# Ecosystem-based Indicators for Monitoring the Status of Rivers in Ghana

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**Abstract**

The ecosystem approach is a widely accepted framework for natural resource management and has been adopted by the Convention on Biological Diversity (CBD) as the primary framework for action under the convention. The ecosystem approach, as defined by the CBD, is underpinned by a set of twelve principles and points of operational guidance that are intended to aid the implementation of the approach. However, these are overarching principles and implementing an ecosystem approach in practice requires practical tools for local managers and policy makers that embody the principles but are appropriate for the challenges faced at a local level. Here, we present a set of indicators, and a toolkit to aid their application, that are intended to support the implementation of the ecosystem approach in the management of riverine ecosystems in Ghana. The application of the indicators is illustrated using data gathered for the Densu, Ayensu and Birim catchments.

## Introduction

The Convention on Biological Diversity (CBD) defines the ecosystem approach as 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way', following

Smith and Maltby (2003). By taking into account ecological, economic and social considerations within a single framework, the approach recognises that humans, with their cultural diversity and varied societal needs, are an integral part of ecosystems.

In its earliest discussions the Convention recognised the need to take a holistic rather than a strictly conservation orientated approach to address the problems of loss of biological diversity. Simultaneously, the emphasis on more traditional approaches to conservation based on single species management and protected areas has been giving way to broad-based integrated methodologies involving a wide range of stakeholders and different scales of application that consider ecosystems as a whole. The ecosystem approach provides the conceptual underpinnings and broad structure by which this more integrated methodology can be implemented.

The ecosystem approach is not a rigid framework but a highly flexible methodology that can be adapted to a wide range of situations and particular problems of sustainable natural resource management. Application ensures that the entire sphere of influence of a problem is taken into account when developing the management actions necessary to achieve a particular solution. It also means that the whole range of factors – social, economic, cultural as well as scientific and technical – which have a bearing on the problem need to be considered. Using the example of a river basin, the maintenance or recovery of good ecological water quality, sufficient to support a healthy fishery for instance, requires not only good scientific understanding of ecosystem dynamics and environmental controls, but also the ability to influence human actions taken at a local level throughout the whole basin, not just in riparian areas. Such influences are invariably linked to patterns of agriculture and various economic and social policies not directly connected with concerns for the riverine environment. The ecosystem approach provides the concept and outline structure by which all these dimensions can be considered within a single framework with a better chance of succeeding in an improved balance of conservation and sustainable development objectives. Twelve principles and additional notes of guidance that have been distilled through a long process of consultation and development underpin the approach.

In further endorsing the approach the Conference of Parties (COP) of the CBD recommended its implementation with appropriate adaptation to local, national and regional conditions. It also requested the identification of good case studies and the implementation of pilot projects (which could apply from the outset rather than retrofitting the logic and methodology of the EA). The COP also expressed the need for more awareness of the approach, experience-sharing and capacity building necessary for implementation. Above all, whilst there is increasing knowledge of what the ecosystem approach is trying to achieve there is still a major gap in the understanding of exactly how to do it.

A suite of indicators of riverine ecosystem health, and tools for its application, has been developed for Ghana in order to address some of these gaps and support the implementation of the ecosystem approach in the management of riverine ecosystems.

*Riverine ecosystem indicators*

No single indicator can provide an adequate picture of ecosystem quality so a suite of indicators has to be chosen that gives a general overview of the condition of the river. The selection of metrics and parameters is the key challenge in developing a suite of indicators that reflect ecosystem quality in rivers. There are a large number of potential parameters or processes that could be measured but not all are suitable as indicators.

Key considerations include the accuracy with which they can be measured and their spatial and temporal variability as, generally, indicators are infrequently measured in space and time and therefore highly variable ecosystem attributes may not be appropriate as indicators. The purpose of the indicators is also an important consideration. Potentially, indicators can be used to give a one-off assessment of ecosystem quality, to monitor changes over time, to provide early warning of problems, act as a communication tool or assess progress towards targets. In practice, the choice of indicators has to reflect the practicality of measurement, the information they can convey and the availability of standards or reference data to show how good or bad a particular value is. Compatibility with existing methodologies (e.g. water quality indices) is also an important consideration.

