# Using biotic indicators to assess water quality in Peru

## by Marlene Guerrero and Barry Lloyd

**The contaminants that make polluted water unsafe for humans are even more fatal to the organisms that live in the river. Marlene Guerrero and Barry Lloyd explain how the presence or absence of these crucial organisms can help us monitor water quality.**

TRADITIONALLY, monitoring river quality involves regularly sampling and transporting samples to laboratories, where (mainly) chemical analyses are undertaken. The purpose of these analyses is to assess the safety and suitability of the water for human activities, including domestic consumption. Monitoring programmes also attempt to identify the sources and magnitude of pollutants with a view to controlling them.

During the last 40 years attempts have been made in both Europe and North America to introduce complementary biological monitoring to assess the effects of chemical and physical changes on the life of rivers. It has been demonstrated that organisms that live in river and stream beds are the organisms most sensitive to such changes, and therefore the most useful to monitor. Those used in this study were all visible to the naked eye and easily collected. They include a wide variety of groups such as fly larvae, worms, crustacea, molluscs, spiders, and flat worms. Whereas 'grab sampling' for chemical analysis is only representative of the moment of sampling and often misses the intermittent polluting discharge, sampling for biotic indicators (such as these organisms) is more informative and reliable because the organisms respond rapidly and may be used to detect changes resulting from both intermittent and chronic pollution.

In the UK, biotic monitoring (the monitoring of living organisms) has developed to the point where there is a reasonable understanding of the ecology of these groups. Biotic responses, such as the loss of diversity and an increase in pollution-tolerant species, can now be related to chemical pollution for at least 50 000km of rivers in the UK. Sophisticated computing techniques are now employed by the river authorities to overcome misleading results arising from the natural variation of the physical and chemical changes in the river.

The biotic monitoring of rivers using these organisms has rarely been attempted in developing countries, although it could provide an appropriate, low-cost, and sensitive approach to the detection of pollution.

The same indicator groups of organisms which are present in northern Europe are also present in the Andean region at high and low altitudes, and they also disappear in response to industrial and organic pollutants. The basic principle underpinning the methodology is that where biotic diversity is high the river is in a relatively healthy chemical state, i.e., well oxygenated, low in polluting organics and low in toxic inorganics. Conversely low biotic diversity indicates a generally poor water quality.

Many Peruvian rivers have high-level organic and metallic contamination from mining, industrial, and domestic activities. These same rivers are the principal source of drinking-water for many towns and cities. By studying the fauna in the River Rimac, the extent to which the state of health of these communities may be related to changes in water quality, brought about by the general effects of pollution, was evaluated.

### The River Rimac study area

The River Rimac is 138km long and drains an area of 3583km$^2$. The catchment area is below the Uco peak at 5100m above sea-level. Rain and snow from the peak drain into the catchment area, which flows to the Pacific and provides practically the only source of water to the six million inhabitants of Lima, the capital of Peru. Lima is on the Pacific coastal desert and since there is virtually no rainfall, groundwater recharge is also ultimately dependent on the Rimac.

The river basin is mountainous, and has two important sub-river basins, the Santa Eulalia and San Mateo rivers, which converge near the town of Chosica above Lima. The upper river basin has several lagoons, especially in the Santa Eulalia river. The San Mateo and Santa Eulalia rivers have 4.34 per cent and 6.33 per cent gradients respectively. Downstream of the confluence of the San Mateo and Santa Eulaliea rivers the gradient is 1.7 per cent. At this point the valley is wide and the agricultural activity is high. Many small rivers drain to the River Santa Eulalia: the Pillihua, the Yana y Potoga on the left bank, and the Sacsa, Pacococha and Carpa rivers on the right bank. Near San Mateo the

*The domestic sewage which is discharged directly into the River Rimac is just one source of pollution.*

