RAPID ASSESSMENT OF WETLAND ECOSYSTEM SERVICES

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The concept of ecosystem services was discussed in the Introduction chapter of these Guidelines. It is worth reiterating that the ecosystem services are the 'direct and indirect benefits derived by humans from the functioning of ecosystems', and that these services have been categorised in many ways. This chapter provides preliminary guidance on the rapid assessment of some of these services which can be easily linked to the biodiversity of an ecosystem. We discussed also the linkages between biodiversity and ecosystem services in the Introduction chapter. Biodiversity plays a central role in te functioning of ecosystems. For detailed discussion, one may refer to Schulze and Mooney (1993), Loreau (2000), Finlayson et al. (2005), Elmqvist et al. (2005), Diaz et al. (2005), Haines-Young and Potschin (2010) and Russi et al. (2013), . The role of different groups of plants and animals was briefly discussed along with the methods of their assessment in the earlier section.

The assessment of ecosystem services requires first an identification of the services that a particular wetland provides. The ecosystem services provided by different kinds of inland wetlands together with their relative extent were shown graphically in the first chapter. It should be borne in mind that all wetlands do not provide all of the services all of the time. The range of services provided by wetlands varies according to their type, size, location and several other factors.

People attach economic values to certain benefits if they are direct or indirect use. Direct uses may be consumptive uses where a product can be harvested, consumed and marketed (such as water, food, fuel, timber, fiber, fodder, medicine, etc.) or non-consumptive uses where the ecosystem is used without taking away something (e.g., recreational use for boating, swimming watching, relaxing, etc.). Humans benefit from several functions indirectly; e.g., decomposition of wastes, nutrient cycling, hydrological cycle and soil formation. People may also consider the option of using an ecosystem for its services in near or distant future. These are referred to as 'option' and 'bequest' values. Further, there are also some indirect benefits which cannot be used. These include cultural and heritage values of the very existence of biodiversity. All ecosystems in their pristine condition may provide fewer ecosystem services of direct use to humans but more of indirect benefits.

Because wetland functions are based on physical, chemical and biological characteristics, identification and measurements of these features can be used to predict whether a wetland is performing particular functions. But detailed measurements of hydrology, water chemistry, soils, plant communities, animals etc. are too expensive and time consuming to be used on every wetland. Therefore, rapid assessment methods have been developed to make an initial prediction of the functions being performed by a wetland.

Rapid assessment methods were first developed in the United States and later used in Canada (Larson et al. 1989). These rapid assessment methods for various wetland functions were also adapted for China and later adapted and described for Indian wetlands (Larson 1995). Also, these methods were used during training of wetland managers. These rapid assessment methods help managers and policy makers obtain a quick inexpensive estimate of the potential importance of wetlands and enable them to prioritise them for conservation measures. These methods do not produce quantitative measures of wetland functions. Rapid assessment methods have been developed further and promoted internationally (CBD/Ramasar 2006, DeGroot et al. 2006). However, in recent years very comprehensive methods based on large amount of quantitative data on many parameters have also been developed for functional assessment of wetlands (Maltby 2009).

There is a growing bulk of literature on economic valuation of ecosystem services than on the how-to-do assessment of the services themselves. During past decade or so, several assessment methodologies have been developed, mostly in Europe. A review of these methodologies shows that most of them require large amount of data, manpower, technical knowledge, time, funds and computing skills (Peh et al. 2013). A relatively simple toolkit with low requirements on all these counts was developed in Belgium (Kettunen et al. 2000). However, recently a friendly and readily available toolkit – named as TESSA (Toolkit for Ecosystem Service Site-based Assessment). has been developed (Peh et al.. 2013b). It includes a suite of methods for the assessment of a few ecosystem services. It is suggested that the toolkit and its methods of which only a few are related to wetlands, should be consulted and tried out in the field.

