Bio-monitoring is the measurement of the body burden of toxic substances in biological organisms (CDCP1; Fig.-1). This concept has now become broader by the inclusion of those species that were previously considered as unfit for this job. Parasites can be perceived differently by different people according to their experience and knowledge (Fig.-2). These organisms were previously considered as disease-causing agents and are now showing great promise in different fields. Last three or four decades have brought a paradigm shift in the thinking of parasitology as ecological importance of parasites have been appreciated because of their complex life cycle. In contrast to human concern about the detrimental effects of worms, however, is the particular interest shown in these parasites/worms: (i) biological indicators (ii) indicators of changes in environmental-natural or man-made (iii) "models" for use in teaching and research2. Parasitologists have been interested hitherto in infection related issues - prevalence, intensity, occurrence etc. The stress has now shifted to the other level (i.e., environmental level) to know in which respects parasites show association with the degrading quality of environment. In the recent past, some researchers have assessed the usefulness of parasites as bio-indicators of environmental impact. A major question to be considered is whether the parasites are of such worth to be considered for the environmental monitoring.

Some may raise question whether to use parasites as indicator or not. Those believing on modern probes will argue that when there are tools/equipments that are available for assessing pollution level at minute level, then why to use biological organisms for the same purpose. Parasites display complex interactions with surrounding environment at different life stages. Another important thing is that modern monitoring probes cannot detect the changes in food chain or food web and can only give rough estimate of the contamination level in an environment. However, we need to adopt holistic approach by integrating both modern as well as biological probes (including parasites) for investigating the pollution status of an ecosystem.

How parasitism and pollution can interact with each other in an aquatic ecosystem has been under debate for quite some time. Parasitism is of common occurrence and the interaction of parasites with the environmental stress is of complex one. Various studies have shown that environmental deterioration affects community structure of parasites. Literature on pollution/parasite associations has shown a significant change in parasitic infection in response to various stresses. Although, some reports of significant change in parasitic infection in response to nutrient enrichment (eutrophication) and metal pollution were observed, but these responses are still inconclusive3.

Environmental parasitology has received a significant attention by different workers in recent times3-4. This has been debatable issue and has increased curiosity in the minds of scientists to deeply understand the environmental impact on parasites. For instance, diversity and composition of helminthes can be used to assess the ecosystem health5. Different workers have correlated parasitic infection with different stresses6-7.

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The environmental relevance of parasites in the impact assessment has opened up new interdisciplinary field that encourages the positive role of parasite-traditionally considered as infecting agents. The interest in this field started in 1980’s during the era when biotechnology was leading in all fronts and parasitology was considered as trivial field with no innovation. However, importance of parasites came into limelight when ecologists were in search of new biological sentinels for ecological assessment. The interest in Environmental Parasitology has increased in last three and half decade as number of published papers has increased. Showing multiple linkages in an ecosystem, parasites are unique ecological sentinels, though skeptics also raise questions about their relevance on practical scale. The past results clearly show that parasites have great promise as a biological tool for assessing the altered environmental quality though needs more holistic approach in future. However, path is not easy for parasites as they has to compete with the best biological sensors that have already shown their effectiveness in impact assessment studies.
There are two ways by which parasites can be used as bioindicators: (i) they can be used as an effect indicator, or (ii) can be used as accumulation indicator. Different researchers have used different approaches to assess the effect indication with parasites. Some have analysed individual organisms, whereas others have focussed on parasite populations and communities with respect to environmental pollution. It has been also shown in literature that conventional effect indication have been less promising than effect indication by population or community structure as latter is more holistic approach than the former one.

In last two decades, different research workers have written reviews on the ecological importance of parasites. Sures, for example, wrote an excellent review article viz., "Environmental parasitology: relevancy of parasites in monitoring environmental pollution" in which author stresses the importance of parasites as effect and accumulation indicators. In the same way different authors have discussed other characteristics of parasites for possible use in environmental monitoring.

