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# The Impact of Dumping Coarse Metalliferous Waste on the Benthos in Evoikos Gulf, Greece

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**Dumping of coarse metalliferous wastes, at about 75 m depth had mostly indirect effects on the benthic fauna, through changing the particle size composition of the sediment. Coarse polluted sediments had greater number of species and individuals and higher diversity than fine sediments but lower than clean sediments of similar particle size. The stability of the community decreased as indicated by the substitution of its characteristic species by others with wide ecological requirements.**

Relatively little is known about the disturbance caused by industrial solid wastes on marine benthic communities compared to the impact of other forms of pollution, such as organic enrichment. The effects on the bottom fauna of china clay deposits have been studied in Cornwall by Howell & Shelton (1970) and Probert (1975). The impact of fly ash on benthos off the Northumberland coast was studied by Bamber (1983). Bourcier (1969) and Bourcier & Zibrowius (1973) have studied the effects of 'red mud'—residual waste from the extraction of aluminium from bauxite. Biological effects of mine waste disposal are reviewed by Ellis (1987). In most recorded cases the dumped material was very fine, finer than the natural sediment and, usually, tailings were discharged to shallow waters or to the intertidal. The present paper describes the effects on the benthic communities of coarse metalliferous residue (particles greater than 200 μm) dumped at depths of about 75 m.

## Materials and Methods

The dumping site is near Larymna, in the Southern part of North Evoikos Gulf, Greece (Fig. 1). The dumped material is the residue of laterite ore after the

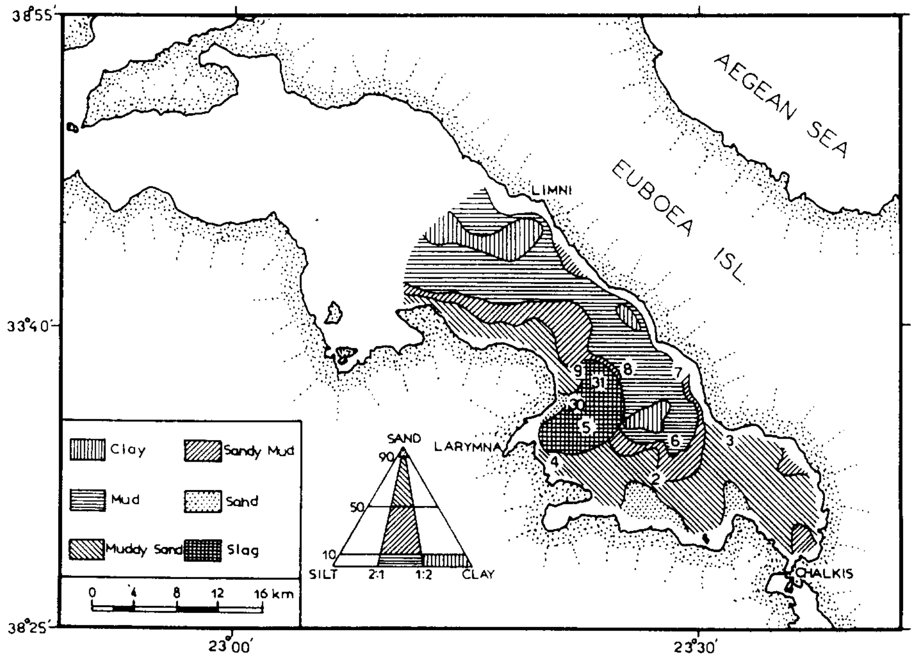

**Fig. 1** Position of sampling stations.

extraction of nickel. The smelter is located in Larymna and the ore is extracted locally and at the neighbouring island of Euboea. Dumping is done by a barge at a rate of approximately 6 t $day^{-1}$. The mean diameter of the slag grains is 0.25 φ and the sorting coefficient is 0.7 φ (Voutsinou-Taliadouri & Varnavas, 1987).

Benthic samples were collected in July and November 1983 and April 1984. In the first survey eight stations (Nos 2–9) were sampled while another two stations (30, 31) on the spoil patch were subsequently added. The sites were chosen to include polluted (5, 9, 30, and 31) and clean (2, 3, 4) stations of approximately the same grain size. Some clean stations (6, 7, 8) with finer sediments were also included, since the sedimentology of the area showed that dumping also took place on fine sediments. Position fixing was by radar range and bearing.