STEPS FOR ASSESSMENT OF ECOSYSTEM SERVICES

As mentioned earlier in the Introduction chapter, the concept of ecosystem services has gained widespread acceptance but there is not yet any specific typology hat has similar acceptance. Sevral classification schemes have been developed and there is growing uneasiness with their simple categorisation by the Millennium Ecosystem Assessment. That categorisation is not helpful in either quantitative assessment or valuation. Ramsar Convention has identified ten most important ecosystem services (http://archive.ramsar.org/cda/en/ramsar-pubs-info-ecosystem-services/main/ramsar/1-30-103%5E24258_4000_0__) and described them briefly in a fact sheet for each of them. These ecosystem services are:
1. Flood control
2. Groundwater replenishment
3. Shoreline stabilisation & storm protection
4. Sediment & nutrient retention and export
5. Water purification
6. Reservoirs of biodiversity
7. Wetland products
8. Cultural values
9. Recreation & tourism
10. Climate change mitigation and adaptation

I also do not adhere to the MEA categorisation; instead I follow a functional approach where each wetland function offers more than on ecosystem service, and each ecosystem service depends upon more than one function. Various ecosystem functions and processes are interlinked. Thus, production function is not simply related to photosynthesis but also to the nutrient transformations and hydrological function. The provisioning service by way of plant material for food depends upon several functions. I am also conscious that currently our understanding of wetland functions is very poor in the South Asian countries, and therefore, even rspid assessments require collection of significant amount of data from the field as wetlands differ considerably in their characteristics. Beforeembarking upon the assessment of ecosystem services, onr needs tocollect some baseline information on the wetland and identify stakeholders who benefit from the wetland. These steps are briefly described below.

Baseline Information on the wetland

The base line information required for the assessment of the ecosystem services is similar to that described in the section on biodiversity assessment. It should include the following information:

Name (including any variant)

Map of the wetland and its surrounding areas (marked with roads, buildings, and other features of human activity, and drainages (river, stream, etc), if any)

Location (State, District, Village, nearest town to approach it; Latitudes and Longitudes, elevation above mean sea level);

Its nature: Natural, human-modified, human-made

Size and shape: Shape, Maximum length and breadth, total area at high water level,

Shore line: length and characteristic (rocky, soft sediment, steep or gentle slope), Maximum depth at the deepest point, *Climate*: (minimum and maximum monthly temperatures, total annual rainfall and its monthly distribution

Catchment characteristics: Area; Physiography; Soil type (clay, loam, sand, rocky, gravelly); Vegetation types and cover; Drainage (important rivers, streams, other wetlands in the river catchment)

The information may be obtained from a variety of published, unpublished sources, google images, personal survey and enquiry from the local people.

Stakeholders Identification and prioritization

The ecosystem services are for the humans and they differ from region to region based on economic, socio-cultural and other factors. Therefore, it is most important to know who the stakeholders (the beneficiaries) are. They may be individuals, groups, organisations, and government agencies. For direct consumptive uses, one needs to know who uses what, when and how much? And how do people access and use various services. For indirect uses, we need to understand the ecological attributes and functioning of the system. It should also be realised that the same plant species may be considered a nuisance in one region but as a vegetable or medicinal plant in another region by the local communities. Therefore also, it is important and necessary to examine the ecosystem services and their linkages with biodiversity in consultation with the local communities. This participatory approach has been emphasised by all concerned organisations such as CBD, Ramsar Convention and TEEB.

In general, it is the local community which lives around the wetland and interacts with it regularly. There will also be many groups of people who do not live there but utilise the wetland's ecosystem services directly on indirectly. The local 'community' is usually composed of individuals who differ in their perception, interests or nature of use of the wetland's benefits. These differences often arise because of social factors such as religion, caste and native places (e.g., migrants), age, gender, economic status in terms of land holding (owners/lesees/landless), wealth, occupation, education and family size. Livelihoods of some groups within the local community may depend almost entirely upon the wetland. Accordingly, all such groups within te community should be covered to get their perspectives. When necessary, separate meetings may be held with these groups. Other individuals and groups who utilise the wetland goods and services bu do no live around it should also be identified and information about them should be collected in a similar manner. It may also be necessary to prioritize the stakeholders according to their relation with particular ecosystem services.

Generally, the methods of PRA (Participatory Rural Appraisal) are used to interact with the community and elicit their views and information onn the ecosystem of interest. However, structured questionnaire surveys are commonly used. The questions related to the social grouping can be included in the questionnaire or separate questionnaires may be designed for different groups. For rapid assessments, however, focused group discussions can be quite helpful in capturing the different perspectives of various social groups.