Yli-Viikari *et al*. (2007) review quality criteria for indicators. Some commonly identified criteria for indicators include:

- Measurable (availability of data and cost effectiveness of collection)
- Analytically sound and based on science
- Well documented
- Responsive to changes in ecosystem state

- Ability to adapt to different spatial scales of assessment;
- Existence of a reference value
- Easy to interpret
- Policy relevance

In addition to the general considerations of selecting good indicators, if indicators are to support the implementation of an ecosystem approach to management there are a number of additional considerations. The connectedness of running waters with their floodplains and catchments must be considered, as does information on the broader landscape-level management (Boulton, 1999). The principles of the ecosystem approach stress the importance of considering connectedness and the scale at which process operate.

Water chemistry has been traditionally used in industrial countries as a measure of freshwater quality, but used in isolation it has several drawbacks and can only form a component of indicators based on an ecosystem approach. Only a few variables, out of several hundred thousands (including many persistent organic pollutants (POP) by which natural and polluted waters vary) are measured, so only a limited picture is obtained; water chemistry is relatively expensive to measure; many variables, including those of the most important polluting substances, vary greatly over short periods, usually much shorter than the sampling intervals; and for many chemical variables (including pH oxygen concentration, conductivity, major ions like calcium, sodium, chloride and sulphate) a simple standard has no meaning. A significant change will have meaning but can only be seen from a run of several years of observations.

Much more useful and accurate information of the state of a water body is obtained from land use and ecological observations. Chemical variables are, however, included in the indicator scheme presented here to ensure compatibility with existing data.

With these criteria, and the requirements of the ecosystem approach in mind, the indicators proposed here are intended to allow an ecosystem-based assessment of the overall condition of a river in a Ghanaian context. As such, they are intended to be relatively easily quantified used ecological field observations, simple measurements and ecological sampling. The indicator set also includes some water chemistry metrics but for the most part these have been kept as simple as possible and can be quantified using cheap and easily obtained equipment (e.g. temperature, conductivity). As a whole the indicator set encompasses catchment-scale indicators of disturbance, water chemistry and ecological indicators it reflects an Ecosystem Approach.

Table 1 outlines the indicators adopted for this scheme and gives a brief outline of the rationale for including the indicator in the assessment scheme. A more complete description of the indicators and the caveats for their use can be found in the information sheets that accompany the indicators.

The set of indicators developed here are intended to take into consideration the general requirements of ecosystem state indicators outlined above and to take into account the requirements of the ecosystem approach. The indicators incorporate an ecosystem approach in that they include consideration of the condition of the wider catchment, not just the location being

TABLE 1

*Indicators for the assessment scheme and brief description of rationale for inclusion.*

| *Indicator* | *Rationale* |
|---|---|
| 1. Percentage of catchment still covered in natural/semi-natural vegetation (%) | Vegetation cover affects hydrology and delivery of nutrients and sediments to rivers |
| 2. Change in total runoff (%) | Changes to the hydrological regime due to climate change or abstractions has an impact on instream and riparian ecology |
| 3. Volume of reservoirs within the catchment as a percentage of total runoff (%) | Changes to the hydrological regime (e.g. frequency of high and low flow events) has an impact on instream and riparian ecology |
| 4. Percentage of bank length (500m section) on both sides still occupied by natural/semi-natural vegetation (%) | Intact riparian zones act as buffers for sediment and nutrient delivery to rivers. Riparian zones also act as important habitat. |
| 5. Concentration of available phosphate – P (µg/l) | Increase in the rate of supply of P can lead to accelerated growth of plants and algae, which may increase to create turbid conditions and nuisance blooms. In extreme cases, these may contain toxins or lead to deoxygenation. |
| 6. Concentration of available nitrate – $NO_3$-N (mg/l) | Nitrogen is very frequently, though not necessarily always, the limiting nutrient to algal growth in the tropics. |
| 7. Concentration of available ammonium - $NH_4$ (ìg/l) | High levels generally indicate severe pollution from defecation of watered stock, or human effluent. Consistently high concentrations suggest a high probability of a pollution problem. |
| 8. Concentration of total suspended solids (mg/l) | Total suspended solids can affect water colour and attenuate light penetration of the water column. This has implications for primary production of plants and algae, and for the temperature of the water column. |
| 9. Conductivity (percentage change, %) | Changes in conductivity can indicate pollution. Conductivity tends to be increased by agricultural activity, because ploughing and addition of fertilisers affects the quality of runoff water. |
| 10. Dissolved Oxygen (percentage saturation, %) | Decreases in concentration may indicate pollution by gross organic matter. Low levels affect survival of fish and other aquatic organisms. |
| 11. Temperature (difference from shaded stream, °C) | Temperature is important in determining the rates of biological processes |