Two samples at each station, taken with a 0.1 $m^2$ van Veen grab, were sieved through a 1 mm mesh sieve, stained with Rose Bengal and preserved in 4% formalin. The particle size distribution of sediment was carried out only once, in July, by geologists of the National Centre for Marine Research in Athens. The pipette method was used and the nomenclature is after Folk (1954). The percentage of slag in the sediment was estimated following the method described in Parfenoff *et al.* (1970).

The diversity of the fauna was calculated by the Shannon-Wiener diversity index (Shannon & Weaver, 1963). The ordination was performed using the program DECORANA (Hill, 1979) in the Laboratory of the Marine Biological Association of the UK, in Plymouth. The option of Reciprocal Averaging with rare species downweighted was chosen as best describing the data. Species found only at one station and in numbers lower than three individuals were excluded from the calculations.

## Results

### *Sediments*

The sediment characteristics and the depths of the sampling stations are shown in Table 1. Stns 2, 3, and 4 were clean muddy sand stations, the percentage of sand ranging from 62 to 89%. Only Stn 2 had a small amount of slag (3.4%) which, however, appeared weathered Stns 5, 9, 30, and 31 were also coarse but with a high percentage of slag. The sediment in Stns 9 and 31 was muddy sand but in Stns 5 and 30 it consisted almost entirely of sand-sized particles of slag. Finally, Stns 6, 7, and 8 were muddy with sand ranging from 1 to 5% and only a negligible presence of weathered slag in station 6.

### *Benthic fauna*

In total 257 species were identified of which 134 were polychaetes, 50 molluscs, 41 crustacea, 14 echinoderms, and 18 belonged to minor taxonomic groups. The most widely distributed were the polychaetes *Chaetozone setosa,* found in 75% of the stations, *Glycera convoluta* in 79%, *Tharyx heterochaeta* in 71% and *Tharyx marioni* in 82% of the stations. Of those only the two species of *Tharyx* were found in relatively high abundances in the muddy stations (6, 7, and 8). *Tharyx marioni,* for example, had a density of 210 indiv. $m^{-2}$ in Stns 6 and 7 in November and 315 indiv. $m^{-2}$ in Stn 7 in April. Most other species had low abundances between 3–35 indiv. $m^{-2}$. An exception was the presence of the bivalves *Kellyella miliaris* and *Leptaxinus ferruginosus* in high numbers in the polluted stations. *Kellyella miliaris* had a density of 590 indiv. $m^{-2}$ in Stn 5 in June and 455 indiv. $m^{-2}$ in Stn 31 in November. *Leptaxinus* had higher densities in Stn 31 with 410 indiv. $m^{-2}$ in November and 285 indiv. $m^{-2}$ in April.

**TABLE 1**

Characteristics at sampling stations.

| Stations | Depth in M. | Sediment type | Sand % | Silt % | Clay % | Slag % |
|---|---|---|---|---|---|---|
| 2 | 58 | muddy sand | 89 | 5 | 6 | 3.4 |
| 3 | 51 | muddy sand | 62 | 16 | 22 | 0.0 |
| 4 | 69 | muddy sand | 73 | 14 | 13 | 0.1 |
| 9 | 80 | muddy sand | 61 | 18 | 21 | 47.1 |
| 31 | 83 | muddy sand | 65 | 12 | 23 | 79.8 |
| 5 | 75 | sand (slag) | 95 | 3 | 2 | 97.6 |
| 30 | 68 | sand (slag) | 98 | 1 | 1 | 95.8 |
| 6 | 75 | mud | 5 | 37 | 58 | 0.7 |
| 7 | 84 | mud | 1 | 40 | 59 | 0.0 |
| 8 | 85 | mud | 3 | 36 | 61 | 0.0 |

Clear-cut communities as those described for the Mediterranean by Peres (1967) were not found. Some species characteristic of the Coastal Terrigenous Mud community such as *Labidoplax digitata, Nephtys hystricis, Laonice cirrata, Jaxea nocturna* were present but they constituted only a very small percentage of the total number of animals. Conversely, species of wide ecological requirements and indicators of environmental perturbation such as *Chaetozone setosa, Lumbrineris latreilli, Prionospio malmgreni* (FAO, 1986) were a lot more abundant.

