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Selection of Suitable Ecosystem Indicators as Tools to Assess the Ecosystem Health of Coastal Lagoons and Their Implications in Management

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Abstract: In recent years, coastal lagoons have been recognized for their significance as productive ecosystems as well as for their important roles in maintaining ecological balance. However, for understanding the structure and functioning of coastal lagoons for preserving their natural quality one has to take into account the rapid degradation of these unique ecosystems. Hence, tools for indicating rapid changes in lagoon ecosystems in order to assess and maintain their health are the needs of the hour. Ecological indicators available to ecosystem managers for this purpose are numerous and often inappropriately selected within the context of lagoon management. Thus it is important to select suitable ecosystem indicators to accurately determine the status of the lagoon ecosystems. This article provides a comprehensive review of the existing ecosystem indicators used in the monitoring of lakes and lagoons. Further, it explores the functionalities of these indicators and correlates them with their applicability in conservation and management of a coastal lagoon. The purpose of this work is to provide a chart of reference for managers of coastal lagoons for easy and suitable selection of ecosystem indicators as tools for use in a cogent environmental monitoring programme.

Key words: Coastal lagoons, ecosystem indicators, lagoon management, ecosystem health.

Introduction

Coastal lagoons are ecosystems of great economic, social and cultural interest to man. Owing to their diverse ecological conditions and complex interactions and processes, they are regions of intense study for scientists. Being unique and different from other transitional environments like estuaries, fjords, bays, tidal rivers and sea straits, coastal lagoons require special attention (Lagoons of India Report, 2000).

In order to maintain their pristine quality and to preserve their unique ecosystem properties, it is necessary to monitor the health of these coastal lagoons periodically. The use of ecological indicators in assessing the ecological status of lagoons has been abundantly recorded in scientific literature. However, different scientists use different benchmarks for assessing ecological quality with the help of indicators (Cook, 1976; Pratt and Coler, 1976; Carle, 1979; Allen and Wilton, 1982; De Pauw and Vanhooren, 1983; Hobson and Kerrans, 1986; Metcalfe, 1989; Moyle and Sladekova, 1994). This gives rise to a general confusion in determining the best possible indicators that can be used for exclusively assessing lagoonal status.

This article reviews the available ecological indicators and the different levels of their applicability to assess lagoon health. Since successful interpretation of scientific data on lagoons is critical for designing an effective modelling approach and subsequent management solutions, it is imperative to lay down the selection criteria

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for scientists utilizing ecological indicators as a means to aid in the effective management of coastal lagoons.

Classification of Ecosystem Indicators

Different ecosystem indicators have been used in assessing different coastal ecosystems. Further, the problems pointed out by these indicators also vary within the context of their application. Hence, these indicators can be classified into several 'levels' based on their properties, i.e., the information that they can provide (Table 1). A comprehensive review of all the prevalent and applied ecological indicators for lagoon monitoring has been provided in 'The Handbook of Ecological Indicators for the Assessment of Ecosystem Health' (Jorgensen et al., 2005). The above studies reveal the effectiveness of the indicators in providing a reliable qualitative assessment of the status of the ecosystem monitored at a particular level (Table 1) corresponding to the specific capabilities of the indicators (Jorgensen et al., 2005). Further using such information, an inference can be made on the selection of the most appropriate indicator for assessing the status of the ecosystem being monitored.

Selection of Suitable Ecosystem Indicators and the Implications in Assessing the Ecosystem Health of Coastal Lagoons

The selection of a suitable ecological indicator to express the system status of lagoons should revolve around some important considerations. It would be easier to address an issue when the scientific aspects of any explicit problem occurring in the lagoon (e.g. eutrophication, non-point source pollution) are known beforehand from a detailed baseline study. This is because the selection of indicators will vary depending on whether an existing problem is known or unknown before progressing further with data collection. For example, if the lagoon has a past record of in-lake problems such as salinity fluctuations or stratification, then the indicators such as salt concentration or amount of nutrients in the water and sediment can adequately express the current status of the lagoon. Other indicators (such as presence or absence of biological species, microbes, etc.) may not bring out the exact status of the lagoon in the light of these problems. Thus selection of an indicator has to be made logically with the support of scientific knowledgebase wherever possible (Table 2).