Inventory of Ecosystem Services

In order to assess the ecosystem service one needs to first analyse the functions related to them. Functions result from different combinations of processes and traits (Table 1). Wetland characteristics (biodiversity, abiotic components and ecological processes) determine the functions which are first translated into a list of services that can then be quantified in appropriate units (biophysical or otherwise), and later used for economic valuation. Ecosystem functions represent the potential for benefits which may or may not be used directly by the humans. Usually, the same function is linked to two or more ecosystem services. The function of primary production is linked with the nutrient cycling function and contributes to the provision of plant biomass which benefits humans directly if put to some consumptive use or indirectly by way of removing carbon dioxide from the atmosphere and nutrients from the water and soil. For example, a wetland may have large number of fish which have a high ecological significance but people may not use them. Similarly, some plants may grow in large amounts and certainly have an ecological role but may not be used by the people. It is therefore necessary to consider assessments of several related ecosystem services. From an economic viewpoint, two ecosystem services can have very divergent values arising from the same function or group of functions.

Table 1. Biological processes related to different ecosystem functions

Ecosystem Functions	Biological Processes
Primary production:	Photosynthesis Plant nutrient uptake
Decomposition:	Microbial respiration Food web dynamics of soil biota
Nitrogen cycling:	Nitrification Denitrification Nitrogen fixation
Hydrologic cycle:	Plant transpiration
Soil formation:	Mineral weathering Soil bioturbation Succession (Plant community)
Biological control:	Predator-prey interactions

Once the main services delivered by the wetland have been selected, it is important to determine if the magnitude of the actual and potential availability of these services can allow sustainable. Examples of indicators suitable for determining the sustainable use of wetland services are reproduced from deGroot et al. (2006) in Table 2.

IDENTIFYING WETLAND FUNCTIONS ANDASSOCIATED ECOSYSTEM SERVICES

Hydrological Functions

Wetlands are invariably situated in low lying areas and hold water in them for different duration depending upon the climate and the source of water. Water may reach them by direct precipitation, from the surrounding higher elevation catchment areas, through streams or subsurface flows (belowground springs). Water is lost from them through outflows, surface evaporation, transpiration by some macrophytes or by infiltration into the ground. Detention and retention of water, release into the atmosphere or into the ground are important processes in which macrophytes play a prominent role. The wetlands thus function to regulate the water cycle and provide several very important benefits to humans.

In the first place, the water retained by the wetland for varying duration becomes available to the humans (a provisioning service). Retention facilitates the movement of water into the ground (groundwater recharge) that also becomes available to humans even during the period and at places without precipitation or readily available surface water. This is both a regulating and a provisioning service.

Second, detention of water in wetlands from surface sources delays its movement downstream and the gradual release later moderates the peak flows. This prevents flooding in adjacent and downstream areas. Thus, flood control is another ecosystem service provided by the wetlands. Floods are reduction when water enters the wetland faster than moving out of it or does not exit at all.

Table 2. Indicators for determining (sustainable) use of wetland services (reproduced from DeGroot et al. 2006)