Table 2 shows the number of species and individuals, the diversity and the evenness for each sampling station and period of sampling. There are obvious differences between polluted and clean coarse stations and between coarse and fine clean stations. Clean coarse stations (2, 3, 4) have higher numbers of species than both polluted (5, 9, 30, 31) and fine stations (6, 7, 8). The same applies to the number of individuals with the exception of Stns 5 in June and 31 in November and April. This is due to the high densities of *K. miliaris* and *L. ferruginosus* at these stations. Similarly, the diversity was higher in the clean coarse stations and lower in the polluted and fine stations. To illustrate the effect of grain size and slag on the diversity, the latter is plotted against the percentage of sand sized particles in the sediment for the ten stations, in Fig. 2. It can be seen that clean Stns 2, 3, and 4 have definitely higher diversities than the polluted Stns 9, 5, 30, and 31 of approximately the same grain size, while the diversity of the polluted stations falls within the same range as that of clean but fine Stns 6, 7, and 8. In fact, some polluted stations show greater diversity than the fine ones.

The ordination of stations produced three axes with eigenvalues 0.315, 0.281, and 0.259 respectively. Plotting of axis 1 against axis 2 in Fig. 3, grouped all the fine (6, 7, and 8) stations together, irrespective of season. This group has high scores on axis 1, while the

TABLE 2
Community characteristics of each station and period of sampling.

| | July 1983 | | | | November 1983 | | | | April 1984 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | No. sp. 0.2 $m^{-2}$ | No. ind. $m^{-2}$ | Diversity | Evenness | No. sp. 0.2 $m^{-2}$ | No. ind. $m^{-2}$ | Diversity | Evenness | No. sp. 0.2 $m^{-2}$ | No. ind. $m^{-2}$ | Diversity | Evenness |
| Coarse clean | | | | | | | | | | | | |
| 2 | 81 | 1595 | 5.5026 | 0.8948 | 52 | 650 | 5.1482 | 0.9311 | 74 | 1265 | 5.3715 | 0.8918 |
| 3 | 81 | 1625 | 5.2908 | 0.8604 | 70 | 945 | 5.0159 | 0.8437 | 62 | 930 | 5.0895 | 0.8812 |
| 4 | 58 | 795 | 5.2245 | 0.9195 | 56 | 860 | 5.1554 | 0.9152 | 59 | 1015 | 4.7953 | 0.8404 |
| Coarse polluted | | | | | | | | | | | | |
| 9 | 33 | 370 | 4.0560 | 0.8289 | 13 | 130 | 3.3238 | 0.9260 | 30 | 420 | 4.2665 | 0.8964 |
| 31 | – | – | – | – | 42 | 1935 | 3.9839 | 0.7617 | 42 | 1040 | 4.0104 | 0.7667 |
| 5 | 25 | 970 | 2.4610 | 0.5463 | 23 | 310 | 3.7288 | 0.8498 | 18 | 250 | 3.4129 | 0.8438 |
| 30 | – | – | – | – | 15 | 210 | 3.3030 | 0.8716 | 14 | 245 | 2.2971 | 0.8007 |
| Fine clean | | | | | | | | | | | | |
| 6 | 16 | 270 | 3.2250 | 0.8312 | 22 | 540 | 2.9835 | 0.6897 | 19 | 540 | 2.7468 | 0.6666 |
| 7 | 19 | 420 | 2.4972 | 0.6061 | 16 | 285 | 3.2653 | 0.8416 | 18 | 820 | 2.6254 | 0.6491 |
| 8 | 28 | 295 | 4.1685 | 0.8939 | 26 | 505 | 2.9310 | 0.6429 | 23 | 375 | 3.7258 | 0.8491 |