This approach helps to reduce the total time spent on assessing the status of the ecosystem. Also if the lagoon's precondition is well known before proceeding with a new sampling strategy, it is easier to identify the most suitable of ecological indicators for the scenario and also to make a detailed description of the ecosystem health itself. Further, this kind of a pre-assessment approach ensures that all the relevant and actual problems of the entire coastal drainage basin of the lagoon have been accurately identified by the ecological monitoring plan.

Another important consideration is the selection of those aspects of the ecosystem management strategy that have to be focussed upon in order to address the issue of

Table 1: Different levels of indication of ecosystem health

S. No.	*Level of indicator*	*Properties used for indicating ecosystem health*	*Level of complexity**
1.	Level 1	Presence or absence of specific species	Low
2.	Level 2	Ratio between groups of organisms	Low
3.	Level 3	Concentrations of chemical compounds (e.g. phosphorus, nitrogen etc.)	Low to Medium
4.	Level 4	Concentrations of entire trophic levels (e.g. producers, primary consumers etc.)	Medium
5.	Level 5	Process rates (primary production, respiration etc.)	Medium
6.	Level 6	Biomass, the ratio of respiration/biomass, respiration/ production, production/biomass, production/consumer etc.	Medium to High
7.	Level 7	Resistance, resilience, buffer capacity, biodiversity, turn over rates of carbon, nitrogen or phosphorus	High
8.	Level 8	Thermodynamic variables—exergy, emergy, exergy destruction, entropy production, power, mass and/or energy system retention time and, Economic indicators such as cost/benefit etc.	High

*Depending on the input data provided

Table 2: Differences in the performances of ecological indicators between the initial stage and mature stage (From Jorgensen, 2005)

Level	*Properties*	*Early stages*	*Late or mature stages*
A	**Energetic**		
	1. P/R	1. >>1 or <<1	1. Close to 1
	2. P/B	2. High	2. Low
	3. Yield	3. High	3. Low
	4. Specific entropy	4. High	4. Low
	5. Entropy production per unit of time	5. Low	5. High
	6. Exergy	6. Low	6. High
B	**Structure**		
	1. Total biomass	1. Small	1. Large
	2. Inorganic nutrients	2. Extrabiotic	2. Intrabiotic
	3. Diversity, Ecological	3. Low	3. High
	4. Diversity, Biological	4. Low	4. High
	5. Patterns	5. Poorly organized	5. Well organized
	6. Niche specialization	6. Broad	6. Narrow
	7. Size of organisms	7. Small	7. Large
	8. Life cycles	8. Simple	8. Complex
	9. Mineral cycles	9. Open	9. Closed
	10. Nutrient exchange rate	10. Rapid	10. Slow
	11. Life span	11. Short	11. Long
C	**Selection and Homeostasis**		
	1. Internal symbiosis	1. Undeveloped	1. Developed
	2. Stability (resistance to external perturbations)	2. Poor	2. Good
	3. Ecological buffer	3. Low	3. High
	4. Feedback control	4. Poor	4. Good
	5. Growth form	5. Rapid growth	5. Feedback controlled

ecosystem health to a known extent. This is highly influenced by the funds available for carrying out the studies as well as the time allocated for the monitoring programme. For instance, some management measures may have to be quickly adopted when the time available for salvaging a highly degraded ecosystem is very less (e.g. during floods or due to severe pollution). These conditions require a swift indication of the health status of the lagoon, whereas, to identify and tackle problems extending over longer time scales, other extensive management plans may be adopted. The monitoring strategy and the use of indicators in this case may be highly selective and detailed to express the current status as well as emerging changes.

