THE BIOLOGICAL ASSESSMENT OF POLLUTION

1. Introduction

The chemical and physical environment obviously has a profound effect on plant and animal communities. Thus, the plants found on a chalk- or limestone-based soil with its high pH are noticeably different to the plants found growing on a peat moorland, where pH's are much lower. Similarly the fauna associated with the two types of plant community will be completely different. Of course the biota can themselves influence the chemical and physical environments. This especially true of plants which can affect such factors as pH and shading. For example, heathers and sphagnum moss can actively reduce the pH of their surroundings. In aquatic systems large populations of phytoplankton, or surface-dwelling macrophytes such as Lemna (duckweed),can shade out the rooted macrophytes. Thus, the interaction between the physical, chemical and biotic environment is extremely intricate and is made infinitely more complex by the presence of pollutants, be they natural or anthropogenic. Therefore, it is of some interest and concern that these relationships be investigated in order that any actual or potential damage can be recognised and the stage that it has reached identified.

Any investigation of the health of ecosystems and the environment generally must involve quantitative measurements at some point and herein lies the problem. It is not so much the actual taking of measurements, although there are times when this can be difficult enough, but rather interpreting the measurements. Thus, if we consider some of the chemical and physical parameters commonly associated with the health of aquatic ecosystems we can see that these are factors which can change quite considerably with time. For example, temperature and light penetration are functions of climatic/meteorological conditions. Nitrate levels and pH values show diurnal and seasonal variations. Nitrate levels rise in winter and drop in summer, reflecting the activity of living organisms, while pH values rise during the hours of sunlight and in summer, but drop during the night and in winter, as photosynthesis waxes and wanes.

Even if it can be established that pollution is present, it is still not clear to what extent an ecosystem has been affected. A lot will depend on

- how much pollutant is present,
- which, if any, of the organism/communities it affects,
- over what period of time it has been entering the environment
- and how long it remains within a particular environment.

Given this situation it is not surprising that, with respect to aquatic environments, simple measurements of physical and chemical parameters by themselves are not particularly informative. Some investigation of the aquatic communities is necessary and, since populations are subject to natural variations (eg on a seasonal basis), it follows that such investigations should be extended over periods of time.

It must be stressed that the important considerations in this type of investigation are biological diversity and species abundance. In most healthy systems there is a wide range of species (high diversity) and a population pyramid (ie comparatively large numbers of producers and herbivores and increasingly fewer carnivores as food chains are ascended. In damaged systems diversity tends to be lower as certain significant communities are missing. The dominant species are often detritivores, scavengers and/or opportunists and their populations, especially those of micro-organisms can be huge.

2. Choice of Biological Parameters

As mentioned above, to know such chemical parameters as dissolved oxygen, BOD and pH of a water body is not, by itself, sufficient to conclude that the water body is damaged. Similarly, to determine these parameters for an effluent does not enable us always to predict the effects of that effluent on the flora and fauna of a river or lake. Only direct examination of the biota can show what those effects may be.

But what form should this examination take? Looking at every single type of organism is obviously not practicable. It would take an inordinate amount of time to catch and count every animal in a particular stretch of water. Besides which some of the more mobile species can wander far from their ‘home’ ground and so their absence or presence can be the source of ambiguity. Therefore, it is necessary to identify so-called ***indicator species*** the presence or absence of which is a direct reflection of water quality and not due simply to the vagaries of chance. Also, such species must be easily observed and counted. Possible groups of organism which might be examined are

- Vertebrates, including fish, amphibians and mammals.
- Micro-organisms.
- Invertebrates.

Vertebrates: In general these do not make satisfactory indicators of pollution and ecosystem damage. They are obviously affected by pollutants and disturbance but most are difficult to observe, difficult to catch and they are less abundant than smaller organisms. In addition, their very mobility, especially in the case of fish and mammals, can mean that even if such an animal is observed in a particular location, it may just be passing through, being some distance from its usual habitat.

Micro-organisms: The inhabitants of severely polluted water are almost exclusively micro-organisms. However, they are not easy to sample quantitatively since the procedure is time-consuming, it requires certain level of expertise and specialised equipment. Furthermore, actually identifying micro-organisms is not easy and is a very specialised skill.