Why should be parasites included in environmental studies? The Environment plays an important role for disease occurrence. There is an interaction among pathogens/parasites, hosts, and the environment, and the latter is least understood (Fig.-3). It is worth mentioning here that parasitic disease can also occur without the above interaction. However, stressful condition increases the chances of disease occurrence. Besides, disease occurrence this interaction will also provide us additional information regarding the environmental status of an ecosystem. Various authors have discussed this important interaction. It has been seen that infectious disease of fishes occurs when susceptible fishes are exposed to virulent pathogens under certain environmental stress conditions.

Environmental deterioration may have both positive and negative impacts on the parasitism. Pollutants can have detrimental effects on the host by decreasing the immune system of the host. The immune compromised hosts are likely to be the safe havens for the parasites. In this case pollutants increases the parasitic infection. Pollutants may also decrease the abundance of parasites as some parasites are more affected by contaminants. In majority of cases, however, contaminants can have negative impact on parasites if following conditions apply:

1. Infected hosts show more impact of pollutants than their counterparts (uninfected)
2. Individual parasites show more response to the environmental stress than hosts
3. Intermediate hosts become extinct due the negative impact of contaminants

However, it is rather difficult to assign an increase in parasitic infection directly to deteriorating environmental quality, as exact impact of any stress is likely to vary by genetic constitution within a species.

It seems host parasitic interaction incorporates natural features that are informative and important for the environment impact assessment. Some species of parasites, particularly helminth parasites have evolved extraordinary means to ensure their transmission and propagation. Furthermore, they rely on complex interactions that include a variety of invertebrate and vertebrate hosts and as such, functional importance of parasites in animal community can not be ruled out.

There are mounting evidences from the literature that parasites are impacted by the pollution/contamination (Table-1).

Why parasite/contaminant associations are still ambiguous? Now, question arises if there is mounting evidence from the literature that parasites are good bio indicators of environmental impact, why parasite/pollutant associations are still inconclusive or ambiguous. There are many reasons for this ambiguity. Some of reasons are given below.

1. Parasites occupy a wide habitat range in water body and show different types of physiological adaptations. Different life stages of parasites are also adapted in a different way with the external environment. Even a single contaminant may show different impact on different stages of parasites.
2. Under representation of contaminants and parasite taxa in early analysis cannot be ruled out.
3. Maximum of studies have been conducted under natural conditions (field conditions) and there is lack of experimental study under controlled conditions (lab conditions).
4. Also, there are scanty studies which has focussed on accumulation properties of parasites as well as hosts in
**Table 1. Evidence of parasite/contamination associations from literature, which shows positive or negative impact (Adapted from Sures, 2004 with some modification)**