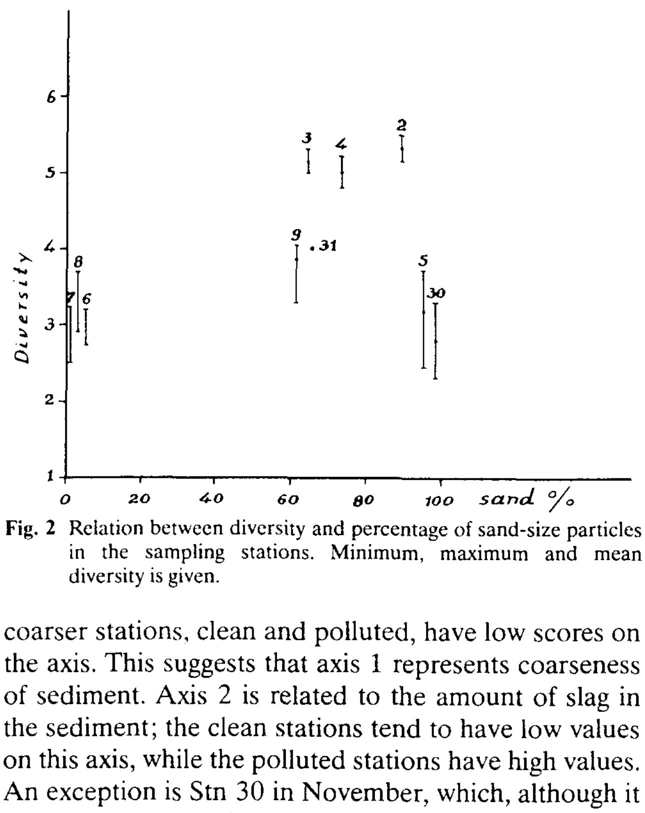

Fig. 2 Relation between diversity and percentage of sand-size particles in the sampling stations. Minimum, maximum and mean diversity is given.

coarser stations, clean and polluted, have low scores on the axis. This suggests that axis 1 represents coarseness of sediment. Axis 2 is related to the amount of slag in the sediment; the clean stations tend to have low values on this axis, while the polluted stations have high values. An exception is Stn 30 in November, which, although it contains a very high percentage of clay (Table 1) appears low in axis 2. This is possibly due to sampling error caused by inaccuracy in positioning the ship. As seen in Fig. 1, Stn 30 is not only at the edge of the slag patch but also at the transition between sand and muddy sand in the undisturbed sediment. Thus, small changes in the position of the boat, may result in major differences in the samples obtained. It is interesting to note that between the 15 species collected in November and the 14 species collected in April there were none in common.

Axis 1 plotted against axis 3 is shown in Fig. 4. Axis 3 may represent environmental instability, more unstable stations (e.g. Stns 5 and 30) having higher values on it. Indeed, 17% of the total number of animals in Stn 30 in November (with high score on axis 3) are indicators of instability such as *Schistomeringos rudolphi* and 30%, including *Chaetozone setosa* and *Pectinaria auricoma* are characteristic of the transitional zone between polluted and unpolluted environments (Pearson, 1975). Another 50% are species of wide ecological requirements, such as *Tharyx marioni* and *T. dorsobranchialis*. Station 9 in November is dominated by *S. rudolphi* and *Polydora*, species of which are known as pollution or perturbation indicators (FAO, 1986).

## Discussion

It is believed that dumping of mine residue (tailings) has principally a mechanical effect on the benthic animals, either directly killing them or making the environment so unstable that few species are able to survive (Carter, 1975). Other problems may arise from increased turbidity and consequently decreased illumination and from the toxicity of the dumped materials (Ellis, 1987).

Some of the effects of tailings are comparable to those of organic pollution. The characteristic zonation described by Bellan (1967) for organically enriched areas, with the nearly azoic area close to the pollution source, followed by a polluted zone with high numbers of individuals and a few species, apply also to pollution by solid industrial wastes such as china clay (Probert, 1975) and red mud (Bourcier, 1969). In the present case no completely azoic area was found, not even at the centre of the spoil ground. Evans *et al.* (1975) mention that in Rupert Inlet, Canada, the benthos was completely obliterated, only where the mine waste amounted to 50 cm or more. Besides, it is known that some species have the ability to return to the surface after burial, and polychaetes in general (Goyette & Nelson, 1977) are more resistant to burial than other benthic organisms. Presumably an azoic area would be found here too if the sampling happened to take place immediately or very soon after dumping on the spot, before recolonization of the area. Seasonal recolonization by settling pelagic larvae is known to occur in tailing beds in Rupert Inlet (Ellis & Heim, 1985; Ellis, 1987) while artificial tailing substratum experiments (Taylor, 1986; Ellis & Taylor, in press) showed development of a diverse community on the sea bed within 12 months. Increased abundance was observed in two, otherwise rare, species of the order Lucinacea, *Leptaxinus ferruginosus* and *Kellyella miliaris*. Unlike other species, such

