

The Environmental Significance of Some Microscopic Organisms Around Nevis, West Indies

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Coastline developments such as hotels and industrial sites impact on the near-shore environment. In these environment-conscious times, developers are required to provide (a) indications of the probable environmental impact of developments, and (b) evidence of actual impacts following construction. Study of the flora and fauna provides the necessary data. Marine animals range in size from whales to microscopic organisms, but the smaller ones are more easily sampled for environmental purposes. One particularly useful and abundant group of microscopic organisms, the Class Foraminifera (forams), has been widely studied by marine biologists, but has yet to be used to its full potential. Forams produce shells that preserve easily and can be used in the planning stage for an engineering project to (a) examine patterns of sediment transport, and (b) identify areas susceptible to pollution. This paper illustrates these environmental applications of foram populations around the island of Nevis. Several species associated with elevated carbon levels live on the Leeward coast only. Ammonia sobrina indicates a bay with high pollution susceptibility. The patterns are common to many Caribbean islands, showing that forams are a major investigative tool for projects that impact on the near-shore environment.

Keywords: Foraminifera, Caribbean, coral reef, pollution, seagrass.

1. Introduction

The many different types of creatures living in the sea range in size from enormous whales to organisms so small that they can only be seen with a microscope. One group of microscopic organisms, the Foraminifera (forams; **Figure 1**), is the subject of this note. All forams are either planktonic, spending their lives floating near the sea surface, or benthonic, living on the seafloor. Because planktonics are very rare in shallow, near-shore water, only benthonics are considered here.

Most microscopic organisms are soft-bodied, but forams produce shells that after death are incorporated into seafloor sediments. The shells of these single-celled creatures, although minute (maximum dimension usually 0.5 mm), are so abundant and readily preserved that they form:

- ~0.75% of total marine CaCO₃ [19];
- ~4.8% of global coral-reef carbonate [19];
- ~23% of the beach sands around Hawaii [11]; and
- ~90% of beach sediments around other Pacific islands [23].

Over 1,200 species of foram have been recorded living in the West Indies [10]. Each has adapted to life in a narrow range of environmental conditions. For example, a great many Caribbean species live only on coral reefs, which provide a multitude of different habitats (e.g., reef crest and fore-reef) that are each occupied by different association of species. Some of these species have been illustrated online [16].

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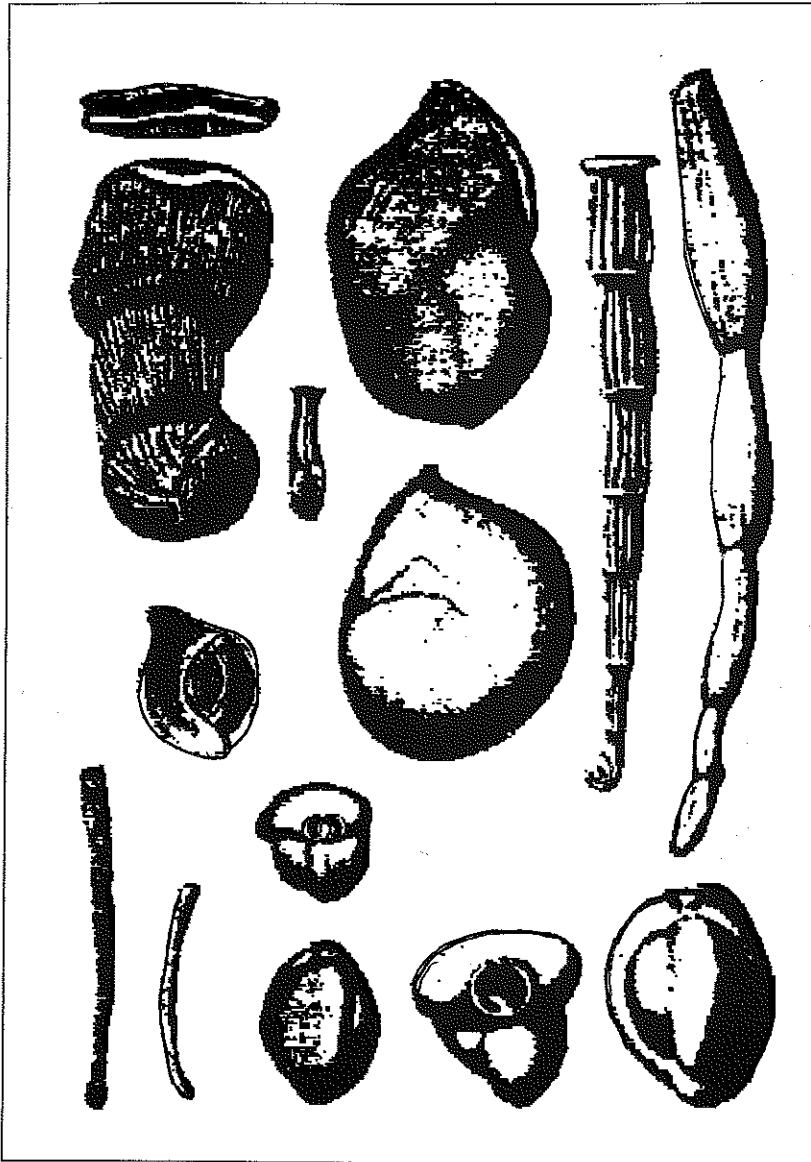