| | |
|---|---|
| 12. Biological (Biochemical) Oxygen Demand (BOD, ppm)) | BOD is widely used as a measure of the degree of gross organic pollution of water. |
| 13. Change in pH at standard time of day compared with pristine reference site (*p*H units) | Different species are suited to different ranges of pH. Outside its normal range, an organism may face physiological stress. High acidity increases solubility of some elements and compounds that may be toxic to animals and plants. |
| 14. Number of species of submerged native plants counted at site (number) | In contrast to floating plants, submerged native plants are indicators of good ecosystem quality. |
| 15. Number of species of introduced plants counted at site (number) | Introduced plants become problems when they grow prolifically, out compete the native biota and reduce the local biodiversity. Heavy plant growths may clog rivers, cause local flooding, reduce available fish habitat and impede navigation |
| 16. Percentage of benthic fauna that are deposit feeders (%) | |
| 17. Percentage of benthic fauna (numbers, families) that are Plecoptera, Ephemeroptera and Trichoptera (%) | Higher proportions of these groups in the benthic fauna are indicators of good ecosystem quality |
| 18. Percentage of benthic fauna (numbers, families) that are predators (%) | |
| 19. Number of fish species (number) | In general there will be a high diversity in pristine stream lengths. Disturbance will reduce the number of niches and the number of species of fish and shellfish found. |
| 20. Number of bird species recorded in standard time over 100m length of the river (number) | There is a great deal of interchange between the wetted channel and the riparian forest to distances of some tens to hundreds of metres to either side of the channel. Emerging insects from the stream provide food for birds, bats and spiders and, therefore, bird diversity is related to the health of the riverine ecosystem. |

assessed, and they cover the physical catchment condition, the water chemistry and the ecology, recognising the key concerns of the ecosystem approach to consider the interconnectedness of ecosystems and ecosystem components.

As ecosystem-based indicators incorporate considerations of landscape, water chemistry and different branches of ecology, even if intended to be applied by professionals the indicators must be suitable for application by non-specialists as professionals in one of these areas will be a non-specialist in others. The indicators developed here are intended to be appropriate for application by non-specialists from locally-based NGOs as well as Government departments or organisations charged with protection, monitoring or reporting on ecosystem condition. Nevertheless, while the indicators chosen here are intended to be as simple as possible, without compromising the objective of providing a robust tool for assessing ecosystem quality, there remain a number of challenges in implementing them widely. These include the lack of appropriate resources for water quality testing and species identification, appropriate training for staff and access to information such as remote sensing data and water resource data required to quantify some indicators. Recognising the challenges that may be faced by some organisations in quantifying all of the indicators, in particular the availability of data for pristine reference sites, the assessment of the indicators is not dependent on having all of the indicators quantified although, for the reasons outlined above, priority should be given to the ecological and catchment condition indicators.

*Indicator toolkit*

The application of the indicators is supported by a toolkit that comprises a spreadsheet tool for indicator assessment, information sheets for each indicator and other supporting material (e.g. invertebrate taxonomic resources).

The spreadsheet tool has been developed in Microsoft Excel and provides a semi-quantitative assessment of the status of the site being assessed for each indicator and an overall assessment for the location where it is applied. The information sheets for each indicator provide the rationale for choosing the indicator, outline methodologies for quantifying the indicator and sources of further information.