Invertebrates: This group provides the most useful indicator species. Many aquatic invertebrates are relatively slow moving or sedentary. They are easy to collect and they are fairly easy to identify, at least down to family level which is usually sufficient. They are readily preserved so that the process of identification can be undertaken in relative comfort off-site.

Now, pollution affects the abundance and distribution of animals and plants in aquatic systems. Consequently waters can be classified according to the distribution and abundance of the macro-fauna within them. In general, pollution appears to restrict the ***variety*** of organisms present. Thus it tends to suppress certain key species but this, in turn, leads to a large increase in numbers of pollution-tolerant species; primarily the opportunists, scavengers and detritivores as their more sensitive predators either die or move away. As the degree of pollution in an aquatic system increases so the key organisms disappear in the following order

Plecoptera (stoneflies): Ephemeroptera (mayflies, damsel flies etc): Trichoptera (caddis flies): *Gammarus* (freshwater shrimp): *Asellus* (water hog louse): Chironomidae (‘blood worms’): Oligochaeta (tubificid worms).

Therefore, investigations into the possible effects of pollution on aquatic communities tend to concentrate on identifying and counting the members of these groups of animals.

3. Biotic Indices

Having identified and counted the appropriate organisms the data so obtained has to be processed in some way. Various procedures are available for this, most leading to the construction of ***biotic indices***. An index so calculated is then usually compared to a scale of values relating to differing degrees of damage. Most biotic indices are quick and easy to construct, but they are only worthwhile if they form part of a wider survey or monitoring programme. Also, they must take into account the following points.

- The presence or absence of an organism must be a function of water quality and not some other ecological factor.
- The system so devised must assess water quality in a reliable manner, be expressible in a simple form yet be sufficiently quantifiable to allow for comparisons to be made between measurements.
- The assessment should relate to water quality conditions over an extended period of time rather than applying only to the time of sampling.
- The assessment should relate to the site being sampled and not to the water course as a whole.
- Sampling, sorting, identification and data processing should be as simple as possible and involve the minimum amount of time and manpower.

Of course some biotic indices meet these requirements better than others. What is more difficulties can be encountered when constructing an index due to the effect of seasons on the presence or absence of certain organisms. Remember that not all changes are anthropogenic in origin; ecosystems change naturally without any help from Man. Consequently, a biotic index can only show that maybe some change has occurred, or that a system is not as well-balanced as it might be. What it cannot do is identify the cause that situation.

4. Common Biotic Indices

Trent Biotic Index (TBI): This was devised to define water quality in Midland rivers. It is based on an examination of key groups of benthic macro-invertebrates in the riffle ridges. According to how many species and individual organisms are present the water is given a score in the range 10 (unpolluted) to 0 (grossly polluted). For example, if sixteen or more species of key organisms are present, including more than one species of plecopteran, then the water scores 10. However, if there are no plecopterans and only two or three species of Chironomid and/or tubificid worms present, the water is heavily polluted and scores just 2. The method is easy to implement and to understand but it is relatively insensitive and is only really applicable to the rivers in the Severn-Trent region. The advantages and disadvantages of the system can be summarised as follows:

ADVANTAGES	DISADVANTAGES
Classifies the main characteristics of polluted waters	It is insensitive to moderate changes in water quality
It does not require rigorous sampling technique	It gives only a narrow range of values
Difficulties of identification are reduced by the selection of key organisms only to examine	It lacks range in the clean to mildly polluted waters
Gives a simple linear scale of index values	It does not give key status to molluscs
It is easily understood by non-biologists	No account is taken of actual numbers of organisms
	It needs to be adapted for rivers outside the Severn-Trent area
	The presence of drift organisms will affect the index score
	Generally, it is not responsive to inorganic pollution

Graham's Biotic Index: This is simply a version of the Trent Biotic Index (TBI) which as been adapted for use in the Lothian region of Scotland. It is in effect a simplified, cruder form of the TBI. As such, while it shares the advantages of the TBI the disadvantages are more exaggerated making it much less flexible.

Chandler's Biotic Index: This was developed to classify the North Esk and other rivers in Lothian. It is similar to the TBI and Graham's but it specifies a much more detailed list of macro-invertebrates. The organisms are identified and *counted* and each individual group is given its own score. Sensitive species have high values while tolerant species have low values. As numbers increase so do the scores of all groups. There is no fixed range of values but scores can go from 0 (no life present), through 45 - 300 (moderate pollution) to 300 - 3000+ (mildly polluted to unpolluted conditions). This is a much more sensitive index than the TBI and, like that index, it does not require a rigorous sampling regime. However, it is more time consuming given the larger number of organisms which has to be examined.