FIGURE 1: *Some Typical Nearshore Forams of the Caribbean Drawn by J.A. Cushman*

Their abundance and diversity gives forams many uses:

- 1) Sediment samples contain shells that have accumulated over at least the past few decades. These record the range of conditions at that site during that time [29].
- 2) The dead shells of species that inhabit restricted environments can, if washed into other environments, be used to track the movement of sediment [4,8-10,20].
- 3) Some species inhabit calm water that contains either little dissolved oxygen or much organic carbon [31, 37]. These forams indicate sites that flush rarely and pollute easily.
- 4) Live populations of forams can be monitored to investigate the impact of shoreline developments such as hotels, golf courses and harbours [e.g., 35].

This paper illustrates the first three of these applications, using as a case study the near-shore

(mostly ≤ 3 m water depth) assemblages of dead forams in sediments around Nevis. Comparison with distributions around Barbuda [2], ~ 100 km to the east, suggests patterns that may be common to all islands in the Lesser Antilles. In these environment-conscious times, such information is useful for all Caribbean projects that impact on the near-shore marine environment.

2. Previous Work

Assemblages of dead forams in near-shore sediments of the West Indies must not be assumed merely to reflect the live assemblages at the same site. The majority of near-shore forams in the nutrient-poor Caribbean Sea live on plants and algae-coated pebbles, rather than in loose, sandy sediments [6,32]. After death, when the shells are washed from the plants and incorporated into the surrounding sediments, much ecological information may be lost: some smaller specimens may be dissolved [22], while currents may transport the shells of large, aerofoil-shaped species [21]. The combined effects of transport and dissolution can result in a death-assemblage (DA) that differs markedly from the associated live assemblage [34]. Nevertheless, DAs provide information of value.

There are no previous studies of the near-shore foram DAs around Nevis, but **Brasier** [2] examined the fauna around Barbuda, ~ 100 km to the east. Using five transects approximately normal to shore and semi-quantitative methods, he suggested that Barbuda is surrounded by three near-shore, foraminiferal DAs:

- A shore-zone DA (0 – 1 m depth) that surrounds the entire island and contains many damaged tests.
- A back-reef DA, between the coral reef and the shore zone on the eastern, windward side of the island.
- A blanket-sand DA on the western, leeward side of Barbuda.

(Because the Trade Winds blow from the east, the eastern coast of all Lesser Antillean islands is called the windward coast, while the western coast is the leeward.)