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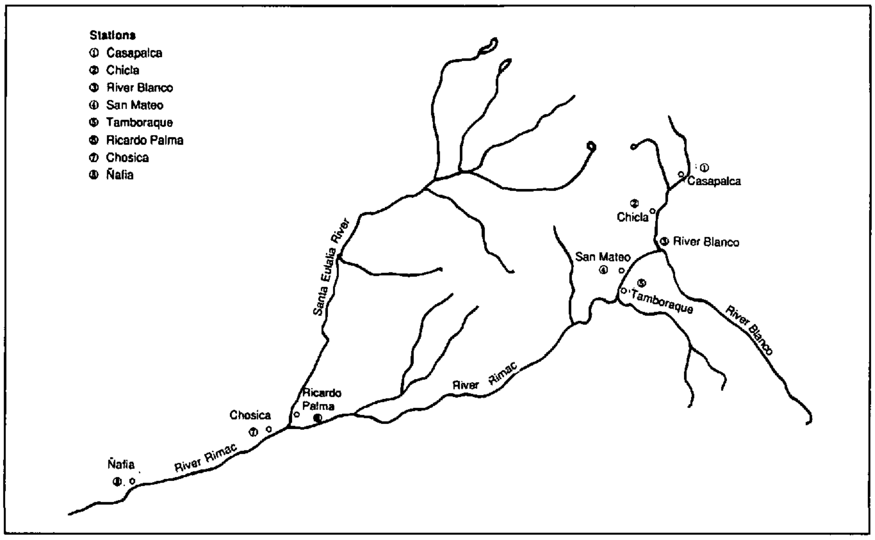


*Figure 1. The eight sampling stations on the River Rimac.*

Rimac receives the discharge of important tributaries such as River Blanco and River Parac on the left bank.

## Inorganic contamination

Mining activity upstream produces major contamination near the head waters of the upper Rimac, introducing many heavy metals including copper, lead, zinc, arsenic, cadmium, mercury and selenium, which can be toxic to humans. Rivers have some 'self-purification' capacity, which is a result in part of bacteria breaking down toxic substances, but this is ineffective in removing metals. Metals are, however, removed from the water to some extent by settling out on silt. The human health risk is also reduced by simple dilution, as uncontaminated water joins the river from unpolluted tributaries.

The River Rimac suffers critical changes during the year, and during the seasonal drought the organisms in the study are removed from some sections of the river. These organisms may also be reduced during the rainy season by high turbidity. pH is also an important parameter, and low pH chemical reactions may mobilize metals from mine wastes and influence the fauna. Dissolved substances such as chloride, sulphate, and carbonates also affect the organisms.

## Organic contamination

The lower River Rimac is organically contaminated by domestic and industrial sewage, especially downstream of the bridge at Ricardo Palma and down to the Pacific Ocean. This is in contrast to the metals contamination, which is nearly all in the upper Rimac catchment area. Much of the flow of this part of the river is used for drinking-water at the Lima treatment plant 'La Atarjea'. The 'Atarjea' therefore receives grossly contaminated water, containing both the upper catchment mining contaminants and the lower catchment organic wastes.

The river also receives a number of sewage and industrial effluents which contain high-level faecal contamination as well as cyanides, phenol, ammonia, and sulphuric acid. All the industrial and sewage effluents are discharged without treatment.

## Sampling and assessment

Seven stations were selected along the length of the River Rimac and one on its Rio Blanco tributary. All of these were sampled monthly for the selected organisms.

**Table 1. Trent Biotic Index**

*Part 1 Classification of biological samples*

| Key indicator groups | Diversity of fauna | Total number of groups (see Part 2) present | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0-1 | 2-5 | 6-10 | 11-15 | 16+ | |
| Column No: 1 | 2 | 3 | 4 | 5 | 6 | 7 | Line no: |
| | | | | Biotic Index | | | |
| Flecoptcra nymphs present | More than one species | — | VII | VIII | IX | X | 1 |
| | One species only | — | VI | VII | VII | IX | 2 |
| Ephemeroptera nymphs present | More than one species* | — | VI | VII | VIII | IX | 3 |
| | One species only* | — | V | VI | VII | VIII | 4 |
| Trichoptera larvae present | More than one species+ | — | V | VI | VII | VIII | 5 |
| | One species only+ | IV | IV | V | VI | VII | 6 |
| *Gammarus* present | All above species absent | III | IV | V | VI | VII | 7 |
| *Asellus* present | All above species absent | II | III | IV | V | VI | 8 |
| Tubificid worms and/or Red Chironomid larvae present | All above species absent | I | II | III | IV | — | 9 |
| All above types absent | Such organisms such as *Eristalis tenax* not requiring dissolved oxygen may be present | 0 | I | II | — | — | 10 |

* *Baetis rhodani* excluded.
+ *Baetis rhodani* (Ephem.) is counted in this section for the purpose of classification.

