2004. Transformation of dissolved and particulate materials on continental shelves influenced by large rivers: plume processes. Continental Shelf Research, 24: 833–858.

DeMaster, D.J. & Aller, R.C. 2001. Biogeochemical Processes on the Amazon Shelf: Changes in Dissolved and Particulate Fluxes During River/Ocean Mixing. In: McClain, M.E., Victoria, R.L. & Richey, J.E. (Eds), The Biogeochemistry of the Amazon Basin. Oxford University Press, Oxford, 328–357.

Debenay, J.-P., Guirald, D. & Parra, M. 2004. Behaviour and taphonomic loss in foraminiferal assemblages of mangrove swamps of French Guiana. Marine Geology, 208: 295–314.

Drooger, C.W. & Kaasscheiter, J.P.H. 1958. Foraminifera of the Orinoco–Trinidad–Paria Shelf. In: Van Andel, T.J. & Postma, H. (Eds), Reports of the Orinoco Shelf Expedition. Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, Naturkunde, 22: 1–108.

Ernst, S. & van der Zwaan, B. 2004. Effects of experimentally induced raised levels of organic flux and oxygen depletion on a continental slope benthic foraminiferal community. Deep-Sea Research, 51: 1709–1739.

Faminow, M.D. 1998. Cattle, Deforestation and Development in the Amazon: An Economic, Agronomic and Environmental Perspective. CABI Publishing, New York, 253 pp.

Gibson, T.G. & Buzas, M.A. 1973. Species Diversity: Patterns in Modern and Miocene Foraminifera of the Eastern Margin of North America. Geological Society of America Bulletin, 84: 217–238.

Gustafsson, M. & Nordberg, K. 2001. Living (stained) benthic foraminiferal response to primary production and hydrography in the deepest part of the Gulf of Fjord, Swedish west coast, with comparisons to Högland’s 1927 material. Journal of Foraminiferal Research, 31: 2–11.

Hallock, P., Lidz, B., Cockey-Burkhard, E.M. & Donnelly, K. 2003. B Foraminifera as biocindicators in coral reef assessment and monitoring: The FORAM Index. Environmental Monitoring and Assessment, 81: 221–238.

Hochman, H.T., Müller-Karger, F.E. & Walsh, J.J. 1994. Interpretation of the coastal zone color scanner signature of the Orinoco River plume. Journal of Geophysical Research, 99 (C4): 7443–7456.

Hofker, J. 1983. Zoological exploration of the continental shelf of Surinam: The foraminifera of the shelf of Surinam and the Guyanas. Zoologische Verhandelingen Uit. Door het Rijksmuseum van Natuurlijke Historie te Leiden, 201: 1–75.

Houghton, R.A., Skole, D.L., Nobre, C.A., Hackler, J.L., Lawrence, K.T. & Chomentowski, W.H. 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature, 403: 301–304.

IDB América. 1999. State of the art treatment plant. Available online at http://www.idb.org/ibdamericas/Archive/stories/1998/eng/c79981.htm (accessed date: May, 2005).

Jorissen, F. 1999. Benthic Foraminiferal Microhabitats below the Sediment–Water interface. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, 161–179.

Justic, D., Rabalais, N.N. & Turner, R.E. 1995. Stoichiometric Nutrient Balance and Origin of Coastal Eutrophication. Marine Pollution Bulletin, 30: 41–46.

Kaiho, K. 1994. Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean. Geology, 22: 719–722.

Kaiser, K. & Zech, W. 2000. Sorption of dissolved organic nitrogen by acid subsoil horizons and individual mineral phases. European Journal of Soil Science, 51: 403–407.

Lamboy, W. & Lesnikowska, A. 1988. Some Statistical Methods Useful in the Analysis of Plant Paleoecological Data. Palaeos, 3: 86–94.

Lentz, S.J. 1995. Seasonal variations in the horizontal structure of the Amazon Plume inferred from historical hydrographic data. Journal of Geophysical Research, 100 (C2): 2391–2400.
Loubere, P. & Fariduddin, M. 1999. Benthic Foraminifera and the Flux of Organic Carbon to the Seabed. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, 181–200.

Maguraan, A.E. 1988. Ecological Diversity and its Measurement. Chapman & Hall, London, 179 pp.

McClain, M.E. 2001. The relevance of biogeochemistry to Amazon Development and Conservation. In: McClain, M.E., Victoria, R.L. & Richey, J.E. (Eds), The Biogeochemistry of the Amazon Basin. Oxford University Press, Oxford, 3–16.