Standards have been established for each of these indicators that are used to assess each of them as bad, poor, moderate, good or high based on their value in order to provide a guide to the ecological quality of the river being assessed. These categories are used in an absolute rather than relative sense. The 'high' category is intended to reflect a totally undisturbed, pristine catchment rather than being the currently existing best quality site in a particular region. The 'bad' category is intended to show that a site is qualitatively different from the conditions that would exist at that location without human impacts. In many cases, particularly nutrients, ecosystems may be much more sensitive than people to particular variables and so the standards set here may appear unduly strict in some cases. For instance, drinking water limits for nitrate are often set at around 50 mg/l (e.g. EU Drinking Water Directive 98/83/EC on the quality of water intended for human consumption) but ecological criteria might set limits at concentrations twenty-five or more times lower (James *et al*., 2005).

The standards established are given in full in Table 2. These are based on field data, values in literature or expert judgement where no other information was available. However, the assessment scheme has been designed so that the standards can be modified later in the light of new information. As, even under pristine conditions, a longitudinal gradient in some of the indicators would be expected from headwaters to lowland streams, and there would be expected differences between catchments with different natural vegetation types (even if pristine), each site being assessed is categorised according to one of six types and there are differences in the standards for some indicators depending on the category it falls within. The categorisation of river types is:

1. Forest catchment, headwater erosive;
2. Forest catchment, middle stage;
3. Forest catchment, lowland floodplain;
4. Savannah catchment, headwater erosive;
5. Savannah catchment, middle stage;
6. Savannah catchment, lowland floodplain;

Those applying the indicator toolkit use the supporting information to quantify as many of the indicators as possible and enter the values into the spreadsheet tool. This provides as assessment for each indicator from bad to high and performs an overall site assessment. The overall site assessment is made using a 75% threshold i.e. 75% of the indicators that have been assessed have to be within a given category or better for the overall site assessment to achieve that class. The 75% threshold was based on the output from ECOFRAME (Moss *et al*. 2003) where a similar tool was developed.

*Application of the toolkit*

The toolkit was tested within the Ayensu, the Densu and Birim catchments with data collected as part of the Darwin Initiative project *Tool kits for the Sustainable Management of Ghana's Riverine Biodiversity* relating to water chemistry, landuse and ecology. [Detailed descriptions of the sites, data collection methodology, analyses and conclusions of the each of these components are presented elsewhere in this volume.

Values for some indicators that consider differences in the value of the indicator from pristine sites could not be calculated due to lack of reference sites (Indicator 9 – Conductivity change, Indicator 11 – Temperature change, Indicator 13 – *p*H change). However, these parameters were measured and, over time, repeated applications of the tool-kit can be used to show changes in these indicators. Two indicators (Indicator 10 – Dissolved oxygen; Indicator 12 – BOD) were not measured as part of the same sampling programme as other water quality parameters but the Water Research Institute provided data for nearby sites (WRI, 2008) and these have been integrated for this assessment.

Twenty indicators were quantified for each of the sites, meaning that a good level of confidence can placed in the overall assessment. The results of the assessment for each indicator and the overall assessment for each site are presented.

## Discussion

The indicator based assessment tool presented here provides a methodology for applying the ecosystem approach to riverine ecosystems in Ghana. Its application using data collected at various sites in the Ayensu, Densu and Birim catchments has shown that it is a practical tool that can be easily applied. The assessment of the sites has shown them all to be in not too good condition, characterised by high nutrient concentrations (nitrate and phosphate), high suspended solids and low plant diversity with highly variable assessments of the invertebrate fauna. This result is consistent with the water quality based assessment of Ansa-Asare and Gordon (this volume) which showed that the Ayensu, Densu and Birim deteriorated in quality over the period of the study and, according to Ghana's Water Quality Index (WQI) were in the 'Fairly