*Part 2 Groups*

The term 'Group' here denotes the limit of identification which can be reached without resorting to lengthy techniques. Groups are as follows:

1. Each species of Platyhelminthes (flatworms).
2. Annelida (worms) excluding *Nais*.
3. *Nais* (worms).
4. Each species of Hirudinea (leeches).
5. Each species of Mollusca (snails).
6. Each species of Crustacea (log-louse, shrimps).
7. Each species of Plecoptera (stone-fly).
8. Each genus of Ephemeroptera (mayfly) excluding *Baetis rhodani*.
9. *Baetis rhodani* (mayfly).
10. Each family of Trichoptera (caddis-fly).
11. Each species of Neuroptera larvae (alder-fly).
12. Family Chironomidae (midge larvae) except *Chironomus thummi* (*-mpanous*).
13. *Chironomus thummi* (blood worms).
14. Family Simulidae (black-fly larvae).
15. Each species of other fly larvae.
16. Each species of Coleoptera (beetles and beetle larvae).
17. Each species of Hydracarina (water mites).

The stations selected were as follows:

*Station 1* Casapalca
*Station 2* Chicla
*Station 3* Rio Blanco
*Station 4* San Mateo
*Station 5* Tamboraque
*Station 6* Ricardo Palma
*Station 7* Chosica
*Station 8* Nafia

The locations of stations are shown on the map in Figure 1. They were chosen because the sites are sufficiently shallow to permit the author to enter the river wearing waterproof boots. While facing downstream a standard $0.1m^2$ area of stream bed was disturbed continuously for three minutes by shuffling over the gravel/pebble bed to release the sediment and organisms into the flow, which were then caught in a net with a fine (0.5mm) mesh. The catch was then sorted on site and the number of groups and species were identified. The main groups were sorted and the number of groups represented were counted according to the Trent Biotic Index.

Table 1 shows how the Trent Biotic Index is derived from identifying the diversity of the groups of indicator organisms. The investigator counts the number of different groups present and identifies the most sensitive group present. If, for example, more than one species of Plecoptera is present, the investigator may enter the table at the top level and move across that row until reaching the column in which the number of groups identified is encountered. The corresponding Index is shown at the top of that column. Thus the highest Index (X) is found at the top right of the table and the lowest index (0) is found at the bottom left of the table.

The main skill required for this method is the ability of the investigator to identify and separate the key groups and species. It is quite feasible for an enthusiastic school biology teacher to train secondary school pupils to identify the main groups in the course of three or four extended field excursions. Thus the Trent Biotic Index is a robust, economical, and straightforward method to apply.

A slightly more time-consuming, skilled, and quantitative technique requires that as well as being sorted into species and groups, the actual number of organisms in each group is counted (i.e. 20 snails, 30 larvae). This latter method, the Chandler Biotic Score, was also used in the study and the results were compared.

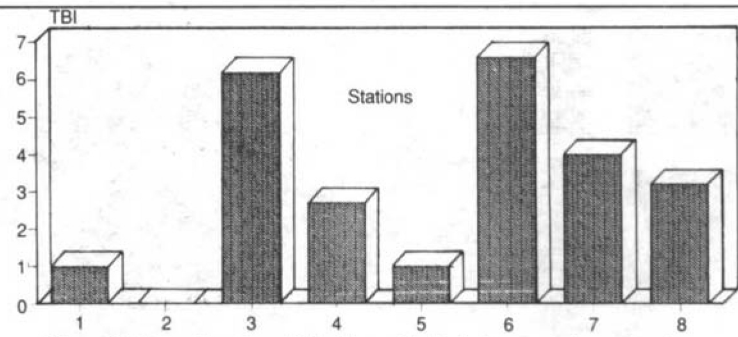


*Figure 2. Determination of the Trent Biotic Index at each station (mean values for eight sampling occasions).*

