Tool kits for the Sustainable Management of Ghana's Riverine Biodiversity: an Overveiw

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Abstract

The Darwin Initiative funded project *Tool kits for the Sustainable Management of Ghana's Riverine Biodiversity* was a collaboration between the Centre for African Wetlands at the University of Ghana, various units of the University of Ghana and the Ghana Wildlife Society. The project also involved collaborators from Burkina Faso, Nigeria, Cote d'Ivoire, Togo and Benin. The project aimed to address the impediments that remain for Ghana (and its neighbouring countries) in applying the Ecosystem Approach (EA) to riverine wetland management and the delivery of the Convention on Biodiversity (CBD). Priority needs were identified as taxonomic capacity building, a contemporary assessment of the status of aquatic biodiversity in Ghana, the development of practical management tools for rivers and increased engagement of stakeholders in decision-making together with an enhanced environmental awareness throughout Ghanaian society. These were addressed in this project by regional and local staff training, reporting on the current status of aquatic communities, the production of educational and taxonomic resources for a range of users, the development of a set of nested indicators of ecosystem health adapted for use at various levels, and the production of a policy document outlining the means of applying the EA in the management of Ghana's rivers.

Introduction

This project focussed on the first of the three main objectives of the Convention on Biological Diversity (CBD) i.e. the conservation of biological diversity, specifically by developing tools for the sustainable management of riverine biodiversity. However, in doing so this will contribute to the second of the main CBD objectives in that it will facilitate the sustainable use of the ecosystem services delivered by riverine ecosystems. The project also has direct relevance for the inland waters biodiversity thematic programme of the CBD and contributed to cross cutting themes of:

- communication, education and public awareness through contributions to the national biology curriculum
- ecosystem approach in particular, the development of a suite of indicators based around the ecosystem approach

- identification, monitoring, indicators and assessments through the set of indicators for widespread monitoring of riverine ecosystem status

The project concept was based on previous studies, which indicated that knowledge of stream biology in the tropics is patchy and taxonomy is of particular concern for lotic invertebrates in Ghana[1]. The main partnerships essential to delivery of the project was between the University of Liverpool, the Centre for African Wetlands (CAW), the University of Ghana, The Water Research Institute of Ghana and the Ghana Wildlife Society. These partnerships were developed over the course of the project through a number of joint workshops and training activities. A key lesson learned with respect to partnerships is the need for UK staff to spend significant periods of time in the host country building and strengthening relationships. Several unavoidable changes in the management of the project in the UK resulted in a loss of momentum and the need to re-establish relationships with project partners and re-energise the project delivery.

Project Achievements

Impact: achievement of positive impact on biodiversity, sustainable use or equitable sharing of biodiversity benefits

This project was designed to facilitate the sustainable management of riverine biodiversity in Ghana through the development of appropriate tools and inputs to education and monitoring resources and policy development. As such there is only an indirect effect on biodiversity, sustainable use or equitable sharing. The important impacts of the project on biodiversity in Ghana, however, has been the contribution towards key policy documents via the Water Resources Commission, and the integration of an ecosystem approach within these policies. This is discussed further below in the context of the project outcomes.

Outcomes

Achievement of the project purpose and outcomes

The stated purpose of the project was to promote '*the sustainable management of Ghana's riverine wetlands in accordance with the principles of the Ecosystem Approach*'. This was primarily achieved through the development of appropriate tools, based on an ecosystem approach, to enable stakeholder organisations to monitor the status of riverine ecosystems. This output makes a very significant contribution to the management of rivers in Ghana as it provides a set of indicators and associated assessment scheme that can be easily quantified using the resources available at a local level to give an overall assessment of the status of a river. If a monitoring programme were to be implemented using these indicators it could provide valuable information for the management of river ecosystems in Ghana. The contribution of the project to national policies relating to river management also helped to achieve the purpose of the project

Outputs

The following sections outline the delivery made against each of the five outputs set out in the project logical framework:

Training workshops held for staff.

The training delivered by the project was intended to build the capacity necessary in local staff to deliver the project objectives. The first workshop was held in January 2006. This was initially intended for six local staff but was this expanded to include a much larger proportion of the project staff (20 participants in total). This was partly achieved because of a change of emphasis from taxonomic training to more methodological training on applying the Ecosystem Approach to the assessment and management of aquatic systems as this has wider applicability to the group as a whole.

Four Liverpool staff delivered further training to members of the Ghanaian project team on the draft toolkit during a week long visit in January 2007. The original intention was to provide further input into the first of the Regional Workshops for visiting scientists from Ghana's neighbours. However, in the event this could not be carried out as funding was not obtained in time. Further interactions, presentations and discussions of the scientific results were completed with the team members. As part of this workshop a wide group of stakeholders were invited to a presentation about the project and launch of the project website, which was reported in the local press.

A third workshop was held in March 2008. This was held as a joint initiative between this project and START, which released the resources required to engage with a wider group of stakeholders from the wider region having participants from Nigeria, Togo, Benin, Cote d'Ivoire and Burkina Faso. This workshop included sessions on the Ecosystem Approach, wetland management, riverine buffer zones and capacity building for ecosystem management in West Africa.

Range of educational and taxonomic resources produced.

The project has provided input into the national Ghana Senior High School Elective Biology Curriculum for two sections that have been outlined (Ecosystem Approach and Integrated Water Resource Management). Information sheets have also been prepared for each of the indicators developed as part of the project that can be used as educational materials suitable for undergraduate level.

A nested set of indicators of ecosystem health produced.

A list of 20 indicators produced in consultation with the project partners and appropriate for a Ghanaian context, are presented below. The indicators have been designed to reflect the whole-ecosystem perspective embodied in the Ecosystem Approach. Indicators reflect physical catchment descriptors (e.g. percentage of the riparian zone with natural or semi-natural vegetation), water quality parameters (e.g. *p*H, conductivity) and ecology (e.g. species distribution of invertebrates). The indicators have been chosen so that the majority are quantifiable with limited resources although some still require chemical analysis or specialist equipment that are only available to larger institutions in Ghana.