Studies since **Brasier's** have been more statistical. For example, **Gischler et al.** [10], in a study of three 0 – 40 m E-W-oriented traverses on three carbonate platforms off Belize, Central America, used agglomerative hierarchical cluster analysis. They found this to distinguish four environments:

- Fore-reef areas;
- High-energy reefs with encrusting species;
- Low-energy, platform interiors; and
- Shallow platform interiors.

The study presented here differs from that by **Brasier** [2] in providing quantitative data, and from that by **Gischler et al.** [10] in using a single transect of sample-sites parallel to shore that encircles much of a Caribbean island. It asks:

- Do foraminiferal DAs vary in near-shore environments around the coast of Nevis?
- In particular, is it possible to distinguish the windward (eastern) and leeward (western) coasts based on foraminiferal DAs and to suggest causes for any differences between DAs?
- Do the foraminiferal DAs indicate sediment transport patterns?
- Do the DAs indicate any sites with a high susceptibility to pollution?

3. Study Areas

Nevis (lat. $17^{\circ} 10' N$; long. $62^{\circ} 35' W$; **Figure 2**) is an almost circular, 93 km^2 volcanic island that attains a maximum height of 985 m. Its shoreline comprises a mixture of sandy beaches, brackish lagoons, cliffs and low, rocky shores. Cliffs are primarily located on the eastern and southern coasts, while the most prominent expanse of sand, Pinney's Beach, extends 4 km

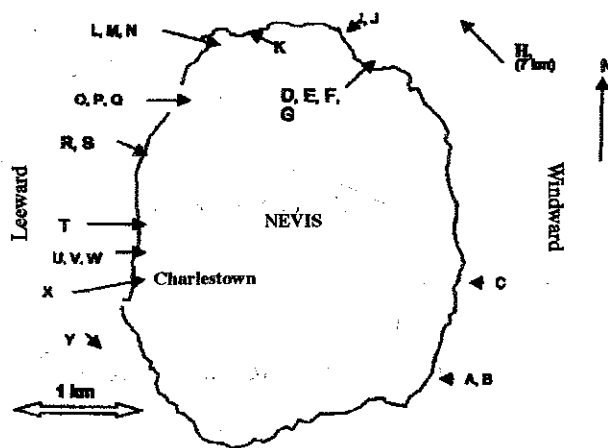


FIGURE 2: Map of Nevis showing Sample Locations

northwards from the main settlement, Charlestown. Smaller beaches occur in Mosquito Bay, Hurricane Cove and Long Haul Bay and at Windward Beach.

The sea around Nevis is tideless. The North Equatorial Surface Current strikes the island from the E to SE and splits into two branches that flow around the northern and southern coasts respectively to collide near Charlestown on the leeward coast. Offshore features comprise bare sand-blankets, fringing- and patch-reefs of coral and algae, and seagrass meadows. Although bare sands and seagrass meadows occur in patches around the entire island, only around Long Haul Bay and Mosquito Bay, on the windward and leeward coasts respectively, do seagrasses encroach into shallow (<3m) water. (In contrast, seagrasses and bare sand are around Barbuda limited respectively to the eastern and western sides of the island [3]). Offshore fringing- and patch-reefs are developed primarily to the north and east of Nevis.

The mean annual temperature on Nevis is 27°C; oceanic temperatures range from 26–29°C. Rainfall is not evenly distributed either across the island or throughout the year; the mean annual rainfall on the eastern, windward coast is ~890 mm, while that on the western coast is ~1,270 mm. Between June and November, Nevis is subject to hurricanes in which rainfall may exceed 305 mm per day and wind speeds exceed 225 km per hour.

4. Materials and Methods

Twenty-five sediment samples were recovered from 12 near-shore (mostly <3 m depth) stations on the northern, eastern (windward) and western (leeward) coasts of Nevis (Figure 2; Table 1). The southern coast

was not sampled. A further sample was taken from Sand Bank Bay (windward coast, South East Peninsula of St. Kitts, ~7 km NW of Nevis) for comparison with those from the windward coast of Nevis. The samples were taken, mostly within 80 m of the shoreline, by recovering the top centimetre of sediment over an area of ~100 cm².