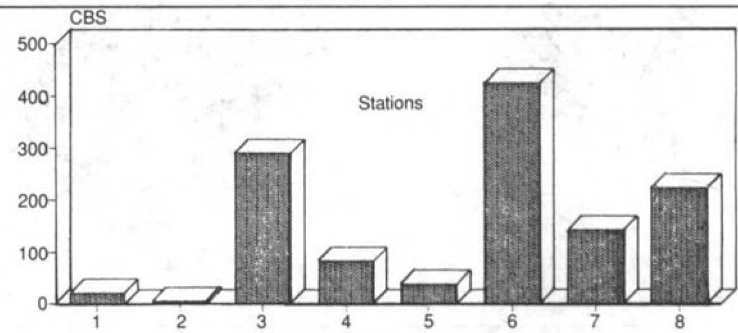


*Figure 3. Determination of the Chandler Biotic Score at each station (mean values for eight sampling occasions).*

## Results

Changes in the selected organisms' communities occur in response to changes in available food, temperature, and erosional and siltration patterns, as well as to changes in the concentration of agricultural, industrial, and domestic pollution.

Changes in species composition and relative abundance must therefore be interpreted cautiously, taking into account both natural as well as human-influenced factors. It was therefore essential to characterize the river at the outset according to previous conventional monitoring approaches.

For most of its length the flow of the upper River Rimac is rapid to torrential, with few slow, depositing areas. This means not only that areas of siltation are limited, but that there are also numerous zones with gravel, large stones and boulders.

Opportunities for the physical aeration of the water to occur abound as a result of cascading and turbulence, and therefore oxygen is rarely limiting. As a consequence most attention may be given to the direct effects of industrial discharges in the upper catchment area: these are principally heavy metals and the associated suspended solids and pH changes arising from mining. In the lower catchment area there are more villages and towns discharging their domestic waste directly into the river. As a consequence the effects of organic pollution dominate, and oxygen depletion has resulted.

The sampling stations may therefore be divided into three types:

- Stations primarily influenced by mining and related activities, but well oxygenated (1,2,4).
- Stations primarily influenced by domestic organic wastes, but oxygen depleted (5,7,8).
- Stations relatively unpolluted and well oxygenated (3 and 6).

Figures 2 and 3 demonstrate the agreement of the two indices for all eight sampling stations. Inspection of these figures reveals that the lowest indices are found at stations 1 and 2, i.e. those points principally affected by mine wastes. Station 4 shows some recovery, because it has received considerable dilution from the better quality water received from the Rio Blanco tributary represented by station 3.

The Rio Blanco is a tributary which has no mining in its catchment area and little human colonization. As a result it has relatively high indices, and the diversity of these, and the relative abundance, is summarized for four sample occasions in Figure 4.

The only superior site is station 6, which at first may seem strange since it is downstream of badly polluted sites on the main river. This apparent recovery is readily explained, however, by the fact that most of the river flow bypasses station 6 in a man-made tunnel for hydroelectricity generation, and the water in the river at this point is largely that from clean feeder springs in or near the main stream. Thus the two stations with the highest indices are indeed those with relatively unpolluted flows (3 and 6).