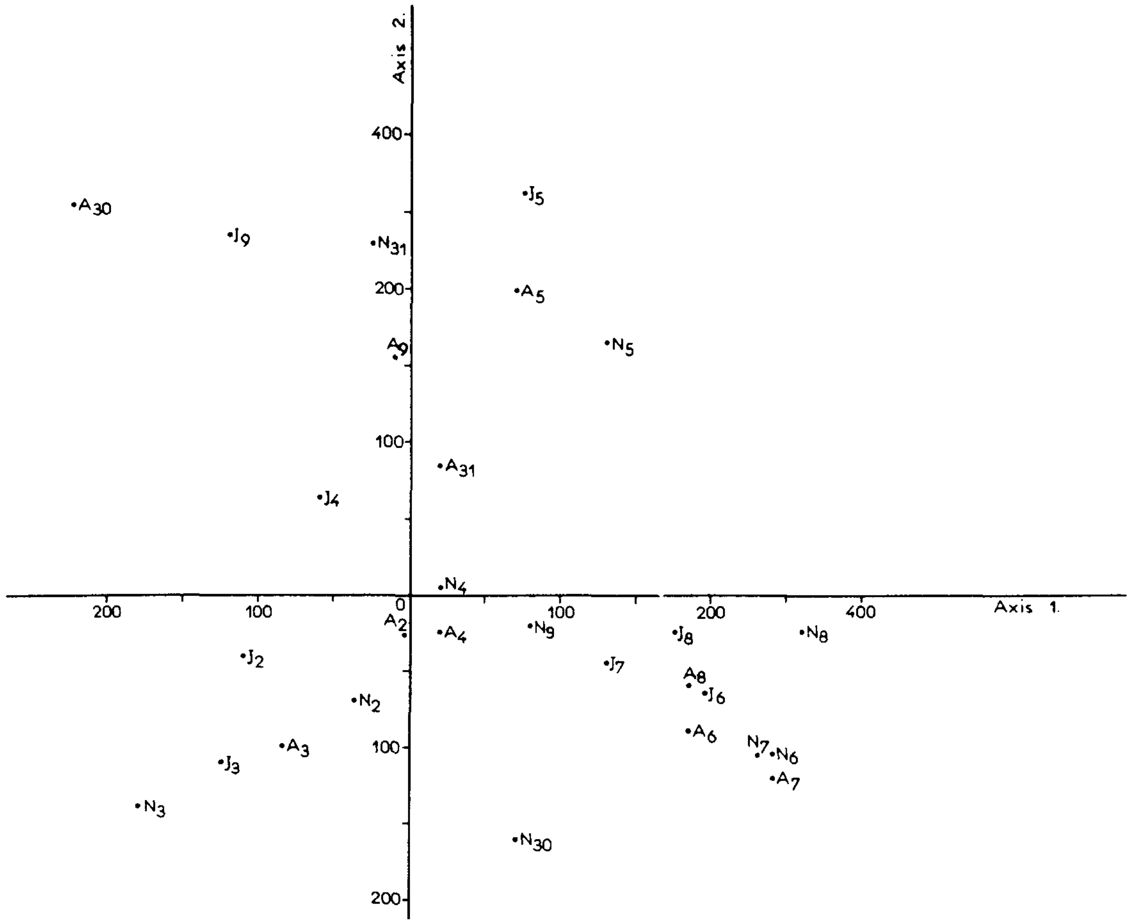

**Fig. 3** Ordination of stations along axes 1 and 2. J: July, N: November and A: April sampling.

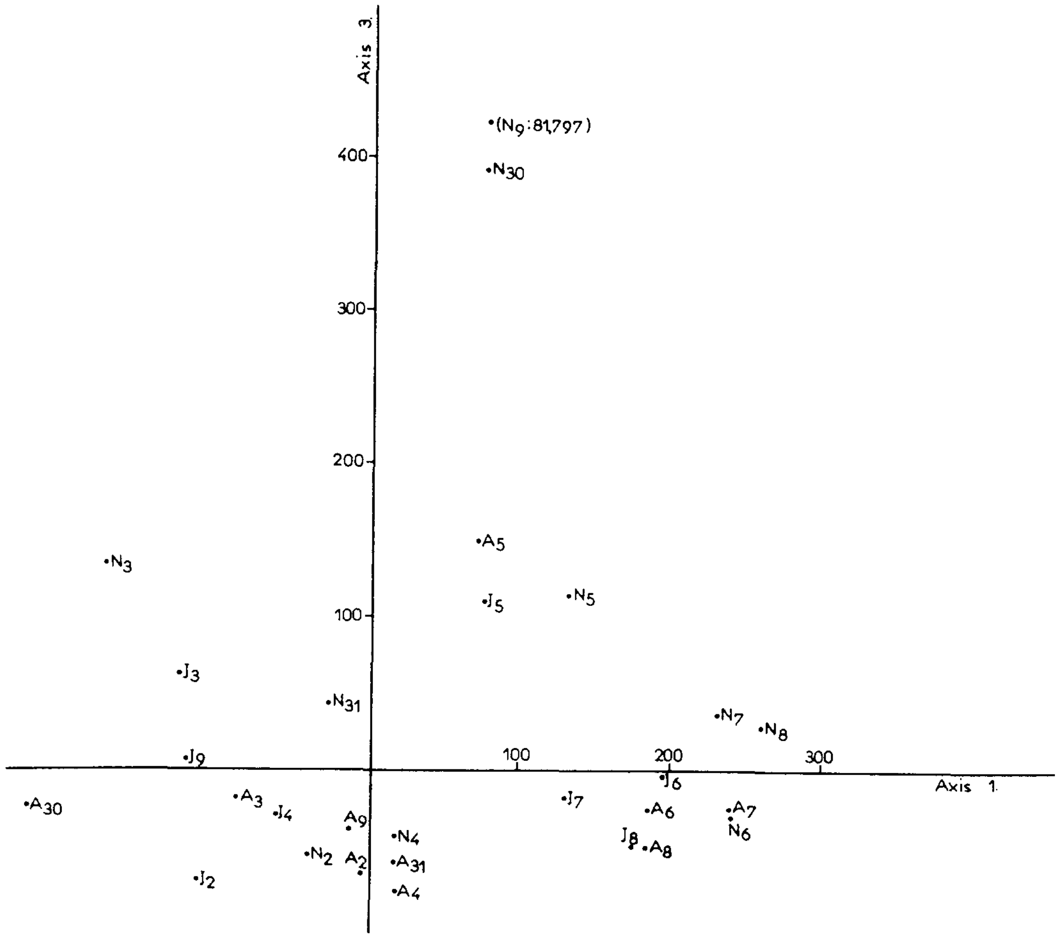

**Fig. 4** Ordination of stations along axes 1 and 3. J: July, N: November and A: April sampling.

as *Capitella capitata,* which owe their increased densities in disturbed areas to their better adaptive strategy (Gray, 1981), the two above species may actually be favoured by the iron in the dumped material. It is known from the literature (Tebble, 1966) that *L. ferruginosus* accumulates grains of iron on its shell. There is no specific mention for *K. miliaris* but as it belongs to the same order of which other members are known to collect iron grains, it may be inferred that its high abundance in the area is not accidental.

Dumping of solid wastes in Larymna had also marked effects on the community level. Compared with clean stations of similar sediment size, the polluted stations had, in general, lower numbers of species and individuals and lower diversity. On the other hand, the species abundance and density as well as the diversity was comparable and some times greater than that of fine sediments. In other cases (Probert, 1974; Bourcier, 1969) dumping of industrial wastes caused a decrease in diversity, but there the dumped material was finer than the native sediment. The increase of diversity in the polluted stations in Larymna should be attributed to the admixture of coarse slag with the natural muddy sediments. As is well documented in the literature (Gray, 1974), mixed sediments have higher diversity than homogeneous, coarse, or fine sediments. The above emphasises the need for caution in the application of a diversity index as a measure of pollution with the assumption that a pollutant always results in lower density. The definition of pollution by Patric (in Stirn, 1981) as "anything which brings about a reduction in the diversity of aquatic life and eventually destroys its balance" would only be partly correct in the cases where coarse material is dumped and mixed with underlying fine sediments.