Mikhailевич, V.I. 1983. The bottom foraminifera of the shelves of the tropical Atlantic. Proceedings of the Zoological Institute, USSR Academy of Sciences, 247: 1–246.

Moles, P. & Bunge, J. 2002. Shrimp Farming in Brazil: An Industry overview. Report prepared under the World Bank, NACA, WWF and FOA Consortium Program on Shrimp Farming and the Environment. Available online at http://library.enaca.org/Shrimp/Case/LatinAmerica/Brazil/ShrimpFarmingBrazil.pdf (accessed date: May, 2005).

Ometo, J.P.H.B., Martinelli, L.A., Ballester, M.V., Gessner, A., Krusche, A.V., Victoria, R.L. & Williams, M. 2000. Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba river basin, south-east Brazil. Freshwater Biology, 44: 327–337.

Osterman, L.E., Poore, R.Z., Swarzenski, P.W. & Turner, R.E. 2005. Reconstructing a 180 yr record of natural and anthropogenic induced low-oxygen conditions from Louisiana continental shelf sediments. Geology, 33: 329–332.

Phleger, F.B. 1951. Ecology of Foraminifera. Northwest Gulf of Mexico. Part 1: Foraminifera Distribution. Geological Society of America Memoir, 46 (1): 1–88.

Phleger, F.B. & Parker, F.L. 1951. Ecology of Foraminifera. Northwest Gulf of Mexico. Part 2: Foraminifera Species. Geological Society of America Memoir, 46 (2): 1–64.

Puckett, L. 1995. Identifying the Major Sources of Nutrient Water Pollution. Environment Science and Technology, 29: 408A–414A.

Ramesar, C. R. 2003. Water is More Important than Gold: Local Impacts and Perceptions of the 1995 Omai Cyanide Spill, Essequibo River, Guyana. Available online at http://scholar.lib.vt.edu/theses/available/etd-08152003-162551/ (accessed date: May, 2005).

Rathburn, A.E. & Corliss, B.H. 1994. The ecology of living (stained) deep-sea benthic foraminifera from the Sula Sea. Paleoceneography, 9: 87–150.

Scott, D.B., Schafer, C.T., Honig, C. & Younger, D.C. 1995. Temporal variations of benthic foraminiferal assemblages under or near aquaculture operations: documentation of impact history. Journal of Foraminiferal Research, 25: 224–235.

Scott, D.B., Medioli, F.S. & Schafer, C.T. 2001. Monitoring of Coastal Environments using Foraminifera and Thecamoebian indicators. Cambridge University Press, Cambridge, 192 pp.

Sen Gupta, B.K. 1999. Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, 384 pp.

Skole, D.L. & Tucker, C. 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. Science, 260: 1905–1910.

Smith, P.B. 1964. Recent Foraminifera off Central America, Ecology of Benthonic Species. US Geological Survey Professional Paper, 429: 1–55.

Smith, R.K. & Buzas, M.A. 1986. Micrdistribution of Foraminifera in a Single Bed of the Monterey Formation, Monterey County, California. Smithsonian Contributions to Paleobiology, 60: 1–33.

Smith, W.O. & Demaster, D.J. 1996. Phytoplankton biomass and productivity in the Amazon River plume: correlation with seasonal river discharge. Continental Shelf Research, 16: 291–319.

Stott, L.D., Hayden, T.P. & Griffith, J. 1996. Benthic foraminifera at the Los Angeles Whites Point outfall revisited. Journal of Foraminiferal Research, 26: 357–368.

Todd, R. & Brönnimann, P. 1957. Recent Foraminifera and Thecamoebina from the Eastern Gulf of Paria, Trinidad. Cushman Foundation for Foraminiferal Research, Special Publication, 3: 1–43.

Wethington, D. & Avisar, R. 2002. The local and global effects of Amazon deforestation. Journal of Geophysical Research, 107: 1–8.

Wood, C.H. 2002. Introduction: Land Use and Deforestation in the Amazon. In: Wood, C.H. & Porro, R. (Eds), Deforestation and Land Use in the Amazon. University Press of Florida, Gainsville, 3–13.

de Rijk, S., Troelstra, S.R. & Rohling, E.J. 1999. Benthic foraminiferal distribution in the Mediterranean Sea. Journal of Foraminiferal Research, 29: 93–103.

van Andel, Tj. & Postma, H. 1954. Recent Sediments of the Gulf of Paria. Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, Natuurkunde, 20: 1–245.