Exploring Biodiversity as Bioindicators for Water Pollution

Akanksha Jain, Brahma N. Singh, S. P. Singh, H. B. Singh* & Surendra Singh

*Department of Botany; Department of Mycology and Plant Pathology,
Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005
*Email : hbs1@rediffmail.com

Biodiversity plays a central role in making life sustainable on this planet for all organisms. The fate of human species is interlinked with fates of all organisms whether plant, animals or microbes living around us and directly or indirectly affecting our lives. The simplest way to understand this is to just remember the mode of energy transfers, nutrient, oxygen and water cycling going on. Our planet is tightly linked by global communication systems, exchange of materials and their maintenance where all of them are being interdependent. For example our health depends upon the environment we live in and food we eat. To protect our self we need to protect our planet, the ecosystems and individual species present around the globe.

Biodiversity is crucial to the poverty alleviation, due to the basic goods and services it provides. Around 70% of the world's poor live in rural areas and depend on biodiversity for their livelihood and well-being. The urban poor too rely upon biodiversity, not only for the production of food and other necessary goods, but also for ecosystem services such as the maintenance of air and water quality and waste decomposition. The impact of biodiversity loss may have most severe consequences for people living in poverty, directly because they have few livelihood options to rely on and indirectly because of functions they perform in the ecosystem. There is an urgent need to develop strategies to protect biodiversity if we want to achieve poverty eradication and sustainable development. More than 3 billion people depend on marine and coastal biodiversity. The areas requiring urgent attention are those for health and water supply, tourism, flood control and waste management. Healthy ecosystems, healthy people demand clean water and the control of vector-based and other diseases depending on ecosystem processes. Water scarcity and declining access to fresh water is a globally significant and accelerating problem for 1-2 billion people worldwide, leading to reductions in food production, human health, and economic development.

Together with the air we breathe, the provision of clean water is arguably the most fundamental service provided by ecosystems. Human activities have fundamentally altered and threatened inland water ecosystems. As a consequence species dependant on inland waters is more likely go to extinction. It has been reported that future extinction rates of freshwater animals could be up to 5 times higher than for terrestrial animals. People living in rural areas and those living in poverty are often the first to suffer when the aquatic environment is disturbed. Clean freshwater is essential for sustaining both people and species. While it is globally recognized that freshwater management must balance development and environmental needs, efforts to implement a more integrated approach have seen limited success in past. Most visibly lacking is the understanding of ecosystem needs into water management measures and the valuation of other goods and services that freshwater ecosystems provide.

Skilful management of our water bodies are required if they are to be used for diverse purpose as domestic and industrial supply, crop irrigation, transport, recreation etc. In order to identify the nature of pollutants and their impact, quick and reliable monitoring systems are essential. So using our biodiversity to respond to the pollutants present and its load with changes in vital functions or organisms capable of accumulating them are best possible indicators available in the nature. There are several environmental conditions for the existence of bioindicators, such as the transmission of light, water temperature, and suspended solids. Therefore, by using bioindicators, we can see the environmental conditions of a certain area or the extent of pollution. Developing indicators to manage water for people and nature may thus benefit us in gathering knowledge about water quality. Indicator organisms are any biological species that defines a trait or characteristics of the environment.

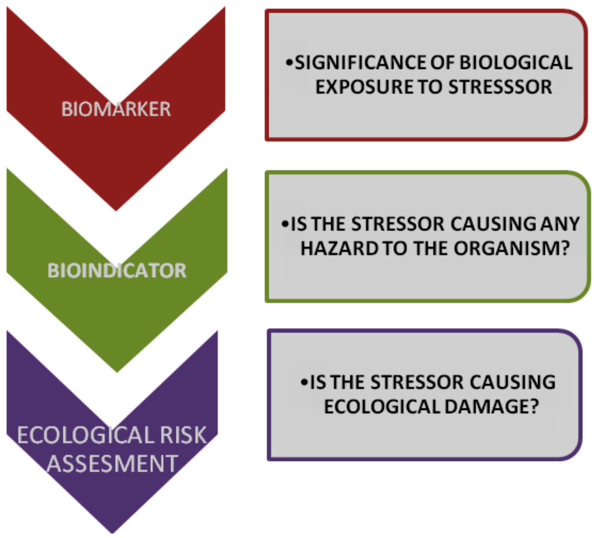

Fig. 1 Design of a bioind icator.