<table>
<thead>
<tr>
<th>Parasites</th>
<th>Host</th>
<th>Location/habitat</th>
<th>Pollution/contamination</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component community</td>
<td>Parca fluviatilis (cyprinid)</td>
<td>Acidification</td>
<td>Reduced parasite diversity</td>
<td>13</td>
</tr>
<tr>
<td>Trichodina sp.</td>
<td>Hippocampus leptodeirus</td>
<td>Contaminated sediments</td>
<td>Higher abundance</td>
<td>14</td>
</tr>
<tr>
<td>Component community</td>
<td>Schizothorax riger</td>
<td>Eutrophication</td>
<td>Higher abundance, intensity and diversity</td>
<td>15</td>
</tr>
<tr>
<td>Diplozoon Kashmirensis</td>
<td>Carassius carassius</td>
<td>Eutrophication/contamination</td>
<td>Combined effect showed synergistic and antagonistic effect</td>
<td>16</td>
</tr>
<tr>
<td>Trichodinid ciliates</td>
<td>Platichthys flesus</td>
<td>Eutrophication</td>
<td>Increase in prevalence and density</td>
<td>17</td>
</tr>
<tr>
<td>Trichodinid ciliates</td>
<td>Platichthys flesus</td>
<td>Eutrophication, general marine pollution</td>
<td>Increase in abundance and density</td>
<td>18</td>
</tr>
<tr>
<td>Component community</td>
<td>Rutilus rutilus (roach)</td>
<td>Eutrophication</td>
<td>Increase in parasite richness</td>
<td>19</td>
</tr>
<tr>
<td>Parasite community of snails</td>
<td>Physella cambria (rotund phyla) and Lymnaea palustris (marsh snail)</td>
<td>Heavy metals</td>
<td>Lower diversity and intensity</td>
<td>20</td>
</tr>
<tr>
<td>Acanthocephalina</td>
<td>Taeniopterus adspersus (gunner)</td>
<td>Municipal and industrial</td>
<td>Increase in prevalence and intensity</td>
<td>21</td>
</tr>
<tr>
<td>(three spined stickleback)</td>
<td></td>
<td>Effluents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component community</td>
<td>Leuciscus cephalus (chub)</td>
<td>Organic pollution</td>
<td>Decrease in species richness</td>
<td>22</td>
</tr>
<tr>
<td>Component community</td>
<td>Sigmodon hispidus (cotton rat)</td>
<td>Petrochemicals</td>
<td>Decrease in number of helminth species</td>
<td>23</td>
</tr>
<tr>
<td>Dactylogyrida</td>
<td>Rutilus rutilus</td>
<td>Pulp and paper mill effluent</td>
<td>Reduced abundance and mean number of species</td>
<td>24</td>
</tr>
<tr>
<td>Rhabdocolyta fennica (Digenaea)</td>
<td>Rutilus rutilus</td>
<td>Pulp and paper mill effluent</td>
<td>Higher abundance and intensity</td>
<td>25</td>
</tr>
<tr>
<td>Component community</td>
<td>Barbus barbus</td>
<td>Pollution/eutrophication</td>
<td>Diversity increased with the decrease of pollution and water quality</td>
<td>26</td>
</tr>
</tbody>
</table>

**It is the use of biological responses to assess changes in the environment generally, due to human induced.**

**Bio-monitoring is a valuable assessment tool that is serving increased use in water quality monitoring programs of all types.**

**It is the use of indicators, indicator species or indicator communities.**

**Important component of an ecosystem in the eyes of Ecologist/researcher with different roles at different levels.**

**Fig.-1. Diagram showing the concept of bio-monitoring and sentinel organism and their use as bio-indicators (The concept Adapted from http://www.water.ncsu.edu/watershedss/info/biomon.html with some modification (see Osmond et al., 1995))**

**Bio-monitoring involves the use of indicators, indicator species or indicator communities.**

**Bio-monitoring promotes the use of indicators, indicator species or indicator communities.**

**Sentinel organisms are advantageous because only the fractions that are biologically available is used up & concentrated by the animal.**

**Sentinel organisms, or indicator species that accumulate pollutants in their tissues from the surrounding environment or from food, are important bio-monitoring devices.**

**Non-productive organism in the eyes of layman with no special role.**

**Disease causing agent in the eyes of epidemiologist/health specialist with negative impact on host.**

**Important component of an ecosystem in the eyes of Ecologist/researcher with different roles at different levels.**

**Fig.-2. Showing the concept of Parasite in the minds of different people ranging from common man to ecologist/researcher.**

Apart from above reasons, some workers are also of the opinion that there is a lack of information on the interaction of pollutants and parasites of fish. The changes in parasite communities cannot be linked to specific causal factors or environmental response to different contaminants.
Why parasites should be included in biomonitoring studies?

Reasons
- Parasites out-number free-living organisms
- Parasites show trophic relations: parasites move through food web
- Impact food web dynamics and alter energy flow
- Parasites are vital components of healthy ecosystems

Fig.-3. Why parasites should be used for bio-monitoring changes because of insufficient knowledge.

The suitability of fish parasites is being debated and discussed at various levels. There is also controversy over the use of fish parasites as biological indicators because some authors opine that the presence and the infection levels of parasites are not only influenced by environmental contaminants but also by a variety of natural factors.

Some researchers believe that ecological parameters of parasites should be given prime importance before knowing the impact of any contaminant on the parasite. For instance, investigators concluded that ecology of each parasite species and its tolerance to known pollutants would be required, in order to discriminate pollution effects from natural effects. Many believe that holistic approach is recommended for knowing exact impact.