In addition to the above, the ecological indicators that are selected to represent a lagoon ecosystem must possess the following properties:

1. The indicators must be quantitative in order to express the progress of the ecosystem health from the time of investigation.
2. The indicators must be able to express the improvements in ecosystem health and must be sensitive to changes in the ecological quality of the lagoons.
3. The selection must be made in such a way that, those aspects of the ecosystem status that variant groups of stakeholders may be interested in are satisfactorily indicated.
4. The selection of the indicator must be justified in approaching a honest evaluation of the ecosystem status and must not be selected to support a biased representation of its health.
5. Finally, the indicators must convey the information to the users in a simple and understandable fashion.

Also, too many or too less numbers of indicators selected may only underscore their redundancy in the monitoring and evaluation of lagoon health. An optimum number of carefully selected and tested indicators will constitute a reliable inference engine for extracting information on the ecosystem status over longer periods of time. However, researchers in the past have highly recommended to follow the changes in biodiversity of ecosystems as the most relevant and reliable indicator of the changes in the ecosystem (Jorgensen, 2005).

Case Studies

Case studies from major lakes and lagoons across the globe have highlighted the importance of selecting suitable ecological indicators in integrated lake or lagoon management (Table 3). The following two examples from India (ILEC, 2005) underscore the important role of ecological indicators in defining the ecosystem status.

In Bhoj Wetlands (Madhya Pradesh), India, the problem of contamination of the ecosystem with heavy metals was investigated using the indicators such as concentrations of heavy metals, phosphorus and other nutrients from water and sediment, littoral and land-based activities. The indicators revealed severe contamination with heavy metals during specific periods of a year coinciding with the religious festivals. Results of the investigation revealed a correlation of high contamination with the cultural settings of the place when the indicators were used to study the ecosystem periodically. Thus it was concluded that contamination with heavy metals was due to the immersion of idols during religious festivals (ILEC, 2005).

Similarly, ecological indicators such as salinity, turbidity, water level and sediment deposition were used to study the effects of river flow scenarios on the spatial and temporal patterns of hydrological and geo-morphological parameters for Chilika Lagoon, east coast India. Reduction in salinity as indicated was evidenced by the lesser inflow of seawater. The mouth of the lagoon to the sea was obstructed by excess sediment accumulation and these factors indicated the degradation of the brackishness of the lagoon, reducing productivity. The study showed that construction of new mouth at the channel zone had proved to be a highly efficient management solution in preserving lagoon quality and to alleviate user-conflicts among local fishermen (ILEC, 2005).

The most important conclusions obtained from these comprehensive experiences in selection of suitable indicators are as follows:

1. A successful monitoring strategy provides valuable insights into the baseline condition of the lake or lagoon.
2. Indicators of ecological status have been the cornerstones in illustrating and predicting the ecosystem health.
3. The indicators used in the studies have in general been numerous and demonstrate a high degree of variations in the lake or lagoon health.
4. The changes in the biodiversity of the ecosystems have been the most widely used and most relevant indicator in all these studies.
5. The need for controlling the nutrient regimes of the lakes has been consistently indicated in all the major lakes and coastal basins.
6. The shift from an autrophs-dominated to a heterotrophs-dominated status of major lakes and lagoons is highlighted as a significant point of concern for ecosystem managers.
7. Long-term monitoring of lakes and coastal lagoons using ecological indicators can have serendipitous effects in interpreting ecosystem changes, quite unrelated to the original goal of the monitoring programme itself.
8. In cases where the scientific information about the lakes and lagoons is not fully utilized, the ecosystem behaviour may be erroneously diagnosed and the scientific input for management also lessened considerably.
9. The roles played by ecological indicators in explaining ecosystem health are invaluable for a holistic ecosystem model development.
10. Finally, the use of ecological indicators helps to attain the three-fold objectives of lake/lagoon basin management namely, to understand the limits of the ecosystem resources, to enlighten difficult-to-see connections between environmental parameters and to provide novel/innovative solutions to manage the problems faced by the ecosystem.