What are bioindicators?

Bioindicators are organisms, chemical markers or biological processes whose change point can be observed to altered environmental conditions and can be used to identify and quantify the effects of pollutants on the environment. It can also be defined as anthropogenically induced response in biomolecular, biochemical and physiological effects on one or more organisms, population, community or ecosystem level of biological organization. Bioindicators can tell us about the cumulative effects of different *pollutants* in the ecosystem and about how long a problem may persist, for example: a) abundance of large marine organism or darkening of coral pigmentation may indicate that a reef has been exposed to poor quality of water for several weeks or months, b) reduced photosynthesis in plants or coral may indicate stress due to exposure of herbicides.

Criteria for selecting bioindicators :

- Indicator should have casual relationship to ecological significant endpoint.
- Indicator should have specific dose responsiveness to specific stressor *i.e.* should be sensitive and specific.
- Indicator should have wide temporal and spatial distribution.
- Indicator should be available all the year and should have low variability to noise in the system.
- Indicator should have results which are transparent and reproducible.
- Indicator should sometime even surrogate the role of other responses.
- Indicator should be easy to collect and should be cost-effective.

Bioindicators may be of two types (Fig. 2), a) accumulation bioindicator: store pollutants without any evident changes in their metabolisms; b) response bioindicator: react with cell changes or visible symptoms of damage when taking up even small quantity of harmful substances. Types of responses observed while using them may be: a) ecological changes: involving changes in population density, key species and species diversity; b) behavioural changes: can be changes in feeding activities, bacterial mobility or web spinning; and c) physiological changes: can be accumulation of heavy metal, CO_2 production, BOD and microbial activity.

Organisms including plants, animals, and microorganisms have been adopted in biomonitoring The majority of bioassays are based on presence-absence or on physiological, behavioural or genotypic

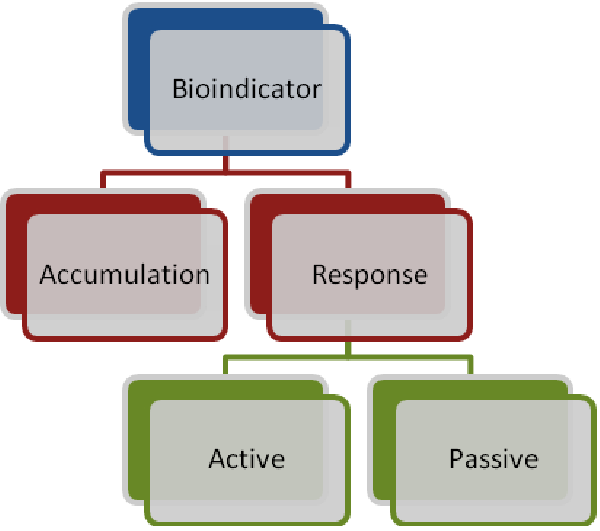

Fig. 2 Types of bioindicators.

expression of certain (or groups of) indicator organisms.

Microorganisms as bioindicators :

Microorganisms are diverse group of organisms found in large quantities and are easier to detect and sample. The presence of some microorganisms is well correlated with particular type of pollution and it serves as standard indicator of pollution. Some bacteria produce stress proteins in response to contaminant like cadmium and benzene.

The main source of organic burden of sewage is human body waste, or, faeces, and microorganisms are themselves a main part of human faeces. If a person has gastrointestinal illness or is a carrier of gastrointestinal pathogen such as Salmonella typhi, the pathogen is excreted along with rest of microbial population. Bacteriphage can too be used as faecal pollution indicators of viral pollution. Two phages somatic coliphage which infects E.coli host strains and F-specific RNA coliphage which infects E.coli and related bacteria can be used as indicators. Some other microorganisms have been dealt later; here we will concentrate on bacteria as bioindicator.

Ideal bacterial indicator for water analysis (contamination of faecal origin) should have following characteristics:

- The indicator bacterium should be present whenever enteric pathogens are present.
- The indicator bacterium should not reproduce in contaminated water and produce inflated values.
- It should survive longer than the hardiest enteric pathogen.
- It should have greater specificity.
- Its detection assay should be easy to perform.
- It should be harmless to humans.
- Its level in water should have some direct relationship with faecal pollution.