The sediments were dried at ~90°C, then sieved over a 63-micron mesh to remove silt and clay. For most samples, 10 ml of residue yielded ~300 foraminiferal tests, so this volume was picked from each. In some cases, this yielded >300 specimens (e.g., Samples O,P), in others considerably fewer (Sample K.). Species were identified using standard references [1,3,12–15,24,27,30,33].

Several methods are used to distinguish environments when working on forams. The simplest is to record the species in a table in which the samples are arranged geographically, and then “eyeball” the data to see what lives in the different areas. However, this method can be taxing, especially where large numbers of samples or species are involved. This was the case in the present study, in which the 25 samples yielded 9,297 foraminifera belonging to 134 species. (A table of all occurrences is available on request from the author).

Where the data-set is large, statistical methods are used to group samples containing similar assemblages. Cluster analysis (Pearson product moment correlation coefficients, weighted average pair-group method-see [7]) is here used to derive dendrograms that show relationships. Two modes of cluster analysis were conducted:

- Q-mode, which groups samples according to their foram assemblages; and
- r-mode, which reveals associations between foram species.

5. Results

5.1 Notable Species Distributions

Most of the 134 species recovered around Nevis were rare: only 20 each formed >1% of the total recovery (Figure 3). Eyeballing the distributions of these 20 revealed that *Ammonia sobrina* and *Quinqueloculina*

TABLE 1: Sediment Samples, Locations and Their Characteristics, Nevis, West Indies

Sample Number	Location	Sample Number in Wilson [35]	Depth	Comments
A	Windward Beach	WIN1	~1 m	Beneath a patch of seagrass debris
B	Windward Beach	WIN2	~1 m	100 m S of WIN1
C	Huggins' Bay	HB1		Splash pool ~30 cm above sea level
D	Long Haul Bay	LBHE2	1.3 m	Anchor scar within seagrass meadow, 40 m from shore
E	Long Haul Bay	LBHE6	1.7 m	Anchor scar within seagrass meadow, 70 m from shore
F	Long Haul Bay	LBHE15	~1 m	Algal-bound sands within seagrass bed
G	Long Haul Bay	LBHE16	~1 m	Bare sand shorewards of seagrass meadow
H	Nisbette Plantation	PN1	15 cm	Shingle band along strandline
I	Nisbette Plantation	PN2	~0.5 m	Bare sand
J	Sand Bank Bay, St. Kitts	SK:SE5	1.5 m	Bare sand in unvegetated bay
K	Hurrican Cove	HC1	2 m	Reddish-brown, polished sand
L	Mosquito Bay	MB1	20 cm	Taken from strandline at head of bay
M	Mosquito Bay	MB2	1 m	20 m from shore, bare sands
N	Mosquito Bay	MB3	1.5 m	40 m from shore, in sparse seagrass meadow
O	Cades Bay	CB1	1 m	20 m from shore, greyish, fine sands
P	Cades Bay	CB2	3 m	40 m from shore, greyish, fine sands
Q	Cades Bay	CB3	3 m	60 m from shore, greyish, fine sands
R	Mariners' Bay	MA1	1 m	2 m from shore, bare sands
S	Mariners' Bay	MA2	2 m	6 m from shore, bare sands
T	Four Seasons Resort	FS1	1 m	5 m from shore, bare sands
U	Rest Haven	RH1	1 m	20 m from shore, bare sands
V	Rest Haven	RH2	1.5 m	40 m from shore, bare sands
W	Rest Haven	RH4	3 m	80 m from shore, bare sands
X	Gallow's Bay	G1	1 m	5 m from shore, bare sands
Y	400 m west of Fort Charles	N951031	10 m	Bare sand from blow-out within seagrass meadow