In Larymna, in spite of the increase in diversity, the balance of the community is disturbed and its instability increased. Indeed, the area did not support any of the typical communities of the Mediterranean as defined by Peres (1967). Most of the characteristic species belonged to the community of Coastal Terrigenous Muds (CTM). This community is very well represented in other Greek areas such as the Patraikos Gulf (Bogdanos & Nicolaidou, 1985) and the Amvrakikos Bay (Nicolaidou *et al.*, 1983). Even in Evoikos itself, a few miles to the north of Larymna, Nicolaidou & Symboura (1985) found that the polychaete species characteristic of this CTM community amounted to as much as 64% of the total polychaete fauna. In Larymna this percentage ranged from 0.3 to 4.8% at different stations while there was a dominance of species with wide ecological requirements, such as *Lumbrineris gracilis,* the two species of *Tharyx* already mentioned, and *Venus ovata.* The replacement of characteristic species by species with wide ecological requirements is considered by Bellan *et al.* (1985), as an indication of instability. A difference in stability between clean and polluted sites was also indicated by the ordination of stations.

Toxic effects of the slag due to its constituent composition were not obvious. If there are such effects they must be less important than the particle size of the tailings, as shown by the higher number of species and diversity in the coarse, polluted stations than in the fine, clean ones. Thus, dumping of solid industrial wastes in Larymna had mostly indirect effects on the benthic organisms through changing the particle size composition of the sediment and icnreasing the instability of the environment.