Services	Ecological process and/or component providing the service (or influencing its availability) = Functions	State indicator (how much of the service is present)	Performance indicator (how much can be used/ provided in sustainable way)
Provisioning			
Food: production of fish, algae and invertebrates	Presence of edible plants and animals	Total or average stock in kg	Net productivity (in Kcal/year or other unit)
Fresh water: storage and retention of water; provision of water for irrigation and for drinking.	1) Precipitation or surface water inflow 2) biotic and abiotic processes that influence water quality (see water purification)	-Water quantity (in m3) -Water quality related to the use (conc. of nutrients, metals, etc.)	Net water inflow (m3/year) (i.e., water inflow minus water used by the ecosystem and other water needs)
Fiber & fuel & other raw materials: production of timber, fuel wood, peat, fodder, aggregates	Presence of species or abiotic components with potential use for fuel or raw material	Total biomass (kg/ha)	Net productivity (kg/year)
Biochemical products and medicinal resources	Presence of species or abiotic components with potentially useful chemicals and/or medicinal use	Total amount of useful substances that can be extracted (kg/ha)	Maximum sustainable harvest
Genetic materials: genes for resistance to plant pathogens	Presence of species with (potential) useful genetic material	Total "gene bank" value (e.g., number of species & subspecies)	Maximum sustainable harvest
Ornamental species: e.g., aquarium fish and plants	Presence of species or abiotic resources with ornamental use	Total biomass (kg/ha)	Maximum sustainable harvest
Regulating			
Air quality regulation: e.g., capturing dust particles	Capacity of ecosystems to extract aerosols & chemicals from the atmosphere	Leaf area index, NOx-fixation, etc.	Amount of aerosols or chemicals "extracted" - effect on air quality
Climate regulation: regulation of greenhouse gases, temperature, precipitation, and other climatic processes	Influence of ecosystems on local and global climate through land-cover and biologically- mediated processes	Greenhouse gas-balance (esp. C-fix), DMS production, Land cover characteristics, etc	Quantity of greenhouse gases, etc., fixed and/or emitted - effect on climate parameters
Hydrological regimes: groundwater recharge/ discharge; storage of water for agriculture or industry	Role of ecosystems (especially forests and wetlands) in capturing and gradual release of water	Water storage capacity in vegetation, soil, etc., or at the surface	Quantity of water stored and influence of hydrological regime (e.g., irrigation)
Pollution control & detoxification: retention, recovery and removal of excess nutrients / pollutants	Role of biota and abiotic processes in removal or breakdown of organic matter, xenic nutrients and compounds	Denitrification (kg N/ha/y), Accumulation in plants, -Kg –BOD /ha/y, chelation (metal-binding)	Maximum amount of waste that can be recycled or immobilized on a sustainable basis; influence on water or soil quality
Erosion protection: retention of soils	Role of vegetation and biota in soil retention	Vegetation cover, root-matrix, etc	Amount of soil retained or sediment captured
Natural hazard mitigation: flood control, storm & coastal protection	Role of ecosystems in dampening extreme events (e.g., protection by mangroves and coral reefs against damage from hurricanes)	Water storage (buffer) capacity in m3; ecosystem structure characteristics	Reduction of flood danger and prevented damage to infrastructure
Biological Regulation: e.g., control of pest species and pollination	Population control through trophic relation; role of biota in distri-bution, abundance and effectiveness of pollinators	Number & impact of pest control species; number & impact of pollinating species	Reduction of human diseases, livestock pests, etc.; dependence of crops on natural pollination

Cultural & amenity			
Cultural heritage and identity: sense of place and belonging	Culturally important landscape features or species	Presence of culturally important landscape features or species (e.g., No. of WHS)	Number of people "using" ecosystems for cultural heritage and identity
Spiritual & artistic inspiration: nature as a source of inspiration for art and religion	Landscape features or species with inspirational value to human arts and religious expressions	Presence of landscape features or species with inspirational value	Number of people who attach religious significance to ecosystems; number of books, paintings, etc., using ecosystems as inspiration
Recreational: opportunities for tourism and recreational activities	Landscape features; attractive wildlife	Presence of landscape & wildlife features with stated recreational value	Maximum sustainable number of people & facilities; actual use
Aesthetic: appreciation of natural scenery (other than through deliberate recreational activities)	Aesthetic quality of the landscape, based on e.g. structural diversity, "greenness", tranquility	Presence of landscape features with stated appreciation	Expressed aesthetic value, e.g., number of houses bordering natural areas; number of users of "scenic routes"
Educational: opportunities for formal and informal education & training	Features with special educational and scientific value/ interest	Presence of features with special educational and scientific value/ interest	Number of classes visiting; number of scientific studies, etc
Supporting			
Biodiversity & nursery: Habitats for resident or transient species	Importance of ecosystems to provide breeding, feeding or resting habitat to resident or migratory species (and thus maintain a certain ecological balance and evolutionary processes)	Number of resident, endemic species, habitat integrity, minimum critical surface area, etc.	"Ecological Value" (i.e., difference between actual and potential biodiversity value); dependence of species or other ecosystems on the study area
Soil formation: sediment retention and accumulation of organic matter	Role of species or ecosystem in soil formation	Amount of topsoil formed (e.g., per ha per year)	These services cannot be used directly but provide the basis for most other services, especially erosion protection and waste treatment
Nutrient cycling: storage, recycling, processing and acquisition of nutrients	Role of species, ecosystem or landscape in biogeochemical cycles	Amount of nutrients (re-) cycled (e.g., per ha/year)	

Indicators for Flood Control

Following conditions indicate the potential of wetlands for flood control:

1. Impervious land cover or lack of woody vegetation that permits large runoff during rainfall
2. steep slopes in the catchment and straightened streams entering the wetland;
3. Other water bodies and wetlands comprise less than 7% of the catchment area of the wetland.
4. The ratio of seasonally flooded wetland area to its permanently flooded area is large, or if the wetland does not have permanent standing water.
5. The wetland lacks an outlet, or when the outlet has less capacity than that of the inlets,
6. Water enters the wetland in broad sheet flow and but the wetland has no exit (outflow)
7. *Groundwater Relations*: Where wetland predictors indicate recharge potential, related flood flow control is possible.
8. Wetland is located on a larger stream.
9. Large amounts of inflow occur during the period when water level in the wetland is low.
10. Wetland is large (area) (higher water storage capacity)

Indicators of Groundwater Recharge

Nature of sediments: Groundwater recharge depends largely upon the characteristics of surface geology and soils. Hydraulic conductivity is influenced sediment characteristics such as porosity, transmissivity and permeability. Coarse sand and or gravel allow greater infiltration in shallow aquifers and rooted macrophytes generally help improve permeability of bottom sediments. Clayey soils prevent water movement into the ground.
Absence of outlets: Wetlands may be sites of groundwater recharge if they have no outlets but experience a drop in the water level soon after the inflows. Loss due to evaporation rates should be checked.

However, the best indicator is the change in the level of groundwater itself which would increase if fed by the wetland. Several wells in close vicinity of the wetland should be examined.

Assessment of Water Related Ecosystem Services

Water used by humans
Information of the use of water for various domestic purposes and its quantity can be obtained from a questionnaire survey of the communities. Water in the wetland may also be used by the people for certain activities (such as bathing and washing) without extraction. Estimates of this water use can be made from the observations on the number of people and the frequency of use. Domestic cattle may also use wetlands as a source of drinking water.

Flood control
The flood control service of the wetlands depends upon and is assessed from their water storage capacity which is the difference between the volume of water in the wetland at the maximum water level and the volume of water at the lowest level (lowest can be zero if the wetland dries up completely). Data on the storage capacity of the wetland are obtained by recording seasonal and inter-annual water level changes. The local communities may be able to provide this information and can be supplemented by field observations such as the area and depth profile of the wetland. For large wetlands, some estimates can also be obtained from remote sensing images taken in different seasons. More details of these methods, with some case studies, are given in the TESSA toolkit (Peh et al. 2013a).

Production of Biomass

Primary and secondary production of biomass are the major functions in an ecosystem. Wetlands are known to be highly productive systems. Primary production directly (through grazing food chains) or indirectly (through detritus pathway) determines the secondary production. Both macrophytes and microphytes are primary producers though macrophytes play a greater role in typical wetlands (see Gopal 2015). The involvement of both these groups in provisioning and other ecosystem services has been discussed in the previous section on biodiversity. The range of primary production by some common macrophytes, as reported in Indian studies, is noted in Table 3.

Indicators

Significant amount of primary production is indicated by the abundance of macrophytes of which the perennial emergent species contribute the most. Some free floating macrophytes such as water hyacinth also have very high rates of primary production. Large water level fluctuations and presence of large amounts of nutrients from different sources also indicate potential for high primary production.

Assessment of Ecosystem Services related to Biomass

The ecosystem services provided by the wetland plants were listed in the earlier section. These can be readily categorized into goods and services according to consumptive and non-consumptive uses.

First assess the provisioning services for consumptive uses. The non-consumptive uses will generally fall under the regulatory, supporting or cultural services.

Table 2. Annual net primary production of some common wetland plants

Species	Production, Mg ha^{-1}
Phragmites species (reeds)	50-100
Typha species (cattails)	10-94
Eichhornia crassipes (water hyacinth)	5-50
Cyperus papyrus	100-125
Arundo donax	90-100
Glyceria species	10-40
Cyperus species (& other sedges)	5-25
Polygonum species	10-30
Vetiveria zizanioides	10-30
Eleocharis species	3-20
Paspalum distichum	10-30
Zizania aquatica (wild rice)	7-25
Submerged macrophytes (e.g., *Hydrilla, Potamogeton, Vallisneria*)	2-10
Floating-leaved macrophytes (e.g., *Nymphaea, Nelumbo, Trapa*)	1-8

Provisioning Services (good)

A large number of them are used directly for food and medicine and indirectly for several purposes (thatch, mat, screens) including handicrafts. Lists of such plants and there uses are provided by Jain et al. (2011), Swapna et al. (20110, Misra et al. (2012) and Ikram et al. (2014) among many others. Methods for the assessment of harvestable goods are discussed in good detail in TESSA which can followed with relatively little adaptation.