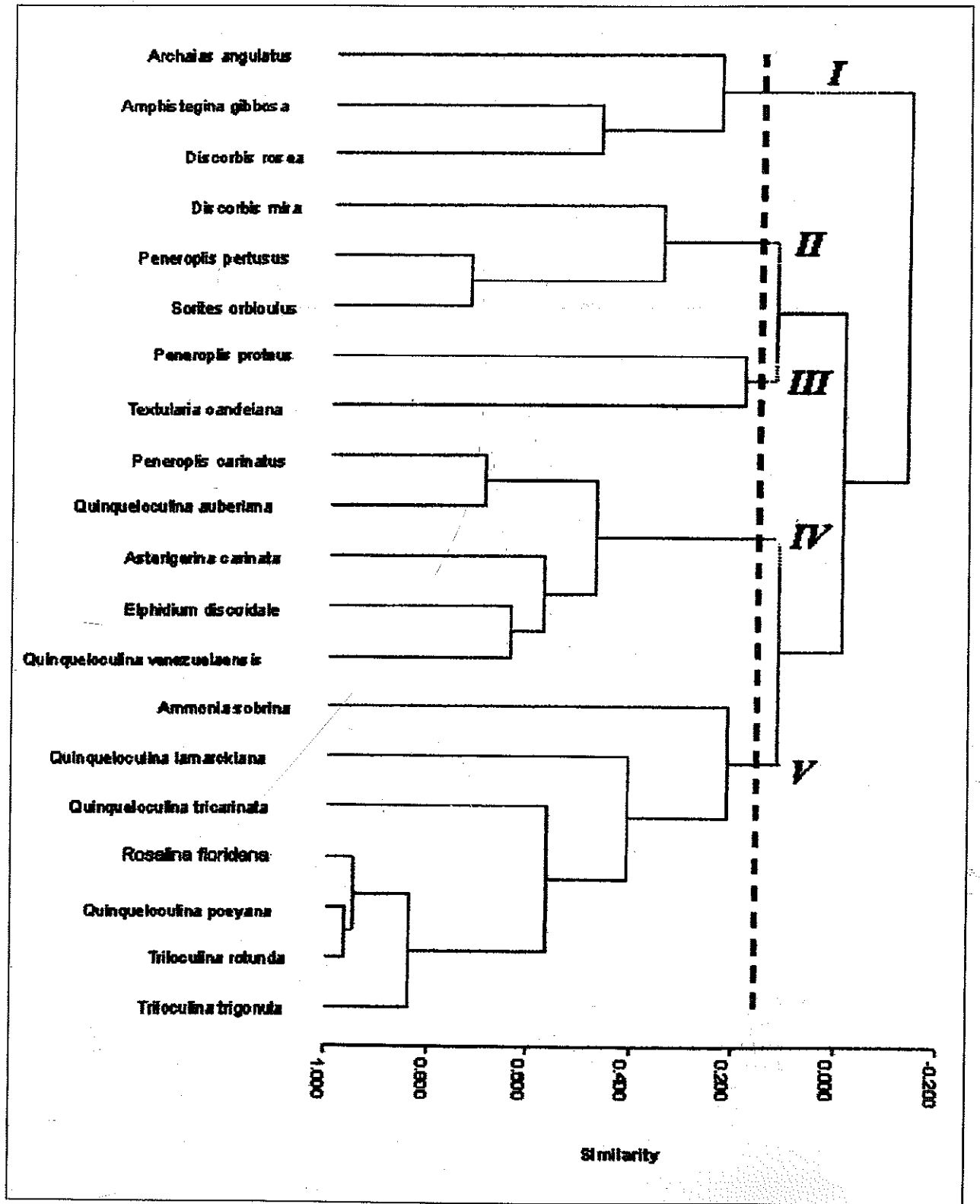


FIGURE 3: *r*-Mode Cluster Analysis of Common Species (>1% of Total Recovery), Weighted Average Pair-group Method and Pearson's Product Moment Correlation Coefficients
 Roman Numerals = Species Associations

auberiana are restricted to the leeward coast. Three rarer (<1%) species are similarly restricted to the leeward coast but widespread along it:

- *Elphidium poeyanum*, 9 samples;
- *Massilina inaequalis*, 5 samples; and
- *Nodobaculariella mexicana*, 9 samples.

