A.A. van Dam, MSc, PhD
E.D. de Ruyter, MSc, PhD
C.T. Chang, MA, PhD
P. van der Zaag, MSc, PhD

LN0332/08/1

Environmental Systems Analysis

A.A. van Dam, MSc, PhD
E.D. de Ruyter, MSc, PhD
C.T. Chang, MA, PhD
P. van der Zaag, MSc, PhD

Lecture Notes

LN0332/08/1
(Draft 2008)

Environmental Systems Analysis

Contents

Environmental Systems Analysis

Module 5, Environmental Science programme, UNESCO-IHE

12 February – 2 March 2007

Coordinator: Dr. Anne van Dam, Dept. of Environmental Resources

e-mail: a.vandam@unesco-ihe.org

phone: 828

Module description

Learning objectives. Participants will learn to:

- Apply systems analysis concepts and methods to problems of the environment and natural resources;
- Describe and analyse environmental and resource systems and their interactions with humans: exploitation, impact and feedback;
- Translate an environmental or resource use problem into a model with clearly defined boundaries and objectives;
- Construct conceptual and mathematical models of resource systems;
- Estimate and evaluate system indicators, e.g. for sustainability or system health, and translate these into management options or scenarios for decision making.

Set-up of the module. Weeks 1 and 2 consist of an introduction in the functioning of environmental systems and the management of natural resources, including the methodology of systems analysis. The module builds on basic knowledge acquired in the Environmental Modelling lectures in the general programme of the ES-programme of UNESCO-IHE. Week 3 of the course is spent on group work in which the students analyse an environmental system and construct models of these systems. The case studies are concluded with a presentation of the models by each group. An overview of the lecture hours and their content is given below.

Examination. A written test of the lecture series is scheduled in the regular exam week after Modules 5 and 6 (week 13; time and place to be announced). The group work is examined on Friday 2 March in the afternoon (third and fourth period) by means of a presentation. Two UNESCO-IHE staff members will judge the presentations. Both the test (50%) and the presentation (50%) determine the marks of the subject.

Evaluation. Participants will be asked to fill in an evaluation form.

A. LECTURES

Unit 1. What is Environmental Systems Analysis (ESA)? ESA as "Science for governance"

1.1. What is ESA?

Environmental Systems Analysis (ESA) is a quantitative, multidisciplinary approach aimed at collecting, integrating, interpreting and communicating knowledge from natural and social sciences and technology. ESA applies systems analysis to describe and analyse causes, mechanisms, effects and solutions of environmental problems.

ESA usually consists of

(1) describing and understanding both the socio-economic (human) and biophysical (natural) components the environmental system;
(2) understanding the resource systems and their exploitation;
(3) applying systems analysis tools for describing and understanding the environmental system. Ideally, the end result of such a process are recommendations to decision-makers in the form of policy options and scenarios.

In the early days of environmental awareness and the application of scientific methods to environmental problems, attention was usually geared towards one specific problem or resource type. Problems were approached according to the principles of reductionist science, one discipline at a time. If models were used, they would address only one part of the problem (e.g., hydrological models, or ecological models, or economic models). With time came the realization that environmental problems are always of a multidisciplinary nature, involving both social and biophysical processes, and need attention of scientists from a wide range of disciplines. Awareness grew of the need for an integrated "ecosystem approach". With this ecosystem approach, the methods used also become more integrated and holistic. This also resulted in the use of integrated models that incorporate aspects of the various disciplines (e.g., bioeconomic models).

"Ecosystems are open systems of matter and energy (composition) in various combinations (structure) that change over time (function). Ecosystems undergo continuous change in response to pressures from component populations (humans and other organisms) and the physical environment. Sustained life is a property of ecosystems, not of species. Individual species cannot survive indefinitely. The smallest unit of the biosphere that can support life in the long run is an ecosystem. Everything in an ecosystem is related to everything else. These interrelationships underline another important characteristic of an ecosystem: it is more than the sum of its parts."

"All components of an ecosystem (physical, chemical, biological) are interdependent. Therefore, resources must be managed as dynamic and integrative systems rather than as independent and distinct elements. The ecosystem approach means that all stakeholders understand the implications of their actions on the sustainability of ecosystems. The dynamics and complex nature of ecosystems requires that the ecosystem approach be flexible and adaptive. The complex nature of problems and issues within an ecosystem can be addressed only by integration of scientific, social and economic concerns. Environmental research, planning, reporting and management must be interdisciplinary."