Our thanks are due to the geologists of the National Centre for Marine Research in Athens who performed the grain size analyses and constructed the sediment map. Also to Dr Linda Maddock of the Marine Biological Association in Plymouth who assisted us with the computing.

Bamber, R. N. (1983). The Benthos of a Marine Fly Ash dumping ground. Central Electricity Generating Board, Leatherhead, Surrey. Lab. Rep. No. TPRD/L/2414/R 82.

Bellan, G. (1967). Pollution et peuplements benthiques sur substrat meuble dans la region de Marseille. Deuxième partie. L'ensemble portuaire marseillais. *Rev. inter. Oceanogr. med.* **VIII**, 51–95.

Bellan, G., Bourcier, M., Picard, J., Salen-Picard, C. & Stora, G. (1985). Conséquences structurelles dues aux perturbation affectant les biocenoses benthiques Méditerranéen de substrat meuble. *Rapp. Comm. int. Mer. Médit.* **29**, 215–221.

Bogdanos, C. & Nicolaidou, A. (1985). The offshore benthic fauna of the Patraikos Gulf (Greece). *Biologia Gallo-hellenica,* **X**, 31–41.

Bourcier, M. (1969). Ecoulement des Boues Rouges dans le Canyon de la Cassidaigne (Décembre, 1968). *Tethys.* **3**, 779–782.

Bourcier, M. & Zibrowius, H. (1972). Les "Boues Rouges" déversées dans le Canyon de la Cassidaigne (region de Marseille). Observations en soucoupe plongeante SP 350 (Juin 1971) et résultats des dragages. *Tethys* **4**, 811–842.

Carter, L. (1975). Disposal of wastes to tidal waters. In *Minerals and Environment* (M. J. Jones, ed.), pp. 149–157. Barnes Harris Associates.

Ellis, D. V. (1987). A decade of environmental impact assessment at marine and coastal mines. *Mar. Mining* **6**, 385–417.

Ellis, D. V. & Heim, C. (1985). Submersible surveys of benthos near a turbidity cloud. *Mar. Pollut. Bull.* **16**, 197–203.

Ellis, D. V. & Taylor, L. In press. Biological Engineering of marine tailing beds. In *Management of Mine Tailing and Dredged Material* (W. Salomons & U. Foerstner, eds), pp. 000–000. Springer, Berlin.

Evans, J. B., Ellis, D. V. & Pelletier, C. A. (1973). The establishment and implementation of a monitoring program for underwater tailing disposal in Rupert Inlet, Vancouver Island, British Columbia. In *Tailing Disposal Today.* Proceedings of the first International Tailing Symposium, Tucson, Arizona, October 31–November 3, 1971 (C. L. Alpin & G. O. Argall, eds), pp. 512–552. Miller Freeman Publications.

F.A.O. (1986). The effects of pollution on marine ecosystems. FIRI/R 352.

Folk, R. L. (1954). Distinction between grain size and mineral composition in sedimentary rock nomenclature. *J. Geol.* **62**, 334–359.

Goyette, D. & Nelson, H. (1977). Marine environmental assessment of mine waste disposal into Rupert Inlet, British Columbia. In *Environmental Protection Service, Pacific Region. Fisheries and Environment Canada.* Report EPS PR-77-11.

Gray, J. S. (1974). Animal-sediment relationship. *Oceanogr. mar. Biol. ann. Rev.* **12**, 223–261.

Gray, J. S. (1981). *The Ecology of Marine Sediments. An Introduction to the Structure and Function of Benthic Communities.* Cambridge Studies in Modern Biology, 2. Cambridge University Press, UK.

Hill, M. O. (1979). DECORANA—A fortran program for detrended correspondence analysis and reciprocal averaging. Cornell University, Ithaca, New York.

Howell, B. R. & Shelton, R. G. J. (1970). The effect of china clay on the bottom fauna of St. Austell and Mevagissey Bays. *J. mar. biol. Ass. U.K.* **50**, 593–607.

Nicolaidou, A. & Symboura, N. (1985). The Polychaete Fauna of Northern Evoikos Gulf. *Rapp. Comm. int. Mer Medit.* **29**, 227–228.

Nicolaidou, A., Moraitou-Apostolopoulou, M. & Ignatiades, L. (1983). A survey of estuarine benthic, zooplanktonic and phytoplanktonic communities of Amvrakikos Gulf, Ionian Sea. *Mar. Ecol.* **4**, 197–209.