The indicators are embedded within a spreadsheet tool designed in Microsoft Excel that assesses each of the indicators on a five-point scale from 'bad' to 'high' for a particular site, depending on the value for the indicator entered into the spreadsheet. The assessment of individual indicators is based on expert judgement and field data and the relationships between individual indicators and their assessment is presented monitoring over several years of observations.

Chemical quality measures persist because of the dominance of water management in industrial countries by chemists and engineers, and the fact that a value with high precision for use in court prosecutions can be obtained. Much more useful and accurate information of the state of a water body is obtained from land use and ecological observations. The twenty indicators used in the Toolkit are elaborated below. Each of these indicators standards have been established that are used to assess each of them as bad, poor, moderate, good or high based on their value. The standards 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, there is a longitudinal gradient in some of the indicators 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 used to assess the indicators depending on river type. 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.

Indicator 1: Percentage of catchment still covered in natural/semi-natural vegetation

Rationale

The vegetation cover of the catchment has a significant impact on the rivers within the catchment. The main areas where vegetation strongly influences riverine ecosystems are hydrology, nutrient leaching and sediment delivery. Urban, industrial and agricultural land use can also act as an indicator of the delivery of pollutants to rivers. For instance, significant agricultural land use can be an indicator of the likelihood of pollution from agrochemicals (fertiliser, pesticides, herbicides). Forest and savannah landscapes normally have low inputs of agrochemicals and hence pollutant delivery to rivers.

Where the land use is changed from forest to agricultural, industrial or urban this will influence hydrology by increasing runoff and creating higher, shorter duration flood peaks. This is as a result of the generally higher evapo-transpiration (Chappell, 2005) and infiltration capacity of forest and savannah ecosystems. Where the natural vegetation is forest, it has a higher evapo-transpiration relative to other land uses as a result of deeper root structures, higher transpiration of available soil water and canopy interception of precipitation.

Replacing natural forest or savannah cover with agricultural, urban or industrial land will, therefore, generally result in lower evapo-transpiration, and hence an increase in total runoff and in the frequency of both high and low short-term flows. However, where forest is replaced with high water demand crops or those requiring irrigation, the effect may be to decrease total catchment runoff and increase the frequency of low flows, sometimes complete cessation of flow.

clearly on a separate sheet so that the assessment is transparent and can be modified at a later date on the basis of new data. An accompanying hyperlinked set of documents give short (1-2 page) descriptions of the rationale for including the indicator in the assessment scheme, information of how to quantify the indicator and links to further information. An overall site assessment is also provided on the same five-point scale from 'bad' to 'high' using the criterion that more than 75% of the indicators must achieve a given category or higher for the overall assessment to achieve that category. This threshold was established based on the experience of an earlier project that members of the project team contributed to.

A simple database has also been constructed so that assessments for multiple sites can be stored and re-analysed easily within the spreadsheet tool. This facilitates the assessment of time series of data for a single site or comparisons across multiple sites.

A report on current status of aquatic communities in Ghana

A report has been prepared on the status of aquatic communities in Ghana based on the field data collected as part of the project. This is especially targeted to the District Assemblies of the Okyeman area.

Policy documents on the application of the EA in the management of Ghana's rivers

Local staff involved in the project have contributed to the development of two key policy documents in Ghana. The first the National Water Policy of the Ministry of Water Resources, Works and Housing is intended to provide a framework for the sustainable development of Ghana's water resources. The second the draft Buffer Zone Policy aims to ensure that buffer zones around streams, lakes and other surface water bodies are maintained or developed in order to 'restore, conserve and maintain the ecological integrity, and to provide optimal socio-economic benefits of such designated areas'. Two of the stated objectives of this policy are: to maintain the ecological and life-support functions of buffer zones; and to ensure equitably and sustainable utilization and management of buffer zone conservation areas, which will contribute to long-term well-being of resident communities. Both of these objectives align with the objective of the CBD and are consistent with the Ecosystem Approach.

The Indicator List: Tool kits for the sustainable management of Ghana's riverine biodiversity

Use of traditional water chemistry in industrial countries as a measure of freshwater quality, has several drawbacks:

- Only a few variables, out of several hundred thousand (including many persistent organic pollutants (POPs) 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
- Many chemical variables (including pH, dissolved oxygen concentration, conductivity, major ions like calcium, sodium, chloride and sulphate, a simple standard has no meaning. A significant change will have meaning but only after

Giertz *et al.* (2004) demonstrated that the infiltration capacity of savannah and forest soils is significantly higher (1.3 to 3.7 times) than cultivated soils in Benin, resulting in higher surface runoff and rates of soil erosion under cultivated conditions. Permanent vegetation cover also reduces erosion and the transport of sediment to rivers. In particular, intact natural and semi-natural vegetation in riparian areas can create a buffer zone which traps sediment eroded from elsewhere in the catchment. However, preferential pathways for water flow and sediment, such as drainage ditches, can reduce the effectiveness of riparian vegetation as a buffer zone.

At a regional scale, changes in land use may also affect total rainfall with greater forest cover increasing rainfall due to its greater rate of evapo-transpiration. There is, however, no strong observational evidence for this (Chappell, 2005).

Measurement and sources of data

The percentage of the catchment covered by natural or semi natural vegetation can be determined from aerial photographs, maps, satellite images, GIS or hilltop survey.

Remote sensing data are available from the Global Land Cover Facility (http://glcfapp.umiacs.umd.edu), including MODIS products such as Vegetation Continuous Fields which gives an estimate of the cover of bare ground, herbaceous plants and trees within each grid square. In combination with Digital Elevation Model data such as ASTER GDEM (available at *http://www.gdem. aster.ersdac.or.jp or http://asterweb.jpl. nasa.gov/gdem-wist.asp)* and open source software tools such as MapWindow, the cover for different vegetation types in catchments can be derived.