1.2. ESA and environmental policy making

To deal with environmental problems and avoid damage to the environment, environmental policies are needed. Many natural resources are common pool resources. There is no restriction in access to the resource, and each user reduces the possibilities of other users to exploit the resource. Examples are lakes, wetlands, fisheries, and aquifers. Because individual resource users try to maximize their own benefits, over-exploitation occurs (Hardin 1968). In Hardin's "tragedy of the commons", open access resources are victim to ever larger numbers of users who give precedence to personal gain over common benefit. There is a need to regulate the exploitation of the resources to ensure a rational and sustainable exploitation. In other words: there is a need for governance.

Initially, strong regulation by the state and private property rights were expected to prevent the loss of resources. In developing countries this approach often suffers from poor enforcement. Moreover, denying poverty-stricken rural populations access to their only source of livelihood is destined to failure. Recent forms of participatory management, in which governments and communities join forces have proven to be successful. For such co-management to work, empowerment and capacity building of communities and a supportive and transparent role of the government are needed (Kahn et al., 2004). Lately, the term governance has gained popularity. Governance implies the involvement of both public and private actors who share an interest in resource management. Apart from the actor level where most of the resource-use problems and conflicts become visible, institutional arrangements and structures (organizations involved, laws, agreements etc.) as well as shared norms and principles are important in governance. The concept of governance implies that research for natural resource management can not focus only on exploitation of the resources but must include the context in which the exploitation takes place (Giampietro, 2004; Kooiman and Bavinck, 2005).

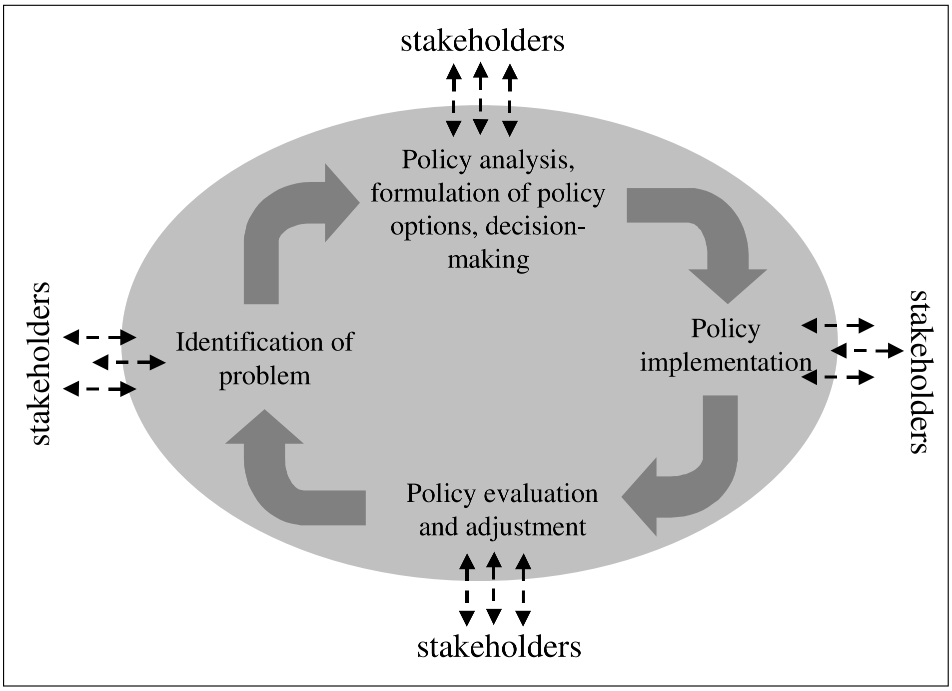


Figure 1.1. Policy process in environmental policy making

Effective governance of productive systems can be achieved if a sufficient shared knowledge base exists. Research often has a strong disciplinary orientation with a low impact on policy making. Good disciplinary research is important but will not benefit actual resource management without integration into a systems approach. Results from related fields, such as agronomy, fisheries, aquaculture and forestry need to be integrated more effectively. Policy tools are needed such as decision-support tools, wetland management plans, economic and ecological indicators, best-practice manuals, and approaches for dissemination and upscaling of successful management models (Gonsalves, 2001). Upscaling can benefit from general, widely applicable modelling frameworks that generate management options for productive natural systems based on results achieved in a limited number of research sites. Participation of communities, decision-makers and other stakeholders is crucial for such research programmes.

Figure 1.1 shows the four main phases of the policy-making process. Policy making starts with the awareness and identification of a problem (problem identification phase). The problem is then investigated and different options for solving the problem are formulated. A decision is then made about the preferred option (policy formulation phase). Then, the policy is implemented by applying policy instruments, such as laws, subsidies, fees, licences, etc. (policy implementation phase). Finally, the effect of the policy needs to be evaluated. If necessary, the policy is adjusted (policy evaluation phase). In some cases, the cycle then starts again with a fresh assessment of the problem and a new round of formulation. In all stages of the policy cycle, involvement of all stakeholders is important.