Some important bioindicator bacteria are :

- Total coliforms and faecal coliforms: the coliform group includes *Klebsiella*, *Escherichia*, *Citrobacter* and *Enterobacter*. Faecal coliforms (Fc) are coliforms which respond to elevated temperature of 44.5^{o}C within 24 hours by acid and gas production. These coliforms are derived from intestines of warm blooded animals (*E.coli*). Fc concentration less than 200/100ml indicates Salmonella occurrence ranging from 6.5 to 31% and 1000/100ml indicate double Salmonella concentration. Their presence can be detected by performing following tests:

1. Multiple tube fermentation test
2. Membrane filter test
3. Presence - absence test
4. Faecal Streptococci: in water, this genus is represented by *Streptococcus bovis*, *S. equims* which are considered to be the true *streptococci*. It is suggested that faecal coliforms/faecal streptococci (Fc/Fs) ratio of 4 or more indicates water contamination of human origin and Fc/Fs less than 0.7 indicates contamination from animal origin.
5. *Clostridium perfringens*: Their heat and disinfection resistant hardy spores are used as indicators for water pollution.
6. Other anaerobic bacteria such as

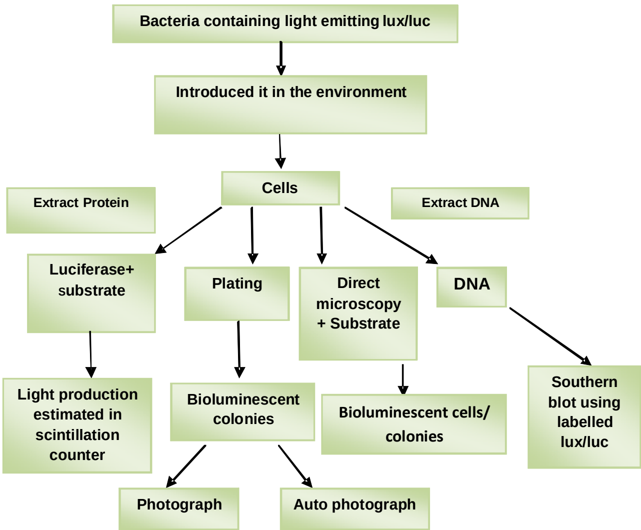

Fig. 3: Assay to check for the presence of toxic contaminant using bioluminescent bacteria

Bifidobacterium and *Bacteroides* are potential indicators. *Bifidobacterium* are primarily associated with human contamination.

7. Other indicators may be *Pseudomonas* spp., yeast, *Aeromonas, Staphylococcus*, acid fast mycobacteria.
8. Some genetically engineered microbes are designed to remove arsenic and other heavy metal from contaminated water.
9. Recently, a bacterium *Vogesella indigofera* was found to respond to heavy metal quantitatively. Under conditions without pollution by metals, this bacterium produces a blue pigmentation which is so distinct that any morphological change might easily be detected visually. In the presence of hexavalent chromium, their pigment production will be obstructed, and the relationship between chromium concentrations and blue-pigment production by the bacterium can be correlated.
10. Marine bacterium *Vibrio harveyi* may be an appropriate bioindicator of mutagenic pollution.
11. Bioluminescent bacteria: These are used to test water for environmental toxins. If there are toxins present in the water, the cellular metabolism of bacteria is inhibited or disrupted. This affects quality or amount of light emitted by bacteria (Fig. 3). It is very quick method and takes just 30 minutes to complete but could not identify the toxin. Examples of such luminous bacteria include *Photobacterium fisceri, P. phosphoreum*.