Parfenoff, A., Pomerol, C. & Tourenq, J. (1970). *Les Mineraux en grains: Methodes d'etude et de determination.* Masson et Cie, Paris.

Pearson, T. H. (1975). Benthic ecology of Loch Linnhe and Loch Eil, a sea-loch system on the West coast of Scotland. IV. Changes in the benthic fauna attributable to organic enrichment. *J. Exp. mar. Biol. Ecol.* **20**, 1-41.
Peres, J. M. (1967). The Mediterranean Benthos. *Oceanogr. mar. Biol. ann. Rev.* **5**, 449-533.
Probert, P. K. (1975). The bottom fauna of china clay waste deposits in Mevagissey Bay. *J. mar. biol. Ass. U.K.* **55**, 19-44.
Shannon, C. E. & Weaver, W. (1965). *The Mathematical Theory of Communication.* Urbana University Press, Illinois.
Stirn, J. (1981). *Manual of Methods in Aquatic Environmental Research. Part 8—Ecological Assessment of Pollution Effects.* FAO Fish. Tech. Pap., 209.
Taylor, L. (1986). Marine macrobenthic recolonization of mine tailings in Rupert Inlet. M.Sc. Thesis, British Columbia University, Victoria.
Tebble, N. (1966). *British Bivalve Sea-shells.* H.M.S.O., Edinburgh.
Voutsinou-Taliadouri, F. & Varnavas, S. P. (1987). Marine mineral resources in the Eastern Mediterranean Sea. II. An iron, chromium and nickel deposit in the Northern Euboikos Bay, Greece. *Mar. Mining* **6**, 259-290.
Wong, M. H., Chan, K. C. & Choy, C. K. (1978). The effect of the iron ore tailings on the coastal environment of Tolo Harbour, Hong Kong. *Environ. Res.* **15**, 342-356.

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# Analytical Results: How accurate are they? How accurate should they be?

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**Chemical analysis contributes noise to the process of observing contaminants in the environment. This noise is characterized by the average distance from the true value (bias) and its standard deviation (precision). Bias is more damaging than poor precision. Both can be controlled through a continuous programme of analytical quality control (AQC), firstly within a laboratory, and secondly between laboratories. For AQC to be meaningful, targets for analytical performance must be set. Simple statistical results are demonstrated using data from several sources, particularly to the results for lead analysis from a recent ICES intercalibration exercise, where the average accuracy was 33%.**

Figure 1 shows a hypothetical distribution of lead in a population. In what follows, 'statistical sample' refers to a collection of sampling units drawn from this population, 'sample' to a particular sampling unit, and 'result' to the concentration/load measured in a sample. A 'sampling unit' is the material prepared for chemical analysis, constructed from one or more organisms.

Knowing this distribution allows all sorts of questions to be answered: e.g. how likely is it that results will be above some critical level? What is the average value? What value should be exceeded only 1% of the time? And so on. Of course, the true distribution is never known and inferences must be made on the basis of a statistical sample. The uncertainty in these inferences will depend on the size of the statistical sample and the way it was taken.

There is a further source of uncertainty however, arising from the measurement technique—the analytical method. If an analysis is repeated on a particular sample, the results will not be identical. Measuring and controlling this source of variability is called analytical quality control (AQC). The main features of AQC can be demonstrated using simple statistical techniques. Cheeseman & Wilson (1978), Youden (1967) and Booth (1979) give a more advanced introduction to the statistical theory of AQC for chemists.

Figure 1 also shows two samples drawn from the hypothetical population. The true concentration of the first sample is 10 mg $kg^{-1}$. Drawn above this value is a second distribution function, representing the variability introduced by storage, preparation, and the analytical method itself. This distribution has been portrayed by a Normal distribution (Youden, 1951), which is often appropriate for replicate analyses.

The important characteristics of the distribution arising from analytical variation are its width and where its mean lies relative to the true concentration of the sample. The width is related to the standard deviation, which is called the *precision*. The mean minus the true concentration is called the *bias*. These characteristics may not be the same at all concentrations. The bias for the second sample (true concentration=35 mg $kg^{-1}$) is negative as in the first sample, but it is larger. The standard deviation is also larger, i.e. the precision is worse.

Precision and bias are sometimes called random error and systematic error respectively (Cheeseman & Wilson, 1978). Sometimes, the term accuracy is used for systematic error, but here, *accuracy* will be reserved