ESA plays an important role in the policy making cycle, especially in the problem identification, policy analysis/formulation and evaluation phases. For this reason, ESA could be called "science for governance"(Giampietro 2004).

1.3. References and further study

Gonsalves, J.F. (2001) Going to scale - what we have garnered from recent workshops. LEISA 17(3), 6-10.

Giampietro, M. 2004. Multi-scale integrated analysis of agroecosystems. CRC Press, Boca Raton.

Hardin, G. 1968. The tragedy of the commons. Science 162, 1243-1248.

Kahn, A.S., H. Mikkola and R. Brummett (2004) Feasibility of fisheries co-management in Africa. Naga, the WorldFish Center Quarterly 27(1&2), 60-64.

Kooiman, J. and M. Bavinck (2005) The governance perspective, pp. 11-24, In: J. Kooiman, M. Bavinck, S. Jentoft and R.S.V. Pullin (eds.) Fish for life - interactive governance for fisheries. Amsterdam University Press, Amsterdam. 427 pp.

Center for International Earth Science Information Network (CIESIN). 1995. Thematic Guide to Integrated Assessment Modeling of Climate Change [online]. University Center, Mich. CIESIN URL: http://sedac.ciesin.org/mva/iamcc.tg/TGHP.html.

Unit 2. Ecosystem components and processes

2.1. Components of ecosystems

Ecosystems consist of living components through which energy from the sun is converted into biomass, movement and heat. In this process, nutrients are cycled through the system from inorganic to dead and living organic forms and back.

The organisms that convert inorganic materials into organic matter are called autotrophs. Most of the autotrophs are green plants (macrophytes, phytoplankton, periphyton) that use energy from the sun (the photoautotrophs). Autotrophs are also called primary producers. Organisms that consume organic material are called heterotrophs or consumers. Consumers are animals that use plants or other animals as their energy source. All living organisms that die end up as dead organic matter or detritus. Detritus can also be a source of food for a special group of heterotrophs, the detritivores or decomposers.

Microorganisms such as bacteria, yeasts, fungi and phytoplankton are essential components of ecosystems. Their small size is compensated by the high numbers in which they appear and the high production rates that they can achieve. They are especially abundant in detritus and in soil.

Another important element in ecosystems is oxygen. Most heterotrophs need oxygen for the conversion of organic matter into energy. Their metabolism is aerobic. Only certain types of microorganisms can do this without oxygen, i.e. anaerobically. Air contains about 20% of oxygen, and it is relatively easy for air-breathing organisms to obtain oxygen. Water can contain much less oxygen and for aquatic organisms who need to get their oxygen from water (fish, amphibians, zooplankton, etc.) it is more difficult to obtain oxygen. The decomposition process in which organic matter is converted into inorganic matter is much faster when it is aerobic.

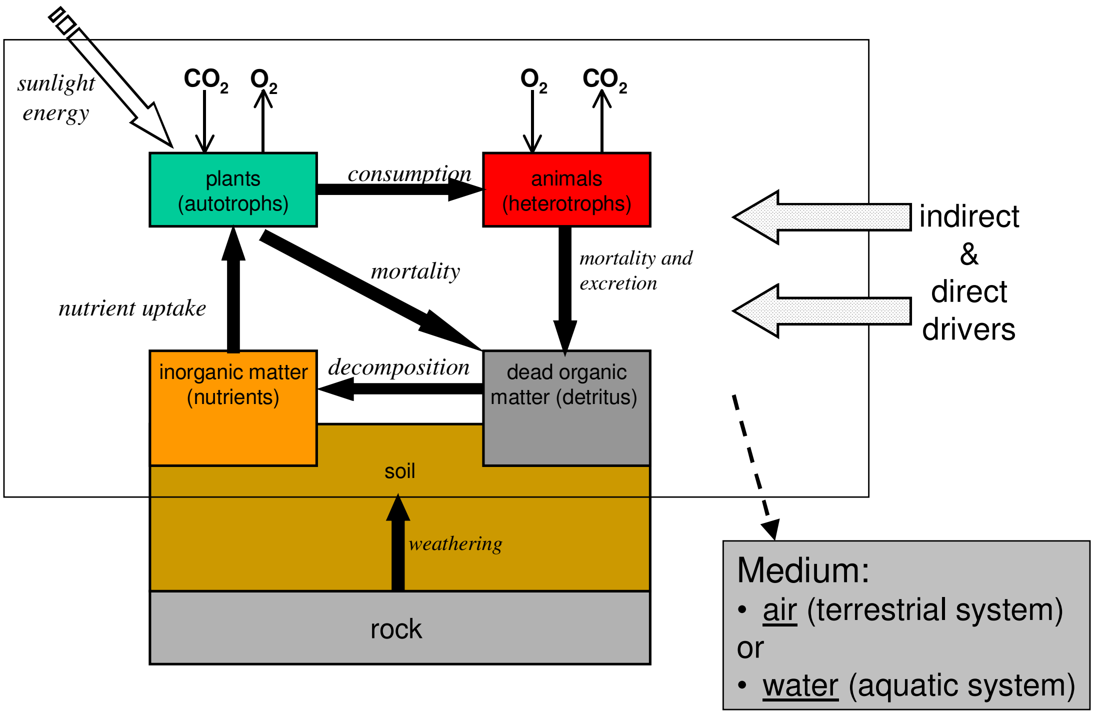


Figure 2.1. Components and processes of ecosystems.