The assessment begins with the identification of plants which are harvested, the volume of harvest, the timing, frequency and method of harvesting, harvesters and the uses. The harvest has to be sustainable to ensure its regular availability. Whereas some plants may be harvested by local communities in small amounts, others may harvest for commercial use and marketing elsewhere. Social groups may also differ in their interest in different plants and for different purposes; e.g., some may be interested in reeds and cattails for thatch or mat making whereas others may harvest grasses for their cattle; some may harvest plants like *Ipomoea aquatica* for their own consumption as vegetable or for the local market. Not all plants will be required or harvested in large amounts; for example, the local community may use a particular plant only as traditional medicine, or the poorest people may harvest it in times of scarcity of regular resource. Some plants may be harvested and processed to obtain other products as a source of livelihood (or even on commercial scale); for example, vetiveria roots are used for extracting an essential oil but not every one harvests it. Sill other plants or plant parts are harvested for their religious or cultural significance. Flowers of lotus and *Nymphaea* are widely harvested for offering in temples, and some people earn their livelihoods from them only. The harvesters may also include people other than those in the local community. They are often people from neighbouring areas, from nearby or distant regions. They would generally have a commercial interest in specific plants.

Following information should be collected for each of the important plants harvested from the wetland:

- Where it occurs in the wetland and harvested from?
- What time of the year it grows (seasonal or throughout) and when it is harvested?
- Who and how many are the people harvesting it?
- How much of the plant (or roots, rhizomes, tubers, leaves, flowers, fruits) is harvested by each individual at each harvest?

- What is the frequency of harvest? By the same or different individuals/groups?
- What are uses of the harvested material? How it is used (processed or not)?
- Whether it is used for self consumption (subsistence) or market or both (what proportion)?
- What is its price in local market and/or outside market and who buys it for what purpose?
- What are the costs of harvesting (methods used – manual or mechanical, time required, etc.) and processing if any?

This exercise is not applicable to cultivated plants such as *Trapa bispinosa* or rice.

The net annual primary production by different macrophytes (at least for different growth forms) can also be estimated by the well know harvest methods using relatively small quadrats (say 50 x 50 cm) but larger number of samples from all parts of the wetland where they occur. The method involves harvesting the plants (usually also the belowground parts) from a specific area (a quadrat), washing them and drying to constant weight. The biomass of aboveground parts in case of emergent species) obtained at the time of peak growth of the species can usually be taken as an approximate net annual production without the need for frequent sampling that is required for more accurate estimation. Other non-destructive methods are also available but are not suitable for rapid assessments. These data will help understand the sustainability of the ecosystem service used by the people. At the same time, the field data will be used for estimation of other ecosystem services from the macrophytes.

Secondary Production

Secondary production occurs at several levels in the food web. The organisms may be herbivores, carnivores or detritivores. From the direct use viewpoint such as for food, one does not distinguish between the trophic levels although it may influence the species of interest. For example, detritivore fishes such as tilapia are usually less preferred than the planktivore fishes. Fish and prawns (crustaceans) are among the most widely used components of biodiversity although many other organisms such as frogs, mollusks and arthropods are also harvested for human consumption, and sometimes considered delicacies (Sunanda Devi et al. 2010, Chakravorty et al. 2011, 2013).

The assessment of the animal biomass as a provisioning service follows the same steps and procedure as described above for plants. The information on the species harvested and amount of each species should be recorded separately as their prices may vary significantly (see Sunanda Devi et al. 2010 for prices of some organisms). Also, some social groups may accept only a particular species as a matter of preference or compulsion. The availability of animal biomass will also normally vary with the season, within the wetland, and be influenced by several biophysical factors. Sustainability of the ecosystem service (i.e., secondary production) may be affected by harvesting practices (e.g., mesh size of fishing nets). These factors also should be considered in assessing the sustainable levels of production.

Water Quality Maintenance

Another most important function of wetlands is related to the maintenance of water quality which involves both function described above – the hydrological function and the biomass production function. Various processes of nutrient uptake, nutrient transformation and nutrient accumulation together with physical processes contribute to the wetlands function of maintaining water quality (recognised now as a regulating service). Wetland plants take up nutrients and sometimes toxic substances also from the water, immobilize them by accumulation in their tissues, and transfer some to higher tropic levels (animals). Wetland plants cause resistance to flow and thereby facilitate settling out of suspended particulates, and also facilitate microbial activity for the transformation of pollutants and nutrients. Hydrological function of detention and retention of water moving through the wetlands enhances both sedimentation and nutrient transformation.