TABLE 2

*Standards used in the assessment of the indicators for different catchment types.*

| | Original Forest Catchment (headwater erosive) | | | | | Original Forest catchment (middle stage) | | | | | Original Forest Catchment (lowland floodplain) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Indicator description* | *Bad* | *Poor* | *Moderate* | *Good* | *High* | *Bad* | *Poor* | *Moderate* | *Good* | *High* | *Bad* | *Poor* | *Moderate* | *Good* | *High* |
| 1. Percentage of catchment still covered in natural/semi-natural vegetation (%) | ≥0, <25 | ≥25, <50 | ≥50, <80 | ≥80, <100 | 100 | ≥0, <25 | ≥25, <50 | ≥50, <80 | ≥80, <100 | 100 | ≥0, <25 | ≥25, <50 | ≥50, <80 | ≥80, <100 | 100 |
| 2. Change in total runoff (%) | ≥50 | <50, ≥25 | <25, ≥10 | <10, ≥0.1 | <0.1 | ≥50 | <50, ≥25 | <25, ≥10 | <10, ≥0.1 | <0.1 | ≥50 | <50, ≥25 | <25, ≥10 | <10, ≥0.1 | <0.1 |
| 3. Volume of reservoirs within the catchment as a percentage of total runoff (%) | ≥50 | <50, ≥25 | <25, ≥10 | <10, ≥0.1 | <0.1 | ≥50 | <50, ≥25 | <25, ≥10 | <10, ≥0.1 | <0.1 | ≥50 | <50, ≥25 | <25, ≥10 | <10, ≥0.1 | <0.1 |
| 4. Percentage of bank length (500m section) on both sides still occupied by natural/semi-natural vegetation (%) | ≥0, <25 | ≥25, <50 | ≥50, <80 | ≥80, <100 | 100 | ≥0, <25 | ≥25, <50 | ≥50, <80 | ≥80, <100 | 100 | ≥0, <25 | ≥25, <50 | ≥50, <80 | ≥80, <100 | 100 |
| 5. Concentration of available phosphate – P (µg/l) | ≥25 | <25, ≥11 | <11, ≥6 | <6, D | ND | ≥25 | <25, ≥11 | <11, ≥6 | <6, D | ND | ≥25 | <25, ≥11 | <11, ≥6 | <6, D | ND |
| 6. Concentration of available nitrate – NO-N (mg/l) | ≥0.75 | <0.75, ≥0.5 | <0.5, ≥0.25 | <0.25, D | ND | ≥0.75 | <0.75, ≥0.5 | <0.5, ≥0.25 | <0.25, D | ND | ≥0.75 | <0.75, ≥0.5 | <0.5, ≥0.25 | <0.25, D | ND |
| 7. Concentration of available ammonium - NH (ig/l) | ≥200 | <200, ≥40 | <40, ≥20 | <20, D | ND | ≥200 | <200, ≥40 | <40, ≥20 | <20, D | ND | ≥200 | <200, ≥40 | <40, ≥20 | <20, D | ND |
| 8. Concentration of total suspended solids (mg/l) | ≥8 | <8, ≥6 | <6, ≥4 | <4, ≥1 | <1 | ≥15 | <15, ≥10 | <10, ≥6 | <6, ≥1 | <1 | ≥30 | <30, ≥20 | <20, ≥10 | <10, ≥4 | <4 |
| 9. Conductivity (percentage change, %) | ≥100 | <100, ≥40 | <40, ≥20 | <20, ≥10 | <10 | ≥100 | <100, ≥40 | <40, ≥20 | <20, ≥10 | <10 | ≥100 | <100, ≥40 | <40, ≥20 | <20, ≥10 | <10 |
| 10. Dissolved Oxygen (percentage saturation, %) | <10 | ≥10, <25 | ≥25, <50 | ≥50, <75 | ≥75 | <10 | ≥10, <25 | ≥25, <50 | ≥50, <75 | ≥75 | <10 | ≥10, <25 | ≥25, <50 | ≥50, <75 | ≥75 |
| 11. Temperature (difference from shaded stream, °C) | ≥5 | ≥2, <5 | <2, ≥1 | <1, >0 | 0 | ≥5 | ≥2, <5 | <2, ≥1 | <1, >0 | 0 | ≥5 | ≥2, <5 | <2, ≥1 | <1, >0 | 0 |
| 12. Biological (Biochemical) Oxygen | ≥50 | <50, ≥20 | <20, ≥10 | <10, ≥5 | <5 | ≥50 | <50, ≥20 | <20, ≥10 | <10, ≥5 | <5 | ≥50 | <50, ≥20 | <20, ≥10 | <10, ≥5 | <5 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Demand (BOD, ppm) | | | | | | | | | | | | | | | |
| 13. Change in pH at standard time of day compared with pristine reference site (pH units) | ≥2.5 | <2.5, ≥2 | <2, ≥1.5 | <1.5, ≥1 | <1 | ≥2.5 | <2.5, ≥2 | <2, ≥1.5 | <1.5, ≥1 | <1 | ≥2.5 | <2.5, ≥2 | <2, ≥1.5 | <1.5, ≥1 | <1 |
| 14. Number of species of submerged native plants counted at site (number) | 0 | 0 | 1 | 2, 3 | ≥4 | 0 | 1 | 2, 3 | 4, 5 | ≥6 | 0 | 0 | 1 | 2, 3 | ≥4 |
| 15. Number of species of introduced plants counted at site (number) | ≥4 | 3 | 2 | 1 | 0 | ≥4 | 3 | 2 | 1 | 0 | ≥4 | 3 | 2 | 1 | 0 |
| 16. Percentage of benthic fauna that are deposit feeders (%) | ≥80 | ≥60, <80 | ≥40, <60 | ≥20, <40 | <20 | ≥80 | ≥60, <80 | ≥40, <60 | ≥20, <40 | <20 | ≥50 | ≥45, <50 | ≥40, <45 | ≥20, <40 | <20 |
| 17. Percentage of benthic fauna (numbers, families) that are *Plecoptera*, *Ephemeroptera* and *Trichoptera* (%) | <20 | ≥20, <30 | ≥30, <40 | ≥40, <50 | ≥50 | <20 | ≥20, <30 | ≥30, <40 | ≥40, <50 | ≥50 | <5 | ≥5, <10 | ≥10, <20 | ≥20, <30 | ≥30 |
| 18. Percentage of benthic fauna (numbers, families) that are predators (%) | <5 | ≥5, <10 | ≥10, <20 | ≥20, <30 | ≥30 | <5 | ≥5, <10 | ≥10, <20 | ≥20, <30 | ≥30 | ≤3 | 3, 4 | ≥5, <10 | ≥10, <20 | ≥20 |
| 19. Number of fish species (number) | 0, 1 | 2 | 3 | 4 | ≥5 | ≤3 | 4 | 5 | 6 | ≥7 | ≤2 | 3 | 4, 5, 6 | ≥7, <10 | ≥10 |
| 20. Number of bird species recorded in standard time over 100m length of the river (number) | 0 | 1, 2 | 3, 4 | ≥5, <10 | ≥10 | 0 | 1, 2 | 3, 4 | ≥5, <10 | ≥10 | 0 | 1, 2 | 3, 4 | ≥5, <10 | ≥10 |