One species of Trichoptera was found at stations 3 and 6, and occasion-

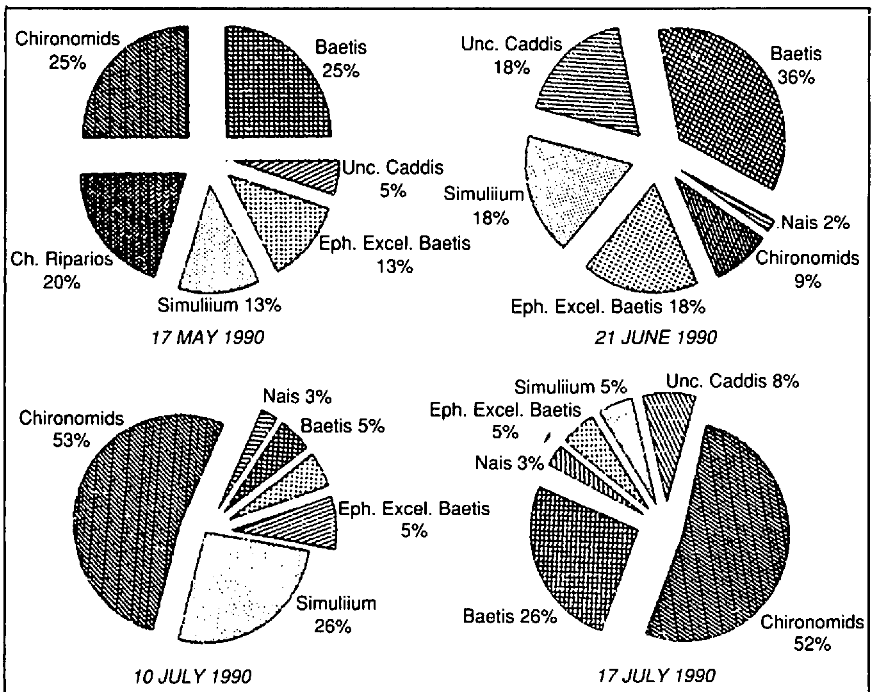


*Figure 4. Percentages of sensitive species collected at River Blanco.*

ally at stations 1 and 4. The presence of Trichoptera is associated with fast flow, adequate oxygen, eroding substrate and submerged vegetation, and of course the absence of significant amounts of toxic substances.

Plecoptera (a type of fly whose larvae live in well-oxygenated water) were restricted to station 6 and absent from all other sampling stations. Plecoptera species are the indicator group for the most sensitive species, and as such are intolerant of any pollution causing the oxygen concentration to be reduced.

Species of Mollusca (including water snails) were only abundant at station 6. They are associated with increasing calcium carbonate and salt levels, and also with the eroding substrate. There was no evidence of molluscs at any other station.

Ephemeroptera (mayflies) were present, but poorly represented. Only two species were found at stations 3 and 6. At all other stations the only mayfly found was the pollution-tolerant *Baetis rhodani*. *B. rhodani* was present occasionally in the upper reaches (stations 1, 2, 4 and 5) and in high densities in the lower reaches (stations 7 and 8). This mayfly has been shown by work worldwide to have some resistance to low levels of organic pollution. The work in Peru shows that it is sensitive to inorganic contamination though, such as that from mining activity.

A similar distribution to that observed for Ephemeroptera was also found for the Diptera (a group of insects). Again the groups represented were limited and eliminated from the upper reaches where mine pollution was dominant. In the unpolluted tributary (station 3), however, both chironomid and Simuliium larvae were significant components of the total invertebrate fauna. Simuliium spp, (black flies) are examples of fly larvae which are dependent on the high level of oxygenation normally associated with fast-flowing streams. By contrast the chironomids are more tolerant of organic enrichment and oxygen depletion, and were therefore found at all stations which supported some life. They were also found in increased numbers in the stations 6, 7 and 8.

Overall the abundance of the selected organisms varied enormously from station to station. The lowest mean value recorded was one at station 2. The highest value of 310 specimens was found at station 3. All counts were from a $0.1 m^2$ area of bottom deposit.

In this preliminary study we have not attempted an advanced analysis to take account of natural physical and chemical variability in the river. Nevertheless, the general pattern of loss of diversity of sensitive species and loss of numbers is in agreement with the responses to pollution found in northern Europe. Most of the work in the past has focused on the response of the indicator groups to organic pollution and oxygen depletion. Although more work is required, it would appear from this study that the same key indicator groups also respond to, and are therefore valuable for, assessing the effects of mine pollution. We therefore propose that these methods should be applied widely for the evaluation of river quality in developing countries, because they provide a potentially robust and economical method for monitoring the effects of pollution.