Indicator 2: Change in hydrology measured as run-off per km^2 of catchment

Rationale

The hydrology of river catchments has a significant impact on riverine and riparian ecosystems. Changes to the hydrology can result from climate change or regulation of river flows as a result of dam construction or water abstractions and discharges. These changes can have negative effects on in-stream and riparian ecology (Petts, 1984).

For in-stream ecology, changes to the timing and frequency of flows can have a negative impact by altering habitat availability and quality for fish, invertebrates and plants. These habitat requirements vary for different species and life stages with some life stages being particularly sensitive to physical habitat changes.

A reduction in the frequency and magnitude of high flows can affect the timing of ecological processes such as fish spawning and migration and limit access to the floodplain for species which move into the floodplain for parts of their life cycles. Changes to frequency and magnitude of high flow events can also alter the disturbance regime of riparian vegetation and result in changes to the plant communities towards more flood intolerant species and a loss of overall catchment species diversity (Deiller *et al*., 2001; World Commission on Dams, 2000).

Sediment transport is largely driven by high flow events and changes to their frequency and magnitude can alter channel geomorphology with a lower frequency causing increased siltation which can affect key life stages for certain species, such as fish spawning and hatching.

Dam construction will alter the magnitude and timing of flows while abstractions and discharges will affect the total quantity of flow. Indicator 3 (number of dams upstream of site) acts as an indicator of changes to the frequency, timing and magnitude of high and low flow events while Indicator 2 (Change in hydrology measured as run-off per km^2 of catchment) acts as an indicator of the changes to the ecosystem due to changes in total flow.

Measurement and sources of data

For gauged catchments, this indicator can be quantified by calculating percentage difference between the current total annual flow from the catchment and the historical value. The current average should be taken over a 10 year period to account for inter-annual variability, with earlier data being used to calculate the historical average. If significant changes have occurred in the catchment to land use or hydrology (e.g. dam construction) over the duration of the flow record then the historical average flow should be calculated using data from before these changes took place.

If there are no flow records for the catchment then this indicator can be estimated using data for neighbouring catchments with similar geology and topography, correcting for differences in total rainfall.

Indicator 3: Volume of reservoirs within the catchment

Rationale

As discussed in the context of Indicator 2 (Change in hydrology measured as run-off per km^2 of catchment), the hydrology of river catchments has a significant impact on riverine and riparian ecosystems. While Indicator 2 acts as a measure of the changes to the ecosystem due to changes in total flow, including the effects of damming on total flow, Indicator 3 represents changes in the timing, magnitude, duration and frequency of high and low flow events.

The nature of the impact of dams on hydrology depends on the purpose and operation of the dam. In general, dams will reduce the frequency of high flow events, reduce the frequency of low flows and, for hydropower dams in particular, can create greater and more rapid flow variation than is naturally the case.

For in stream ecology, changes to the duration and frequency of flows can have a negative impact by altering habitat availability and quality for fish, invertebrates and plants (World Commission on Dams, 2000). Habitat requirements vary for different species and life stages, with some life stages being particularly sensitive to physical habitat changes, and ecosystems are thus affected by the magnitude and timing of flow releases from dams.

Changes to the frequency, duration and magnitude of high and low flows can also affect the timing of ecological processes, such as fish spawning, and, with respect to high flows, can limit access to the floodplain for species which move into the floodplain for parts of their life cycles.

The disturbance and flooding regime of riparian vegetation may also be affected by changes to high flows. Reduced disturbance of riparian and aquatic vegetation from can result in changes to the vegetation communities, such as increased aquatic weeds (e.g. water hyacinth), a greater abundance of flood intolerant species and a loss of overall catchment species diversity (Deiller *et al*., 2001). Reduced flooding can also impact floodplain ecosystems through reduced water supply and nutrient inputs.

As discussed in the context of Indicator 2, sediment transport is largely driven by flood flow events and changes to their frequency and magnitude can alter channel geomorphology, with a lower frequency causing increased siltation. This can affect key life stages for certain species, such as fish spawning and hatching.

In addition to changes to sediment dynamics as a result of hydrological changes from dam operation, the presence of dams prevent downstream movement of sediment. This results in greater deposition of sediment upstream of dams, due to lower flow velocities and physical blockage of the river, and increased erosion downstream, as a result of reduced sediment load from upstream. The erosion effect is, however, offset to some degree if the flows released by the dam are insufficient to mobilise sediment. Reduced sediment delivery downstream can have serious consequences for channel geomorphology (and hence aquatic habitat) and coastal erosion (World Commission on Dams, 2000).

Dams also influence the chemical and physical properties of the water, such as temperature and dissolved oxygen content. Temperature and dissolved oxygen in reservoirs can become stratified with lower temperatures and dissolved oxygen at lower depths. The effects on the physical and chemical properties of the river water will, therefore, depending on whether releases from the dam are from the upper or lower part of the water column. The water temperature regime can be an important influence on aquatic species, determining, for instance, the bioenergetics of fish feeding and triggering of life cycle events.

As they can act as a physical barrier to the migration of fish, dams can result in changes to the species distribution and composition upstream and downstream of the dam and, potentially, loss of species. Dams may also affect movement of invertebrates.

Measurement and sources of data

Dams within the catchment should be identified and the volume of each reservoir should be estimated. This can be done by reference to the authorities operating the dams, published literature or by calculation from map data and/or site visits. Data on annual runoff are available from the Water Resource Commission.

This indicator is calculated as the percentage of the total annual runoff volume represented by the volume of the reservoirs in the catchment.

Indicator 4: Percentage of bank length (500 m section) on both sides still occupied by natural or semi-natural vegetation

Rationale

Riparian vegetation serves several important ecosystem functions:

- Acts as a buffer zone, reducing nutrient delivery to the river. It also traps sediment and associated nutrients and pollutants and thus prevents or reduces their delivery to the river.
- Reduces bank erosion.
- Improves instream habitat through the addition of large woody debris.
- Provides flood plain habitat during floods.
- Increases channel roughness during floods, which reduces downstream flood peaks.