ND = Not Detectable
D = Above detection limit

Good' class in 2005 and the 'Poor' class in 2006, 'Fairly Good' and 'Poor' being the second and third of four classes, respectively. The WQI is intended to show the suitability of water for various uses such as domestic, recreation and agriculture (i.e. irrigation and livestock watering), where such uses are naturally sustainable and, therefore, would be expected to, on average, give a higher rating than the indicator scheme presented here, which is based on the ecosystem requirements. As discussed above, ecosystems can be more sensitive to high levels of some parameters compared to people, particularly for nutrients which have been demonstrated to be very high at the sites assessed for this study (Ansa-Asare and Gordon, this volume).

As such, the indicator scheme presented here can complement already existing indicators used in Ghana e.g. the Water Quality Index by taking the most ecologically relevant water quality parameters and adding ecological indicators and indicators of catchment status to proved an assessment scheme that recognises the ecosystem approach.

While this iteration of the indicator toolkit has concentrated on assessing the physical environment and ecology, a wider interpretation of the ecosystem approach should include indicators of the sustainability of the interaction of people with the riverine ecosystems. These types of social and economic indicators are, however, difficult to define and measure with accuracy and repeatability and it is not always possible to define the limits of sustainability for such indicators.

The current version of the toolkit is available at Institute for Sustainable Water, Integrated Management and Ecosystem Research,(SWIMMER), University of Liverpool, UK and Institute of Environment and Sanitation Studies (IESS) of the University of Ghana, Legon

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