It may however be cautioned that wetlands have a limited ability to perform this function and hence to rovide the water quality regulating service because when the pollutant and nutrient load exceeds the capacity of the wetland plants for uptake, these substance start affecting adversely the growth of those very plants, animals and microbes in the wetland through a series of physic-chemical changes (e.g., oxygen depletion and reduction in light penetration) or simple toxicity. Wetlands receiving large amounts of wastewaters may not only fail to provide water quality regulation but also to provide other services, especially the provisioning services and recreational services. A decline in the water quality may make the water unfit for drinking or domestic uses or swimming, etc.

Indicators or Predictors (modified from Larson 1995)

Wetlands are likely to be most effective in this function under the following conditions:

1. They perform flood control and have effective predictors as listed earlier.
2. The velocity of water flowing into the wetland slows down suddenly.
3. Silt is observed accumulating in the wetlands.
4. Fine clay is observed on the surface of plant stems.
5. Wetland is sheltered from waves or currents.
6. Where salinity is low (< 0.5 ppt).
7. Where filter-feeding clams or immature insects are present.
8. When stirred-up sediments travel short distances before settling to the bottom.

Indicators of Nutrient Transformation (modified from Larson 1995)

1. Wetlands receive runoff from agricultural or urban areas.
2. The catchment has steep slopes, highly erodible soils, barren of vegetation, experience intense precipitation or high winds or are low in the watershed.
3. Wetlands have the potential to retain sediments.
4. Sediment organic content (dry weight) is 10-20 percent.
5. Depth along most of the water flow path is <1 m.
6. Length of the flow path is at least 15 times the average width.
7. Vegetation type is suitable for effective sediment retention (e.g., *Scirpus, Phragmites, Typha*).
7. Short draw down period: sediments are never exposed to air, or for only a few days each year.

Assessment of water quality maintenance

The water quality maintenance (regulation) can be assessed rapidly by examining the physic-chemical parameters of interest (turbidity, dissolved oxygen, nitrate nitrogen, ammonia-nitrogen, phosphates and H_2S (or sulphides) in the water at the point of inflow and outflow. These parameters can be examined readily with the help of portable electronic probes of field kits (though with less accuracy). For other pollutants, water samples should be collected carefully and carried to the laboratory and analysed following standard procedures. A significantly lower value of all these parameters would mean the wetland is functioning for water quality maintenance. For the wetland to function effectively, the inflowing poor quality water should pass through the vegetated areas and slowly n order to allow enough time for the biota to transform the nutrients. If the flow is short-circuited (bypasses the vegetation) and passes out quickly, the function is unlikely to occur.

Biogeochemical Functions

The nutrient transformations within the wetland were discussed from the viewpoint of thei relation to biomass production and water quality maintenance. These transformations are only a part of the larger biogeochemical cycles. Wetlands influence significantly the global cycles of carbon, nitrogen and sulphur. Wetlands contribute to the nitrogen cycle through denitrification as well as nitrogen fixation by blue green algae. However, the cycling of carbon involving both the oxidised and the reduced phases is of great importance because of its major role in climate change.

Wetlands being highly productive systems (as noted above), fix large amounts of carbon into their biomass. Under the prolonged or permanently submerged conditions, the large amount of organic matter produced by the macrophytes in unable to decompose and mineralise completely and accumulates in sediments (carbon sequestration). In northern climates the organic matter produced by the mosses remains undecomposed due to low temperature and acidic conditions and accumulates as peat in huge amounts despite very low rates of primary production. Thus, wetlands function as sinks of carbon and help mitigate climate change.

At the same time, wetlands with anaerobic organic sediments also produce methane, another greenhouse gas, which contributes many times more to the rise in atmospheric temperature (global warming). Paddy fields are also known to contribute significant amounts of methane to the earth's atmosphere. Recent studies have shown that globally, the role of wetlands is balanced in favour of carbon sequestration over the longer time scales (>100 years).