- Provides a source of coarse and fine particulate organic matter to streams, thus providing an energy input to the food chain.
- Shades the river, which can be important for temperature regulation of the water in small streams.
- Provides a corridor for riparian vertebrates to move through and becomes especially important where the catchment has been seriously disturbed.

Measurement and sources of data

A 500 m length of the stream above the site being assessed should be walked and a visual estimate made of the percentage of the bank length with intact natural or semi-natural vegetation 5 m perpendicular to the stream bank.

Indicator 5: Concentration of phosphorus

Rationale

Phosphorus (P) is present in water as organic or inorganic compounds, usually in the form of phosphate (PO_4). Both organic – associated with organic molecules – and inorganic P can be dissolved in the water or suspended in particulate form. The term 'total phosphorus' (TP) comprises all forms of P. Plants and algae use inorganic PO_4 for growth and reproduction. Animals obtain their P from plants or other animals that have fed on plants, and they recycle it via excretion and decay. Inorganic P is remineralised from organic P by microorganisms in the water column and sediments. If an increase in water P concentration occurs (eutrophication), sediments low in P may take it up and store it. Conversely, P can be released into the water column from P-rich sediments, especially in low oxygen conditions.

In the environment, P is present in rocks that are gradually worn away by weather, especially rain, into soils and rivers. In many catchments there is a constant supply of P, which washes down into water bodies when runoff occurs. The total loading of P to a water body is often directly related to runoff rates. Phosphorus is continually recycled in the natural and human environments, and there is a low level of supply from the metabolism of aquatic organisms. In addition, there are many external P sources such as farm animal effluents, irrigation waters, drained wetlands, cities, and industrial installations. In rivers, P is gradually shunted downstream towards the sea, but it can build up to very high concentrations in lakes.

Total nutrients ultimately set a limit on biomass. Plants and algae need many different nutrients, and P is (with nitrogen) one of the most likely to become exhausted if plants' demand for nutrients exceeds the rate of supply. Where TP concentrations are increased, there follows a general increase in plant and animal biomass, with concomitant changes is species assemblage compositions.

If, as is commonly the case, other plant nutrients are in abundance in a river, an increase in the rate of supply of P can lead to accelerated growth of plants and algae, including phytoplankton, which may increase to create turbid conditions and nuisance blooms. In extreme cases, these may contain toxins or lead to de-oxygenation, and the consequent mortality of aquatic animals.

Measurement and sources of data

Phosphorus in its dissolved form can be important, and therefore should be measured, at very small concentrations e.g. <10 ìg L^{-1}. Measurement usually consists of determination of inorganic PO_4 by reaction with ascorbic acid and ammonium molybdate, whereupon the P concentration is directly related to the colour density of the solution, and can be read on a spectrophotometer (APHA 1992). Dissolved P is measured on filtered water, so that P-containing particles are removed. Measurement of TP is made on the unfiltered water sample and involves 'digestion' of the sample using an acid solution at high temperature. This converts all of the P present into PO_4, which can then be measured in the same way as for dissolved P.

Indicator 6: Concentration of nitrogen

Rationale

Nitrogen (N) comprises over 78% of the atmosphere in the form of N_2, a relatively inert gas that is unavailable to plants because of its chemical structure. There are several other forms of N, some of which are important greenhouse gases but, in aquatic environments it is commonly found as nitrate (NO_3), nitrite (NO_2) and ammonium (NH_4). Nitrogen gas is converted into these forms largely by microorganisms in soil, and some forms that exist in water, such as cyanobacteria. Lightning, too, converts N into forms usable by plants by combining it with oxygen, and accounts for around 5% of the global supply. In recent decades, the natural N-cycle has become overwhelmed by industrial sources of plant-usable N, which now constitute around four times that supplied to the environment by natural processes (Fowler *et al.* 2004).

Nitrogen is used by organisms in their construction, metabolism, growth and reproduction and is excreted into the environment and leached by living and dead organisms. Large quantities of N are applied to agricultural land and used in animal feeds, therefore major sources of soluble N are found in agricultural runoff such as irrigation water, concentrations of animals or animal wastes, and in sewage treatment works. Nitrogen is much more soluble than phosphorus and does not as readily become attached to particles. This means that an increased concentration of NO_3 in river water can be an indicator of an agricultural or sewage pollution event. When N is stored in sediments, it is usually as part of living or decaying organisms or tissue, and tends to be released into the water column in soluble form as NH_4.

Nitrates are produced by the bacterial conversion of NH_4 to NO_2 then NO_3, but decomposition of N-rich organic material can deplete oxygen and promote hypoxia, which then slows the process and results in comparatively low concentrations of NO_3 compared with NH_4. It is therefore important to measure both of the main forms of dissolved N. Both NO_3 and NH_4 can be toxic to aquatic life in high concentrations, especially NH_4.

Plant-available forms of N are important in aquatic systems because they are essential plant nutrients. Available N may be the limiting nutrient where phosphorus (P) is abundant, and increased N concentrations can cause rapid growth of algae and plants if a supply of P is present. Such eutrophication can lead to the development of toxic blooms of algae, which are difficult and expensive to remove. Increased plant growth leads to consequent changes in the composition of the plant and algal assemblage, which has implications for the invertebrates and vertebrates that rely on them.

Where redox conditions are suitable, N is denitrified at the sediment surface or in the water column and is lost to the atmosphere as N_2 gas. This is an important because it means that, unlike P, which is recycled within the water body, N is not recycled within the water column to the same extent that P is. This is particularly important in tropical systems where denitrification rates appear to be high and phosphorus may be remineralised during periods of rewetting of soils and sediments following drought. Nitrogen is very frequently, though not necessarily always the limiting nutrient to algal growth in the tropics. Hence it is necessary to measure the nitrogen status of the water as well as that of phosphorus. Nitrogen availability may also influence the biodiversity of plant communities.