Thus, some species can be used to distinguish sediments on the windward and leeward coasts of Nevis. Species of *Ammonia* and *Elphidium* inhabit areas with high organic carbon levels [31], so their presence on the leeward coast of Nevis may reflect the accumulation of organic carbon in calmer water.

The remaining species either do not show any exclusive preference for windward or leeward coasts, or are too rare to be of use in this regard. No widespread species were restricted to the windward coast.

5.2 Q-Mode Cluster Analysis of Sediment Samples

Because cluster analyses based on the most commonly occurring species produce dendrograms similar to those that use the entire fauna [10], only those 20 species forming >1% of the fauna around Nevis were used for cluster analysis. The resulting dendrogram of sediment samples (Figure 4) comprises 6 clusters:

- *Cluster 1* comprises 2 samples (P and Q) from Cades Bay on the leeward coast, while *Cluster 2*, which is closely allied to *Cluster 1*, comprises a third sample (O) from this bay.
- *Cluster 3* contains only a single sample from Windward Beach (Sample A) on the windward coast.

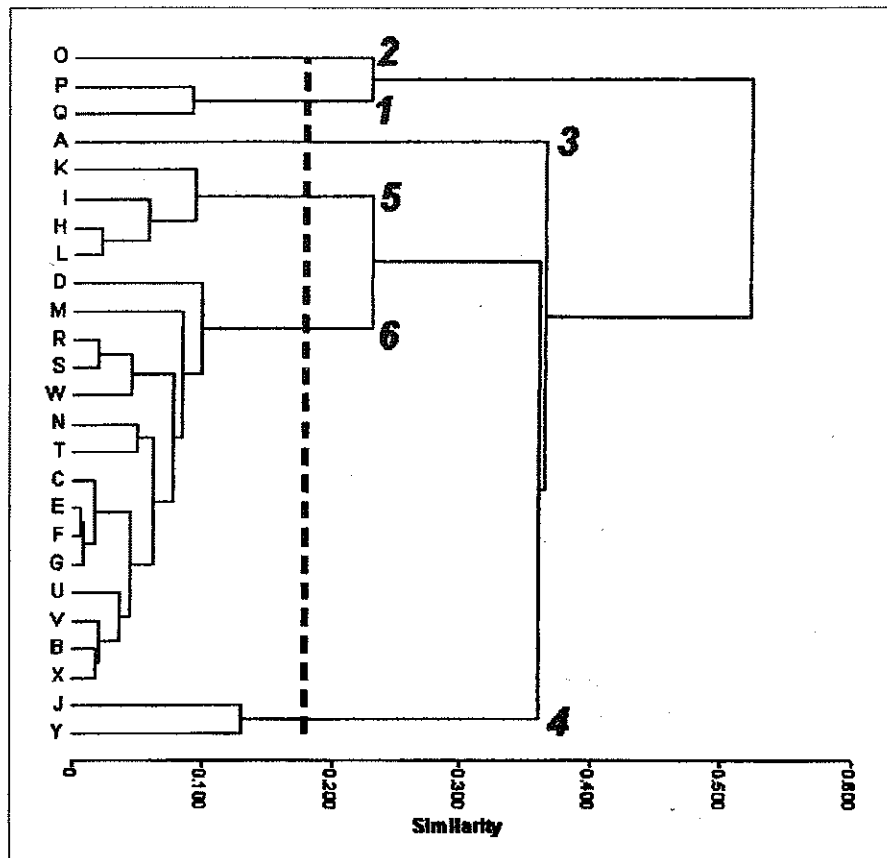


FIGURE 4: Q-Mode Cluster Analysis of Samples based on Absolute Abundance Data of Individual Taxa in the Samples. Weighted Average Pair-group Method and Pearson's Product Moment Correlation Coefficients were used because they produced the Most Readily Interpretable Dendrograms. Only those species forming >1% of the Total Recovery were used. For Sample Codes, See Table 1: Cluster Numbers in Italics