Plants as bioindicators :

The presence or absence of plants or vegetative life can provide important clues about environmental health, or they can be accumulators of metal or their metabolism product, for example, the total algal biomass in aquatic system serves as an important metric for organic pollution and nutrient loading such as nitrogen and phosphorous. Plants are increasingly being used as highly effective and sensitive tools for recognizing and predicting environmental stresses. The problem of water pollution has become acute now-a- days due to industrialization and urbanization. Aquatic plants provide useful information on the status of aquatic environment as they do not migrate from one place to another and they quickly attain equilibrium with their ambient environment. Some examples of lower group of plants as pollution indicators are as follows:

- *Synechococcus leopoliensis* (blue-green alga) and *Dunaliella* showed heavy metal pollution by accumulation, and are good water pollution indicator
- Cellular malformation, chlorosis and significant increase in heterocyst frequency have been seen in *Anabaena cylindrica* under cadmium stress.
- *Selanastrum capricornutum* (also known as *Pseudokirchneriella subcapitata*) was applied to pollution and is now used for assessment of water pollution.
- Toxicity tests can be performed on *Chlorella vulgaris*, *Scapricornatum, Senedesmus subs-picatus* by observing culture conditions, culture volume and light intensity.

- A change in species diversity of phytoplankton is indicator of polluted aquatic ecosystem, for example, *Euglena clastica*, *Phacous tortus* and *Trachelon anas*.
- Toxicity tests can be performed on *Chlorella vulgaris*, *Scapricornatum*, *Senedesmus subspicatus* by observing culture conditions, culture volume and light intensity.
- Charophytes are affected by moderate eutrophication. Therefore, they are often used as bioindicators for good water quality.
- *Eloidea canadensis*, *filamentous alga Ceramium strictum*, *C. teniucorine*, *Phaeodactylum tricornutum* and *Champia parvula* are also proposed organisms as indicators,
- Floating *Eichhornia crassipes* for mercury, non-rooted submerged *Ceratophyllum demersum* and rooted submerged *Potomogeton crispies* for assessing heavy metals like cadmium, copper, iron, lead, zinc and manganese in rivers.
- Mosses and liverworts can also be used to access heavy metals.
- *Portedaria cordata* can measure distance from discharge site of copper and lead.
- *Eloderdensa* can be used for mercury pollution by observing chloroplast structure and their membranes.
- Elegrass is most widespread plant in temperate coastal areas. It is a useful water quality indicator because water clarity regulates its extension towards deeper water i.e. deep limit. Ecological status is classified by relating the actual level of bioindicator (reference level), reflecting a situation of limited anthropogenic influence.
- Disappearance of root hairs and colouration of hydathodes in the juvenile leaves of *Limnanthemum cristatum* occurs due to high leaf tissue chromium concentration.
- *Wolffia globosa* have also shown sensitivity for cadmium and has potential to be used as indicator of cadmium contamination.
- Transgenic plants are also being designed as bioindicators.

Animals as bioindicators :

An increase or decrease in an animal **population** may indicate damage to the ecosystem. For example, if depletion of important food sources occurs, animal species dependent upon these food sources will also be reduced in number *i.e.* population decline. **Overpopulation** can result due to growth of opportunistic species. In addition to monitoring the number of certain species, other mechanisms of animal indication include monitoring the concentration of **toxins** in their tissues, or monitoring the rate at which deformities arise in animal populations. Some examples are given below:

- Zooplanktons like *Alona guttata*, *Moscyclopes edex, Cyclips, Aheyella* are zone dependent pollution indicators.
- Coral Bioindicator: Temporal variation in range of indicators includes (Fig. 4) symbiont density, concentration of chlorophyll, skeletal density, colony brightness of *Pocillopora* and density of macro-bioeroders and colony brightness of massive *Porites* spp. Long term turbidity > 3NTU leads to sublethal stress and > 5NTU implies severe stress.
- Leeches are used as a sensor-bioindicator of river contamination of PCB's. Samples can be collected to measure PCB's levels.
- Oyster *(Crassostrea gigas*), crabs (*Geotica depressa*) can show trace metal indication. Crab (*Holoecius cordiformis*, a semaphore crab) can indicate the presence of lead in Australian estuaries.
- Brine shrimp, *Artemia salina* is used to estimate pollutant by its immobilization after 24 hours of incubation. Shrimps *Juvenile*, *P. setiferus*, *Crangon septemspinosa* and *Palaemonates vulgaris* have shown cadmium sensitivity.
- Dab (*Limanda limanda*) increase in malformation of embryo indicates DDT and PCB's pollution.
- Seabirds: Cory's shearwater, *Calonectric diomedea* found in Mediterranean Sea has been reported to show high concenterations of heavy metals, indicating sea water pollution. The

seabird red billed *Larus novachollandiae scopuline* is used to indicate mercury levels in New Zealand seas.