Measurement and sources of data

In lakes and rivers, concentrations of NO_3-N of <0.5 mg L^{-1} and <0.2 mg L^{-1} NH_4-N are considered normal, but concentrations can be tens of mg L^{-1} in effluents.

A common technique for NO_3 detection is the cadmium reduction method (APHA 1992), but this involves the use of cadmium, which must be disposed of with care after use. An alternative simple method uses an NO_3 electrode in the form of a probe, but the accuracy of the probe can be influenced by pH and chloride fluctuations.

Indicator 7: Ammonium

Rationale

Ammonium concentrations in pristine tropical waters vary greatly over a very low background mean concentration not far above the detectable limit (usually about 10 µg NH_4-N L^{-1}. Ammonium is the first easily detectable product of protein decomposition and concentrations above a few tens of micrograms N per litre generally indicate increased production from eutrophication, which will be independently indicated by a change in land use from natural vegetation to agriculture, or establishment of human settlement close to the river. Values greater than 500 µg NH_4-N L^{-1} generally indicate severe pollution from defecation of watered stock, or human effluent. However, decomposition of carcasses of dead wildlife, fallen into the river, for example monkeys, small antelope, can give temporarily (several weeks) very high concentrations. Concentrations consistently above 500 µg NH_4-N L^{-1} suggest a high probability of a pollution problem.

Ammonium is readily taken up by algae and plant roots and has a very short turnover time (hours) in pristine waters. Some of it is converted by nitrifying bacteria to nitrate, with release of energy and nitrate is used as an oxidising substrate by denitrifying bacteria and converted to nitrous oxide or nitrogen, which escape to the atmosphere as gases. I pristine tropical waters it is rare to detect nitrate above trace concentrations (<0.1 mg NO_3-N L^{-1}). Values greater than this will usually indicate a problem of eutrophication.

Measurement and sources of data

Ammonium is readily measurable by standard chemical methods, using a colourimetric reaction with sodium nitro-prusside and phenol in an oxidising solution. The reaction should be carried out on filtered water (< 1 µm pore size filters) or as the reagents will decompose proteins in particulate matter and give an overestimate. Nitrate also can be measured, again with filtered water by standard methods that involve prior reduction to nitrite using cadmium and then a colourimetric reaction.

Indicator 6: Concentration of nitrogen
Rationale

Nitrogen (N) comprises over 78% of the atmosphere in the form of N_2, a relatively inert gas that is unavailable to plants because of its chemical structure. There are several other forms of N, some of which are important greenhouse gases but, in aquatic environments it is commonly found as nitrate (NO_3), nitrite (NO_2) and ammonium (NH_4). Nitrogen gas is converted into these forms largely by microorganisms in soil, and some forms that exist in water, such as cyanobacteria. Lightning, too, converts N into forms usable by plants by combining it with oxygen, and accounts for around 5% of the global supply. In recent decades, the natural N-cycle has become overwhelmed by industrial sources of plant-usable N, which now constitute around four times that supplied to the environment by natural processes (Fowler *et al.* 2004).

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Measurement and sources of data

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Indicator 9: Conductivity (measurement)

Rationale

Conductivity is a measure of the presence of dissolved ions in the water column, and increases with the concentrations of ions such as Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, Na^+, Mg^{2+}, Ca^{2+}, Fe^{3+} and Al^{3+} because these conduct electricity.

The concentrations of ions, and hence conductivity in the water, is influenced by the underlying bedrock. Igneous rocks, such as granite, are less soluble than sedimentary rocks e.g. limestone, and therefore are not as subject to weathering. Sedimentary rocks, which are softer, gradually leach minerals at a comparatively faster rate, and these promote plant growth, leading to greater primary production and greater concentrations of soluble ions that drain into water bodies. Conductivity tends to be higher in water bodies draining clay soils, especially agricultural areas, because ploughing and addition of fertilisers affects the quality of runoff water.

A particular water body can be expected to have a typical range of conductivity, perhaps varying seasonally, but which can be used to indicate deviations from the normal range due to pollution events. The conductivity of a river may dramatically increase where a solute-rich tributary or outflow joins, and in this way can be a useful monitoring tool.

As a consequence of the natural variation in conductivity with geology, reference values for this indicator cannot be given as absolute values. Reference values are considered in terms of percentage changes from a natural level.

Measurement and sources of data

Conductivity normally is measured using a probe that passes an electrical current between two electrodes. The resistance of the water to the current is reflected in a fall in voltage negatively related to the concentration of ions, and is reported in microSiemens (ìS). Temperature affects the reading, so conductivity measurements are usually standardised to 25°C.

Rivers supporting a community of fish are likely to have a conductivity range from 25–2000 ìS cm^{-1}, but that of industrial effluents might be much higher. Deionised water should be expected to have a conductivity of < 5 ìS cm^{-1}.

Measurements can be made in the water body directly, or from samples brought back to the laboratory.

Indicator 10: Dissolved oxygen

Rationale

Dissolved oxygen is widely used as a measure of water quality. Dips in its concentration may indicate pollution by gross organic matter. It must be used very carefully in tropical waters, however. Concentration standards for temperate regions must not be applied because oxygen concentrations at saturation decline steeply with temperature. Water at 0 ºC dissolves about twice as much (14 mg L^{-1}) as at 30 ºC (7 mg L^{-1}). Percentage saturation is often the more useful measure. However, because of high biological activity in tropical climates, saturation may normally be below 100%, especially where swamp waters feed a river. Swamps are naturally deoxygenated, even anaerobic, and their organisms are well adapted to this.

Saturation will also change rhythmically during twenty-four hours and will be greatest in late afternoon and lowest just before dawn. The latter time gives the best estimate of potential problems, as it is the lowest oxygen availability that indicates the true risk to fish rather than the day time value. Values will also vary dependent on flow. They will tend to be higher during flood flows than during dry periods when the base flow will be of water that has percolated from soils where decomposition may be intense. Critically low values for fish survival will depend on the composition of the fish community and will be absolute concentrations not percentage saturation values. As a rule of thumb, 4 mg L^{-1} will allow most tropical fish to survive.