However, we need extensive studies at different life stages of parasites in field and lab conditions to solve some of the ambiguity regarding the parasite/pollution associations. Meanwhile, parasites can still act as promising early warning indicators due to their unique position in an ecosystem.

Environmental Health and Parasitism: At present lot of attention has been given to eco health, whereby an ecosystem can be considered as being healthy or not. In broader sense, healthy ecosystem is one that is sustainable—that is, it has ability to maintain itself at any cost. An ecosystem can be defined as a complex of living organisms, their physical environment, and all their interrelationships in a particular unit of space (Britanica Concise Encyclopedia). Due to numerous factors, like, climate change, pollution, habitat fragmentation etc., our ecosystem is in trouble. Health of an ecosystem is dependent on the good functioning of all its components whether they are abiotic or biotic. In order to have a complete view about the healthy status of an ecosystem, it is appreciated that one should apply holistic and integrated approach. This approach of integrating various aspects is essential because it is generally not known which environmental stress responses or combinations of responses might be affected and therefore suitable for revealing the effect of stress on eco health.

Importance of parasites as an indicator of an ecosystem health has been discussed in detail by some researchers. Some workers have given prime importance to parasites for assessment of environmental health. Effective management of our natural resources requires an understanding of ecosystem structure. As parasites are, cosmopolitan and therefore they have great impact on ecosystem as well as on the host. Parasites may also regulate host population dynamics, influence community structure and reflect the host’s position in the food web. There is need for integrating environmental parasitology with eco toxicology so that both the branches will benefit. This will in turn help in predicting the environmental health of whole ecosystem, which is a major concern for ecologists and environmentalists.

There is debate among parasitologists and ecologists whether to call healthy ecosystem one, which is rich in parasites or vice versa. In past some workers have put forward their viewpoints on this issue and there has been little consensus in this regard. Therefore, before we make conclusions on the relationship between environmental health and parasitism, we must know the importance of parasitism in ecological processes. This will provide us clue about the role played by the parasite in an ecosystem. This has been also discussed by Horwitz and Wilcox where they agreed with earlier workers that parasites structure the ecosystem functioning. We recommend here linking of other ecosystem processes with parasitism. For this we need to take integrative approach.
whereby we should study other ecological processes and see whether there is any link.

Are parasites real contenders for revealing environmental impacts? This is still unresolved question that cannot be answered at this time because we are still lacking information on bioaccumulation capability of parasites. There is a need of holistic approach to elucidate the environmental impacts on parasites. However, in recent past some workers have used meta-analysis to determine possible statistical interactions between environmental impact variables and parasites. Notable contribution is from Martinez (Vidal-Martinez et al. and Blanar). Vidal-Martinez et al. in their meta-analysis compiled relevant studies published in the previous years and demonstrated significant effects and interactions between parasite levels and the presence and concentration of various pollutants and/or environmental stressors. They found that the 52 studies and their 242 comparisons, as well as the field studies subset, revealed no significant overall effects or interactions. All the experimental and accumulation studies subsets showed significant overall effect sizes for both factors and the interaction. They finally suggests that environmental impacts have significant effects on parasites, and is the first to determine quantitatively the interaction terms of these factors.

Blanar et al. attempted to show how meta-analysis can be used to show the capability of parasite-fauna for the biological assessment programme. They stated that monogeneans and digeneans are right choice for biological indicators of contamination in water bodies.

CONCLUSIONS

From the above discussion, we conclude that parasites should be considered as sentinels for environmental monitoring provided we have an idea about the life cycle stages, ecology and accumulation capability of a particular parasite species. The environmental parasitology is a novel area, which will unravel the hidden enigmas in future course of time. With this, we are shifting to the ecosystem approach, a synonym for an integrated or holistic approach. This approach of integrating various aspects is essential because it is generally not known which environmental stress responses or combinations of responses might be affected and therefore suitable for revealing the effect of environmental stress on parasites as well as their hosts. Long-term surveys (parasitological surveys) are needed to elucidate the impacts of deteriorating environmental quality on the community structure of parasites. We also need to improve methodologies, study design, and modelling procedures.

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