Based on the above inferences, a compilation of the indicators, their nature and their selectivity in depicting the ecosystem characteristics has been given in Table 3. This table can be used as a reference chart for rapid and appropriate selection of indicators while investigating a coastal lagoon ecosystem.

Conclusion

From the above discussion it can be seen that the use of ecological indicators is the key to an effective lagoon or lake monitoring strategy. The successful selection of indicators, in the right combination often preludes a successful modelling and management programme. This work presents a general base of reference for the managers of lagoon ecosystems to select the appropriate indicators for their ecosystem monitoring and modelling programmes (Table 3). However, it should be noted that

Table 3: Selection of indicators to denote the health based on the existing problems in a lagoon ecosystem

	Problems in a lagoon ecosystem	*Possible ecological indicators capable of implying the status*
In-lake problems	Salinity changes	Salt concentration, appearance of salt-tolerant or salt-sensitive species of microorganisms
	Eutrophication	Concentrations of nitrogen, phosphorus and decrease in concentrations of dissolved oxygen, siltation, phytoplankton concentration, primary production
	Weed infestations	Species and biomass of weeds and their taxonomy
	Unsustainable fishing practices	Biomass and trophic concentration of fishes, algae, zooplankter, birds and changes in the food web, estimates of fishing activities, use of fish pens and fine mesh sizes of nets, increased turbidity
	Newly introduced species	New species of fishes, algae, zooplankter, crabs, microorganisms and other biota, their life cycles etc.
	Changes in nutrient exchange regimes	Concentrations of nitrogen, phosphorus and dissolved oxygen in water and sediment, their residence times, nutrient exchange rates, mineral cycles etc.
	Acidification	pH and pH buffering capacity of the water and the sediment
Problems of basin origin	Non-point source pollution	Concentrations of nitrogen, phosphorus, BOD, COD, presence of coli forms and other pathogenic microbes in water or sediment
	Water abstraction and changes in run-off	Volume of water, rate of evaporation, precipitation, water level, hydrological cycle, land use practices, shore land activities, salt panning, abstraction of water for horticulture and agriculture, construction of dams on source rivers, aquaculture practices
	Effluents and storm water	Volume of water, rate of precipitation, water level, bathymetry of the lagoon, physico-chemical characteristics of the effluents
	Excess sediment inputs	Total solids, suspended sediment concentration, dissolved sediment concentrations, colloids, grain size of sediments, long shore and cross shore transport mechanisms, sediment budget, and accumulation of sandbars, decrease in lagoon depth, siltation, transparency of water column
	Industrial pollution	Concentrations of industrial effluents, heavy metals, solvents, oil and grease, hazardous chemicals, BOD, COD, decrease in lagoon productivity etc.
Littoral problems	Use of agrochemicals and pesticides	Concentrations of nitrogen, phosphorus, potassium from fertilizers, pesticides, absorption of the nutrients at different trophic levels, bio-concentration in tissues of aquatic biota
	Changes in land use pattern	Developmental activities and industrialization on the lake shore or lagoon shore, loss of wetlands, burning of fossil fuels
	Constructions, man made structures and other engineering technologies	Effects of construction of hydraulic control structures, dams, hydroelectric plants or thermal power plants, shoreline and littoral habitat destruction, flood diversion canals and sluice gates, artificial circulation and water-level drawdown on the productivity of the lagoon or lake
Transboundary problems	Toxic and hazardous chemical contamination	Movement of chemicals and their plume by advection and dispersion, the characteristics of toxic and hazardous chemicals discharging industries along the coast with accumulation into lagoon, groundwater contamination
	Long-shore sediment transport	Sediment transport mechanisms, sediment budget, and accumulation of sandbars, decrease in lagoon depth, inflowing sediment plume
	Invasive species	Presence of invasive parasitic fishes and sea lamprey, decrease in productivity of lagoon, disappearance or decrease in the number of native species
Problems with regional global implications to climate	Release of greenhouse gases	Methane cycling from the lagoonal sediment and water to atmosphere; cycling of carbon-dioxide, increase in local and regional temperatures, changes in meteorological characteristics of the region etc.
	Loss of habitat and biodiversity	Loss of wetlands and mangroves, decrease in number of inhabitant and migratory species of flora and fauna, decrease in lagoon productivity and yield
	Atmospheric deposition of nutrients into lagoon	Atmospheric concentrations of phosphorus sulphur etc., their flux patterns and biogeochemical cycling, deposition of mercury from fossil fuel based power plants