Measurement and sources of data

Oxygen may be measured by the standard Winkler chemical reaction, which is highly reliable, but tedious, or by electronic probes, which are reliable if they are properly maintained. If not (if allowed to dry out for example), they give false readings. Temperature should always be simultaneously measured so that saturation percentage can be calculated.

Indicator 11: Temperature

Rationale

Temperature is important in determining the rates of all biological processes and in consequence it is very difficult to isolate the specific effects of temperature from those of other drivers of these processes. There are no absolute standards for temperature. Some habitats are naturally hot, others naturally cold. Small changes, however can be crucial because rates of biological processes typical more than double with a 10 ºC rise. A rise in global mean temperature of only 0.67 ºC since the beginning of the industrial period has already had measurable biological consequences and the rise of up to 3 ºC in polar regions has resulted in major changes in fish communities, nutrient loading, seasonality and productivity.

In the tropics such rises are already occurring and will intensify, but local effects will be more immediately recognisable. Pristine streams are heavily shaded by forest even in relatively arid regions, because the relatively high water table close to the stream will support denser vegetation than soils a few tens of metres distant. Shading reduces insolation and temperature and allows higher oxygen concentration. Removal of forest cover has the opposite effect, and an open river will provide a very much more disturbed habitat than a naturally shaded one. Comparisons of likely effect can be deduced from measurements relative to a local shaded stream of similar size, but the shaded reaches must be of substantial length (>1km) to provide a valid comparison. Temperature will vary with time of day and season and so these must be standardised for comparisons.

Measurement and sources of data

Temperature is easily measured with mercury-in-glass or alcohol thermometers, but these are easily breakable. Thermistor probes are now more usually used and are fairly robust, but need regular maintenance and careful storage for reliability. Indicator 4 will provide a surrogate for temperature effects if suitable instruments are not available.

Indicator 12: Biological (biochemical) oxygen demand (BOD)

Rationale

Biological oxygen demand has been widely used as a measure of the degree of gross organic pollution of water in the industrial world and measures the rate of uptake of oxygen over five days at (usually) 20 ºC in dark conditions. It thus gives a measure of microbial uptake of oxygen in the water, but does not measure what might be happening at the sediment surface or associated with plants and debris in the river. It is essentially the chemist's grudging acknowledgement that biology is important and is only a relative test. Pristine waters will have a BOD of less than 1 mg O_2 L^{-1} $(5\ days)^{-1}$. Increasing values may indicate pollution by organic matter but need careful interpretation. Waters derived from natural swamps will have a high BOD and in some seasonal habitats, organic contributions from the surrounding forests are a normal feature of river ecology. Most rivers, indeed are naturally heterotrophic, with respiration in the system based more on imported organic matter than on photosynthesis of plants and algae within the stream. Very high BOD (say in excess of 10 mg O_2 L^{-1} $(5days)^{-1}$ will almost certainly mean a degree of organic pollution, the evidence for which will usually be visible.

Measurement and sources of data

It is usual to abide by the standard procedure, but the method can be adapted to local conditions for comparative purposes, as long as conditions are standardised.

Indicator 13: Values for acidity/alkalinity - pH (analysis)

Rationale

At any given time, the water of any given water body may be acid, neutral or alkaline, depending on the balance of its chemical constituents, and *p*H is used as a measure of this quality. The degree of acidity depends on the relative concentrations of the constituents of water, H_2O, which are a positively-charged hydrogen ion (H^+) and a negatively charged hydroxyl ion (OH^-). Both of these ions are removed by chemical bonding to dissolved chemicals, and this can result in an imbalance in their concentrations in the water column. Accordingly, when H_2O dissociates into these two ions, and one of them is taken up by a substance present in the water, the other will be present in comparative excess. An excess of H^+ makes the water acidic, while an excess of OH^- makes it alkaline. Pure water contains equal concentrations of both ions and is neutral (*p*H 7).

The *p*H scale runs from extreme acidity (*p*H 1, the acidity of 1.0 M HCl) to extreme alkalinity (*p*H 14, which is that of 1.0 M NaOH), and is a logarithmic scale, so that each unit is 10x greater or less than the neighbouring unit. This means that a liquid at *p*H 6 is 10x as acid as it would be at pH 7, and 100x as acid as that at *p*H 8. A range of pH values is normal in common liquids e.g. sea water is usually around *p*H 9, while orange juice is about pH 3.5. Rain falls as dilute carbonic acid with a *p*H usually of around 5.6.

The underlying bedrock influences the balance of *p*H in the water draining it, because sedimentary rocks leach chemicals that raise pH values compared with those from hard rock (igneous) catchments. Carbon (C) compounds are important in buffering *p*H because different forms of carbon (e.g. carbonate and bicarbonate) require different quantities of H^+. Values are never stable in a water body because *p*H is influenced by many different factors that may change over hours. Photosynthesis, for example, removes CO_2 from the water column, shifting the form of C in the water column towards CO_3, thus moving *p*H values up the scale, sometimes by 2 or more units in a day, before values fall again at night as CO_2 is produced e.g. through respiration.

Different species are suited to different ranges of pH, most animals preferring a range of *p*H 6.5–8. Outside its normal range, an organism may face physiological stress, which may lead to behavioural changes and increased mortality. High acidity increases solubility of some elements and compounds that may be toxic to animals and plants, e.g. aluminium is very toxic to invertebrates because it attacks the nervous system.

Measurement and sources of data

Measurement of pH is made by a pH electrode and meter, and should be done in the field or within 2 hours of sampling because the value will change as the sample reacts with the atmosphere.