ADVANTAGES	DISADVANTAGES
Absence of fixed levels allows a wide range of water qualities to be categorised	The order in which the organisms are placed with respect to their pollution-tolerance is debatable
It does not require rigorous sampling technique	More time is required for the sorting, identifying and counting of the organisms
It incorporates a more extensive list of invertebrates	It does not produce the fixed scale of values which non-biologists find easy to use
It includes *abundance* of species as an additional parameter	*Gammarus* is given a fixed score of 40 irrespective of its abundance
It is able to discriminate between quite small differences in pollution particularly in the mild to moderate region	Generally, it is not responsive to inorganic pollution

Community Diversity Index: Unlike species diversity indices *community* diversity indices are based on total numbers of species and their relative abundances. This provides a better numerical measure of community structure. One of its great advantages is that it provides a non-biased numerical value which is independent of sample size. However, the individuals in the sample must be identified down to the lowest taxonomic group. The index is calculated using the following formula:

$$d = -\sum_{i=1}^{t}\left[\left(\frac{n_i}{N}\right).\log_e\left(\frac{n_i}{N}\right)\right]$$

where d = the diversity index
t = the total number of species present
n = number of individuals of each species
N = the total number of individuals

Clean waters have *d* values greater than 3, moderately polluted waters have values in the range 1 - 3, while heavily polluted waters have values of less than 1.

ADVANTAGES	DISADVANTAGES
It provides the best approximation of community structure and is a function of numbers present	The computation of the index is lengthy
It has a broad application as no special species lists are required	The use of exact numbers requires a more rigorous sampling procedure
It uses a convenient decimal scale	All organisms should be identified to species level
It is sensitive to small changes in water quality	It provides very little in the way of qualitative description

Kothe's Species Deficit: This is used in situations where there is a point source of effluent entering a river. The index is calculated by taking the difference between the numbers of species above (A_1) and below (A_X) the source and expressing it as a percentage of the total number upstream (A_1). Thus:

$$Deficit = \frac{A_1 - A_X}{A_1} \times 100$$

ADVANTAGES	DISADVANTAGES
The linear scale with easily understood percentages is useful if pollution is entering a system through a point source	It is based only on the presence or absence of organisms as a whole
It does not require a rigorous sampling regime	The results are greatly affected by seasonal changes
Results can be expressed graphically allowing trends to be identified and assessed	No indicator species are considered
	There has to be an unpolluted reference station available

BMWP Score: This is the Biological Monitoring Working Party Score. It is a very simple system which examines a series of key ***families*** grouped into nine blocks according to their sensitivity to pollution. The most sensitive organisms are placed in Block 1 while the most tolerant family of all, the Oligochaeta, is the only one in Block 9. The intermediate blocks show a increasing degree of tolerance from Block 2 to Block 8. The families in Block 1 score 10, the families in Block 2 score 8 and so on down to Block 9, the Oligochaeta, which scores 1. A kick sample is examined and when an organism belonging to one of the key families is found a cross is inserted against that family on the score sheet. Any further members of the same family are ignored, so one is only concerned with whether a family is represented or not. Once the examination is over all the crosses in a block are added up and multiplied by the score and the result entered as a sub-total. For example three families from Block 1 would give a sub-total of $3 \times 10 = 30$, and so on. All the sub-totals are then added together and the result gives the sample score, which is returned to the Department of the Environment. The larger the score then the cleaner is the water.

5. Summary

Thus, there are a number of biological methods available for assessing water quality. Some, such as the Trent Biotic Index and Kothe's Species Deficit are very specialised and so not suitable for general use; although the TBI can be adapted to local conditions as shown by the Graham's and Chandler's systems. The Community Diversity Index is perhaps the most complete and detailed of all, but by its very nature it demands much skill on the part of the investigator, since sampling has to be performed extremely rigorously and organisms have to be identified down to species level. Also, it is time consuming since every macro-invertebrate present has to be identified and counted. Perhaps the system of most use generally is the BMWP score. For this it is only necessary to examine certain key indicator species and identification is down just to family level, which is a comparatively straightforward procedure. In addition, it does not depend on rigorous sampling.