- Earthworms: *Allophora molleri* and aquatic biota can be used for heavy metal pollution indicator. Behavioural, sublethal and lethal tests can be applied to check concentration of 2,4,6-trinitrotoluene using earthworm *Eisenia fetida*. *E. foetida* has been shown to accumulate mercury and a positive correlation exists between mercury concentrations in worm tissues, the substrate they consume and length of exposure.
- Other benthic macro invertebrates are also used for example to access dissolved oxygen and ammonium in seawater which are two most important water quality parameters inversely related to vertebrate scores example are mayfly nymphs, caddisfly larvae, water pennies and stonefly larvae which survive in swift cool and well oxygenated water supply. Their sampling thus indicates good water supply. Blackfly larvae, leeches and aquatic worms are quiet tolerant to pollution.
- *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies) are flies which are pollution intolerant their higher percentage related to tolerant species at site indicates better water quality.
- Freshwater Mussels: Since they can live for decades, so their presence or absence indicates water quality example glochidia, pearlshell. The filter feeding mussels are known to accumulate heavy metals in coastal water. The Mediterranean mussel (*Mytilus galoprovincialis*) is used to monitor heavy metals using both metal accumulation and response to certain enzymes to pollution.
- Down water pollution for example heavy metal and pesticides can be monitored on reproductive system of *Astyanax fasciatus* by comparison of mean oocytes, gonadal index and gonado-somatic relationship of specimens captured from polluted and non-polluted sites which shows decrease in these parameters with increasing water pollution.
- Fishes are good indicators for hydrosphere contamination for PCB's especially silverfish, tench in fish tissues. *Tilopia nilotica* can be used to indicate iron, manganese, nickel, lead, cadmium, zinc in different tissues with lethal effects and bioaccumulation.
- Mercury levels in stripped dolphins have been found to be present than any other water organism
- Fishes can be suitable pollution indicators for sewage nitrogen pollution. They use to integrate N- inputs over long time period. Relevance to fish muscle ?-15N reflects movement of sewage nitrogen through food chain. Fishes like trout, blue-gilled sunfish, zebra fish and fathead minnow can also be employed as bioindicators.

Based on quality, water can be divided into following groups:

- Class I water: It is clean, transparent and odourless so it can be used as drinking water after going through a simple purification process.
- Class II water: It can be used for purposes like bathing and swimming.
- Class III water: It is muddy water and can be used for industrial purpose.
- Class IV water: It is polluted and cannot be used, so even swimming in this water can cause skin troubles.
- Class V water: It is highly polluted so no organisms can survive.

Detection and enumeration of bioindicators of water contamination

More rapid and reliable tests for the presence of microorganisms in water are the future area of thrust. Although biotechnology-based tests currently exist for drinking water, there are still many pollutants that are not detectable. Scientists are busy trying to replace time consuming, traditional methods with newer, faster, and more reliable tests based on biotechnology. Thus bioindicators helps us in following way:

- It indicates presence of contaminant.
- It helps to identify mechanism of toxicity.

Fig. 4: Cycling of observation, information and inferences among different groups.

- It provides early warning of impeding environmental damage.
- It provides early indication of environment recovery/remediation.
- It is Important in linking stressor to ecologically relevant factors.
- It can be incorporated into ecological risk assessment.

Protecting the diversity is our moral and spiritual duty. The use and benefits from biodiversity and their application for alleviating poverty involves many actors, ranging from local communities, to exploiters, conservationists, researchers and various government and non-governmental agencies (Fig. 4). It is required to build effective partnerships among the above actors to achieve poverty alleviation through biodiversity use. Conflicts over polluted waters must be avoided. They harm people, food production, nature, the environment, and sustainable development in general.

Effective, efficient and equitable management of the available water is only achieved when all women, men and children are involved in making decisions on how to best share, supply and protect water and both get the knowledge to use simple bioindicators in nature to understand water quality. Project components can then be planned to address the different needs, bringing in much-needed flexibility to implementation. The links between gender, poverty and water are easiest to identify when we look at domestic water use and sanitation practices. Gender is a key variable when we look at economic activities. Sometimes local women support is required, to empower them to take up leadership roles, but if provided with training by water experts and policy makers, they will truly do good work.

****