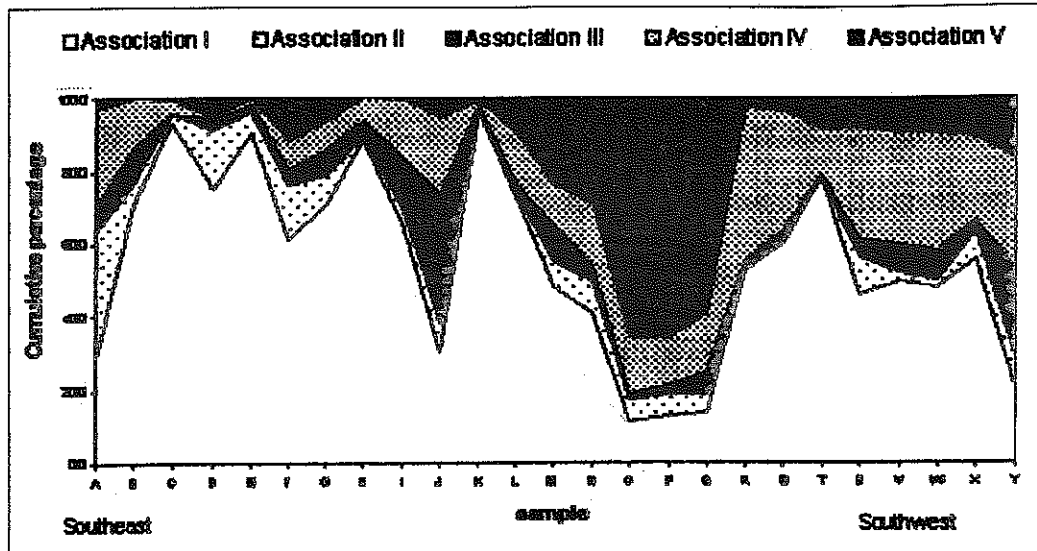


FIGURE 5: The Distribution of Near-shore Foraminiferal Associations around Nevis

- *Cluster 4* comprises two samples: Sample J from Sand Bank Bay, St. Kitts and Sample Y from the leeward coast of Nevis.
- *Cluster 5* contains the three samples from the northern coast of Nevis (Samples H, I and K), together with Sample L from the head of Mosquito Bay, which lies at the northern end of the leeward coast.
- *Cluster 6* groups the remaining 15 samples, which were taken from both the windward and leeward coasts. This cluster indicates that a more-or-less generalised DA surrounds much of the coastline of Nevis.

5.3 r-Mode Cluster Analysis of Foraminiferal Associations

Associations between the 20 most common species were examined using r-mode cluster analysis (Figure 3). Five associations (distributed as shown in Figure 5) are recognised:

- *Association I* is abundant on the wind-swept eastern and northern coasts of Nevis (samples A through K), but is also abundant at the head of Mosquito Bay (Sample L), where it comprises 78.5% of the fauna. It is less common elsewhere on the leeward coast (Samples M through Y, mean = 41.4%),

and rarest in Cades Bay (*Cluster 1*, mean = 12.3%). Although this association is common around much of Nevis, some species comprising it prefer to live in windward locations in association with coral reefs [27]. The abundance of this association in back-reef sediments on the windward coast shows that sediments on the windward coast are transported towards the shore during storms [cf. 20].

- *Association II* is most abundant on the windward coast. It forms 34.8% of the fauna in *Cluster 3* from Windward Beach, and >10% of the fauna in two of the four samples from Long Haul Bay, where it was abundant in sediment samples taken within the meadow, but rare in bare sands adjacent to it. Kloos [17] reported a similar association with seagrasses. Because the species in this association are discoidal and easily transported [21], *Association II* is restricted to low energy areas on the windward coast. Baffling by seagrasses in Long Haul Bay may encourage the preservation of this assemblage, but rapid burial may also play a role: tests of some *Association-II* species are destroyed by boring algae that would be unable to colonise buried tests [18].