The climate regulation function of wetlands is assessed by the estimation of the amounts of carbon sequestered in biomass and soils, and the amounts of carbon released as methane. The amount of carbon fixed by the plants is determined from the biomass estimated by the harvest method mentioned earlier. The amount of carbon is generally, on an average, equivalent to 45% of the dry biomass. Carbon sequestration in the soils is determined from the analysis of organic carbon content of the soils at an annual interval. If the wetland dries up completely and has mineral soils left during the dry hot period, the carbon sequestration is most likely zero or negligible.

Methane emission may occur from the open water surface (or waterlogged soil surface) if the organic matter concentration is high and the water is acidic. In most cases however, methane is generated by the activity of methanogenic bacteria in the rhizosphere (root zone) of the macrophytes, and diffuses into the aerenchyma of roots and shoots before getting released into the atmosphere. Therefore, estimation of methane requires its collection by placing closed chambers over the plants (or soils) and analysis with the help of a gas chromatograph. It cannot be assessed rapidly in the field (unless one has access to portable gas chromatographs). Also, there are large inter-specific and seasonal variations which mean that elaborate sampling is required.

Cultural Services (Socio-cultural importance of wetland services)

Humans benefit from the wetlands in several other ways. People go there for swimming, or boating, or watching the wildlife, particularly the birds which arrive from far off places and congregate in large numbers, or simply enjoy the aesthetics and scenic beauty. For some people, wetlands have a spiritual significance, and indeed, many wetlands in south Asia are considered sacred. Wetlands are also preferred sites for certain religious activities. Others find mental peace and inspiration for art and literature from some wetlands. Humans often learn and discover new ideas from wetlands; for example, the properties of lotus led to the discovery of hydrophobic materials (Karthick nd Maheshwari 2008). In Malaysia, the firefliesThese non-material, socio-cultural benefits have been termed as cultural services. Among them, the recreational use of wetlands by visiting them for some short period activity as bird watching or water sport are most important. Obviously these activities are also linked with biodiversity and other functions of wetlands. A wetland with large diversity of plants and animals (such as turtles, crocodiles, otters, dolphins, ornamental fishes, and even molluscs and dragonflies, other than waterfowl) and with good quality water will attract more people. DeGroot et al. (2006) recognise therapeutic value, amenity value, heritage value, spiritual value, and existence value as main socio-cultural values. They list certain criteria that determine the socio-cultural importance of wetlands (Table 4).

The cultural services are usually assessed in terms of the number of visitors to the site. The people visiting the site from distant places reflect the importance of the wetland's cultural services more than the people living around it. The assessment should also take ino consideration the social grouping, their economic status, and the nature of activities undertaken in and around the wetland. These services also generate livelihoods of many people who facilitate their visit in different ways (transport, food, accommodation, guiding through the wetland, etc.). In Malaysia, a colony of fireflies associated with a patch of mangroves along the Selangor river, in Kuala Selangor, has turned into a large tourist attraction and the nearby village has been transformed into a tourist town flourishing with boats, hotels and restaurants. These activities are also included in the assessment of benefits from the ecosystem.

Table 4. Socio-cultural valuation criteria and measurement indicators (from De Groot et al. 2006).

Socio-cultural criteria	Short description	Measurement units/indicators
Therapeutic value	The provision of medicines, clean air, water & soil, space for recreation and outdoor sports, and general therapeutic effects of nature on peoples' *mental and physical well-being*	- Suitability and capacity of natural systems to provide "health services" - Restorative and regenerative effects on people's performance - Socio-economic benefits from reduced health costs & conditions
Amenity value	Importance of nature for *cognitive development*, mental relaxation artistic inspiration, aesthetic enjoyment and recreational benefits.	- Aesthetic quality of landscapes - Recreational features and use - Artistic features and use - Preference studies
Heritage value	Importance of nature as reference to personal or collective *history and cultural identity*	- Historic sites, features and artefacts - Designated cultural landscapes - Cultural traditions and knowledge
Spiritual value	Importance of nature in symbols and elements with *sacred, religious and spiritual significance*	- Presence of sacred sites or features - Role of ecosystems and/or species in religious ceremonies & sacred texts
Existence value	Importance people attach to nature for *ethical* reasons (*intrinsic* value) and inter-generational equity *(bequest* value). Also referred to as "warm glow-value"	- Expressed (through, e.g., donations and voluntary work) or stated preference for nature protection for ethical reasons

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Flamingos over Lake Sambhar (Photo: Amir Bhat)