the selection of indicators for an integrated lagoon management scheme may become tedious if it is not carried out in conjunction with the existing knowledgebase on the lagoon characteristics. Problems in a lagoon are often synergistically expressed, although their underlying causes may vary. As illustrated by the examples provided in this paper, use of indicators can help to resolve these issues and also correlate the relationships between the problems of the lagoon to its actual environmental status.

Thus, selecting suitable indicators is essential for a balanced, time-inexpensive, focussed and cogent modelling-cum-management strategy, as it has far-reaching effects on the health of the ecosystem itself. By recounting the experiences of lake and lagoon managers worldwide, this article has provided an easy chart of reference for ecosystem strategists faced with the task of selecting suitable ecosystem indicators to augment their research and to fortify with insightful lagoon development plans aimed at the yet-distant goal of global sustainability.

References

Allen, M.D. and J.N. Wilton (1982). Algae as biological indicators of water quality. *J. Inst. Wat. And Env. Mgmt.*, **12**: 112-121.

Carle, F.L. (1979). Environmental monitoring potential of the Odonata with a list of rare and endangered anisoptera of Virginia, United States. *Odonatologica*, **8**(4)**:** 319- 323.

Cook, S.E.K. (1976). Quest for an index of community structure sensitive to water pollution. *Env. Poll.*, **11:** 269-288.

De Pauw, N. and G. Vanhooren (1983). Method for biological quality assessement of water courses in Belgium. *Hydrobiologia*, **100:** 153-168.

Hobson, G.J. and V.L. Kerrans (1986). Biological Indicators. *J. N. Amr. Benthgl. Soc.* **4:** 115-199.

International Lake Environment Committee (2005). Managing Lakes and their basins for sustainable use: A report for Lake basin managers and stakeholders, Lake Basin Management Initiative, International Lake Environment Committee Foundation, Japan, 200 p.

Jorgensen, S.E., DeBernanardi, R., Ballatore, T.J. and V.S. Muhandiki (2003). Lake Watch 2003: The Changing State of the World's Lakes, International Lake Environment Committee Foundation, Japan, 100 p.

Jorgensen, S.E., Xu, F.L. and R. Constanza (2005). Handbook of Ecological *Indicators for the Assessment of Ecosystem Health*. Elsevier, New York, 300 p.

Lagoons of India State-of-the-art report (2001). ENVIS Publication Series: 3/2001 CAS in Marine Biology, Parangipettai, 50 p.

Metcalfe, J.L. (1989). Biological water quality assessment of running waters based on macroinvertebrate communities: History and present status in Europe. *Env. Poll.* **60:** 101-139.

Moyle, R.M. and E.B. Sladekova (1994). Role of periphyton as an indicator of water quality. *J. Res. and Devt.*, **9:** 38-46.

Pratt, J.M. and R.A. Coler (1976). A Procedure for the routine biological evaluation of urban run-off in small rivers. *Wat. Res.*, **10:** 1019-1025.

World Bank (2005). Lessons for Managing Lake basins for Sustainable Use, Environment Department Report No 32877, World Bank, Washington D.C., 100 p.

World Lake Vision Action Report (2007). Implementing the World Lake Vision for Sustainable Use of Lakes and Reservoirs. International Lake Environment Committee, Japan, 250 p.