- *Association III* is most abundant in *Cluster 4*. It is not possible to suggest what ecological factors control the distribution of this assemblage, which is common in shallow-water sands on the windward coast of St. Kitts and deep-water (~10 m) sands on the leeward coast of Nevis.
- *Association IV* is a major component of the sample in *Cluster 3* (Sample A, windward coast, 25.6%), but is most widespread on the leeward coast, where the mean concentration is 23.2%. The somewhat antithetic distribution of *Associations I* and *IV* provides some support for **Brasier's** [2] suggestion of distinct windward and leeward assemblages.
- *Association V* is most abundant in sheltered embayments with seagrass beds and high levels of organic carbon. Although common (11.5%) in one sample from Long Haul Bay, and in the leeward samples collected south of Charlestown, it is most strongly developed to the north-west of Nevis: in Mosquito Bay it forms ~29% of the assemblage, while in Cades Bay (*Clusters 1* and *2*) it forms ~66%.

6. Summary and Conclusions

Foraminiferal DAs in 25 samples from near-shore (mostly 0-3 m) waters around Nevis comprised 134 species of foram, but only 20 formed >1% of the total recovery. Some of the rarer species (*Elphidium poeyanum*, *Massilina inaequalis* and *Nodobaculariella mexicana*) are limited to the leeward coast, but widespread along it, as were two of the 20 common species (*Ammonia sobrina* and *Quinqueloculina auberiana*). These five species, which distinguish leeward assemblages from windward, reflect either lower wave-energy or more abundant organic carbon along the Leeward coast.

However, cluster analysis of samples conducted using common species only, did not clearly distinguish windward and leeward DAs. This suggests

that Nevis is surrounded by a general, circum-island DA. This is modified locally by the removal or addition of species.

The removal of species from the DA may be due to either organic activity [18] or abiotic winnowing, breakage or dissolution [21]. Of these processes, winnowing is the most obvious around Nevis: sediment samples from the north coast, which form a discrete cluster, contain a winnowed remnant of the generalised assemblage. The sand at the head of Mosquito Bay was washed westward from this north coast DA during hurricanes.

The addition of species to the DA may reflect:

- An influx of specimens transported from elsewhere. For example, on the windward coast, the shells of some species are transported shoreward from coral reefs during storms.
- The addition of species to the local live assemblage. For example, on the Leeward coast, the generalised fauna is augmented by species adapted to lower energy, organic carbon-rich environments.

The sheltered embayment at Cades Bay (leeward coast) contains a distinctly different DA that shows that this bay is rarely flushed and has a high susceptibility to pollution.

Q-mode cluster analysis revealed five foraminiferal associations. These did not show a one-to-one correspondence with the r-mode clusters of sediment samples. *Association I* was of predominantly windward aspect, while *Association IV* was more strongly developed on the more sheltered leeward coast. *Association II* was recovered from low-energy environments on the windward coast, where it was allied with seagrass meadows, while *Association V* was characteristic of low-energy, leeward embayments with a high susceptibility to pollution.

Over the last few decades, members of the Class Foraminifera have become an important tool in the assessment and monitoring of environmental impacts [28]. The results of this study around Nevis have implications for near-shore projects around all Caribbean islands. They show how forams reveal:

- (a) Pathways of sediment transport and
- (b) Low-energy sites that have high pollution susceptibility.

As is evidenced by the few species names used in this report, working with micro-organisms requires considerable training. This need not be a deterrent to application in engineering matters: most universities teaching geoscience (including The University of the West Indies) will have a qualified micropalaeontologist on staff who is able to conduct the work. It is hoped that the results presented here will encourage the use of benthonic forams as aids in selecting sites suitable for development.

Acknowledgements

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