Indicator 14: Number of species of submerged native plants (rhodophytes, podostemonads, bryophytes) (counted at site)

Rationale

Rivers are normally heterotrophic systems and a complete absence of photosynthetic algae and aquatic plants may be expected in densely shaded pristine forested streams. As the river widens, however, the greater light intensities away from the edges will allow some plant and algal growth, which creates additional niches for invertebrates. There are four groups of plants that might be found: submerged attached to rocks, submerged, rooted in sediment, floating and emergent. Emergent and submerged rooted plants in pristine headwater rivers are scarce, but become more common as the river widens and enters its floodplain stage. Floating plants (see below) can only survive where flows are negligible and are usually exotic species if present in quantity. In headwater streams, more than occasional rooted submerged and emergent plants are indicators of low flow and increased sedimentation. Floating plants are indicators of low flow and increased nutrient enrichment for they derive their entire nutrient supply from the water. All these groups are associated with agricultural development of the catchment and reduced ecosystem quality.

The plants attached to rocks, however, are useful indicators of high quality in headwater rivers. Their abundance will be low for low nutrient concentrations, but their diversity tends to be highest in pristine sites and to decline as the site is disturbed. There are three groups of plants generally visible to the naked eye. These are red algae (Rhodophyta), which occur as tufts of greyish blue or pink colour on rocks in fast flowing water. They should be distinguished from sewage fungus which can look rather similar but will be in slower flowing water and very abundant and associated with unpleasant smell. Red algae can also form vivid red flat growths over rocks (e.g. *Hildenbrandia*). The second group comprises bryophytes (mosses and liverworts), which have small leaves and grow as green tufts, often in extensive mats, and will appear above the water line in the dry season; and the third is a group of higher plants, the podostemonads, (e.g. *Tristicha trifara*) which are highly specialised river dwellers. They form flat plates (rather like squashed green chewing gum) over the rock surfaces, from which short (a few cm) stalks with small flowers emerge from time to time. There may also be some fern species obligately growing in rocks in the river, but many plants will be essentially forest species growing on rocks above the water line.

Measurement and sources of data

There are no absolute standards, but the higher the quality the stream, the more species of these three groups will collectively be found. A 500 m stretch might be expected to have 5–10 species in its pristine state. The species need not be named, though this is desirable, but careful observation is needed to avoid double counting and the plants must be normally growing under water.

Indicator 15: Number of species of introduced plants (counted at site)

Rationale

Introduced species are now often major problems, be they plants, invertebrates or fish. They become problems when they grow prolifically, outcompeting the native biota and reduce the local biodiversity. Heavy plant growths may clog rivers, cause local flooding, reduce available fish habitat and impede canoe navigation. Four particular floating plant species are widely important in the tropics and are easily recognised. They are *Pistia stratiotes* (water lettuce), *Eichthornia crassipes* (water hyacinth), *Azolla* species (floating fairy fern) and *Salvinia molesta* (floating water fern). All are native to South America and alien to Africa. They tend to grow vigorously where flows have been reduced through water diversion, climate change or damming, and where nutrient levels have been boosted by agriculture or settlement. Even the presence of any of these four should be regarded as detrimental. Once one has established, however, it tends to prevent invasion of the others or is completely replaced by one of the others. The indicator is thus presence of any one of these four taxa.

Measurement and sources of data

Indicator 15 species within a habitat of interest can be recorded by counting singly in less dense occurrences, or by quadrats/transects (to represent subsets or samples of dense vegetation) or even by photographs. The plant are treated appropriately, examined and identified. Whenever possible, samples are taken to Herbaria for confirmation and authentication of identity.

Indicator 16, 17, 18: 16, Percentage of benthic fauna that are that is other than deposit feeders - 17 Percentage of benthic fauna (numbers, families) that are Plecoptera, Ephemeroptera and Trichoptera - 18 Percentage of benthic fauna (numbers, families) that are predators (measured on sorted samples)

Rationale

Macroinvertebrates are easily sampled and the major groups and families easily recognised in rivers. They have thus been widely used world-wide to characterise river systems. A pristine headwater river has most of its usable energy provided by plant material falling or blown in from the surrounding forest. Leaves, twigs, bud scales and flowers are colonised by fungi that process the material into usable food for invertebrates by increasing its protein content. The material is then fed on by shredder invertebrates (including crustaceans and dipteran larvae) and any fine material by filter collectors from the stream of fine debris passing in the water flow (caseless caddis larvae, simuliids). As the river widens, and algal films colonise the rocks, scraper invertebrates (mayflies and stonefly nymphs, caddis larvae snails) become more e abundant, and where sediment is deposited behind obstacles and in quiet water, deposit feeders colonise (chironomids, oligochaetes, bivalve molluscs). The community is completed by predators (beetles, bugs, caddis larvae, water mites, leeches) and fish and river birds complete the food webs as top predators.

In general a pristine headwater stream will be torrential and there will be little opportunity for sediment to be deposited. Where there has been disturbance, and flows have been reduced, more sediment will be deposited and the percentage of individuals that are deposit feeders will increase when an overall sample is taken. The three groups of chironomids, oligochaetes and bivalves are easily recognisable. Chironomids can also be scrapers and many different species exist. The deposit feeders tend to be red or pink coloured with haemoglobin, like the oligochaetes. The percentage of numbers of this group of the total number in a sampler taken by kick sampling is thus a measure of degree of disturbance. A pristine headwater stream will have >20% of individuals that are deposit feeders. A heavily silted damaged one will have >80%. Note that pristine lowland floodplain streams will have a very high proportion (up to 100%) of deposit feeders.

Certain groups of invertebrates appear to be generally less tolerant of deoxygenation, eutrophication and silting than others. A high proportion (typically 25%) of mayflies (Ephemeroptera, stoneflies (Plecoptera) and caddis flies (Trichoptera will thus characterise a high quality stream. The proportion will be reduced in a disturbed stream and will become zero in heavily silted, organically polluted waters. Likewise, predators, which are the most active of invertebrates and require high oxygen concentrations, are thus more abundant in pristine than in disturbed streams, with typically 50% representation. This may seem high but the reproduction and turnover of the prey are fast and the predators will take microinvertebrates (nematodes, small crustacea) that are too small to be held by nets that sample the macroinvertebrates. A disturbed stream will have a much lower proportion of predators. For the present purposes, predators can be taken to be beetles, bugs, water mites, leeches and damselfly and dragonfly larvae, all of which are readily recognisable.

Measurement and sources of data

Indicators 16, 17 and 18 can all be measured on a single kick sample taken over 3 minutes and covering the full width of the stream and a length of a few metres. The animals are washed clean in the net (not less than 125 µm mesh) and examined and sorted live if possible, pr preserved in ethanol if not. Spates may wash out many animals so samples should be taken during base flow conditions if possible.

Indicator 19: Number (and types where they can be identified) of fish species (test fishing at site or compiled by local people)

Rationale

Fish provide food, as do crabs and large prawns from tropical streams. In general there will be a high diversity in pristine stream lengths with perhaps 20 species of fin fish, and two to three crabs and prawns. Again, disturbance will reduce the number of niches and the number of species of fish and shellfish. Efficient sampling o f a fish community is very difficult and it is pointless to attempt it for routine monitoring. Fish avoid capture and may move rapidly out of the way. Local fishermen however usually understand the habits of the fish well and have devised efficient means of capture for particular species. Local consultation will generally produce a list of species found by local fishermen and local markets provide useful information also. Monitoring the number of species available gives an indicator of changes over time and of local prices of stock size (higher prices, lower stock). These indicators are relatively crude and need to be monitored over a period to establish any upward or downward trends but they do measure directly a particularly important ecosystem service provided by rivers. As in all the indicators, local reference conditions should be established from pristine sites where there remains intact forest around the stream for substantial lengths (several kilometres) and where the catchment beyond the riparian zone remains in native vegetation.

Measurement and sources of data

Information should be gathered from as many local sources as possible and compared with the situation in reference sites that are undisturbed.

Indicator 20: Number of bird species recorded in standard time over 100 m length of the river (assessed at site)

Rationale

River systems do not just comprise the wetted channel. They include very important riparian zones and 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. The forest provides energy and debris that gives structure to the stream habitats and also invertebrates that fall in and may be major sources of fish food.

Intactness of the riparian zone is thus a major indicator (Indicator 4). Riparian zones may appear intact however, but can nonetheless be fundamentally damaged if there is periodic disturbance. Birds are particularly sensitive indicators of disturbance, particularly two groups, of specialist river birds and of canopy forest specialists. Use of total species number is less sensitive, but these two groups are particularly useful.

Measurement and sources of data

Some expertise is necessary for recognition of the birds, particularly the canopy specialists which are usually quite hidden in the foliage but reveal themselves by their song. The number of species should be established in high quality reference sites for comparisons with disturbed sites

Conclusions

Threats to the river systems of Okyeman

Population pressure and poverty. The main threats to aquatic systems in the Okyeman area are people and poverty. Due to increasing populations, people are now encroaching into areas for farming that before would have been kept free of cultivation. The fact that people are poor and that they have no alternatives drives then to farm right to the edge of the rivers where they can possible get a longer growing season as they cannot afford irrigation machines.

Lack of awareness by the general community and policy makers of water management and under-resourced Community Water and Sanitation Agency

In our site visits, it was clear that the few officials that we met were not aware (or said that they were not aware) that their upstream activities would have impact on downstream communities. Issues such as the poor location of village rubbish disposal spots, location of pit latrines very close to river banks, allowing household waste to drain into rivers were all seen and known by these officials.

Low level of community participation in conservation. Some of the villages were very dirty, full of old plastic water sachets, no one seemed concerned or worried about this state of affairs.

Over-exploitation of river fisheries, including the use of inappropriate methods. At almost every site there were signs of fishing, often nets with very small mesh sizes were seen. The amount of fishing pressure is intense, especially from children and young adults.

Intensification and expansion of agriculture and increased use of pesticides and herbicides. The introduction of new methods of applying agro-chemicals on cocoa has led to a massive increase in the use of fertilizers, and pesticides. There is a lack of effective monitoring arrangements on the entry use and disposal of agrochemicals in the area. The fact that individuals are farming practically in the river and destroying riparian vegetation in the dry season resulting in loss of cover, increasing erosion and greater possibilities of ingress of agrochemicals direct in to streams is another point of concern.

Expansion of infrastructure and development of new industries, such as tourism and recreation. The Traditional Authority and the District Assemblies want their people to have better living conditions. As such they are embarking on a number of new activities to promote the area (e.g., hang gliding). Some of these activities place additional stress on water resources at the micro level which may have significant cumulative and knock on effects.

Recommendations

1. All the district authorities should embark on a massive re-education campaign to address the low levels of environmental awareness that pertains in the basins;
2. Bye-laws on sanitation and environmental health in the three basins be created where they do not exist and strengthened where they exist as well as being rigidly enforced. To this end, it is further recommended that the law enforcement agencies undertake re-training in the area of environment;
3. A programme should be initiated immediately to identify groundwater resources of the basin that could be developed for use on a sustainable basis with the view of reducing pressure on the contaminated surface water;
4. Programmes for the protection, conservation and rational use of these ground water resources on a sustainable basis are initiated;
5. Effective water pollution prevention and control programs, based on an appropriate mixture of pollution reduction-at-source strategies, environmental impact assessments and enforceable standards for major point-source discharges and high-risk non-point sources be initiated;
6. Establish, district capacity to monitor biological, health, physical and chemical quality criteria for all water bodies (surface and groundwater), with a view to an ongoing improvement of water quality;
7. An authority or commission be established as an institution to promote an integrated approach to environ-mentally sustainable management of land and water resources, including the protection of aquatic ecosystems and freshwater living resources. For the Okyeman Traditional Area, this organization would be charged with putting in place strategies for the environmentally sound management of fresh waters and related ecosystems, including consideration of fisheries, aquaculture, animal grazing, agricultural activities, and biodiversity.

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