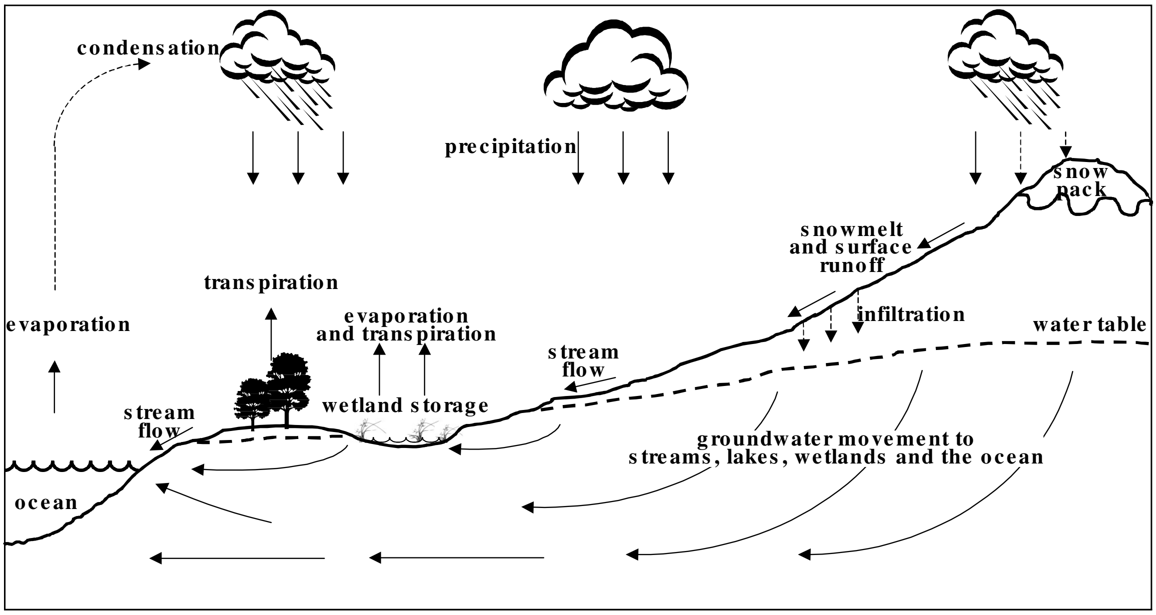


Figure 2.2. The hydrological cycle describes the flows of water on the planet between oceans, land and atmosphere.

The complete cycle of inorganic and organic matter through autotrophs and heterotrophs in an ecosystem is called the foodweb. In terrestrial systems, the foodweb is located partly in the soil (roots) and for the rest in the air (stems, leaves etc.), from which the animals obtain oxygen and which is also the medium for all the other gaseous exchange (notably carbon dioxide but also some other gases). The air also provides free access for the irradiance energy in the sunlight to reach the green plants. In aquatic systems, the air is replaced by water and the soil is saturated with water. The autotrophic and heterotrophic organisms in principle perform the same functions as in the terrestrial system, but they are adapted to the aquatic environment (Figure 2.1).

2.1.1. Water

The hydrological cycle (Figure 2.2) describes the flows of water on the planet between oceans, land and atmosphere. It involves the transformation of water into different forms (liquid, gas, solid). The hydrological cycle is driven by the radiant energy from the sun. It includes a number of processes:

- Evaporation of water from the oceans, lakes and soil into the the atmosphere. When water evaporates, it changes from the liquid to the gas phase.
- Condensation. The water vapour rises, cools down and condenses to form clouds. This can happen especially when moist air hits the land and is lifted into cooler air layers by hills or mountain ranges. When water condenses, it changes from the gas to the liquid phase. The clouds are moved around by wind. For condensation to happen, condensation nuclei are needed: miniscule particles around which water vapour droplets can coalesce. Such particles can be dust or clay or soot from fires or sea salt.
- Precipitation is water falling from the atmosphere onto the surface of the Earth (land or ocean). It can take various forms (rain, snow, hail). When condensation forms water droplets that are big enough to overcome the resistance of the air, precipitation occurs. Through precipitation, the water returns directly to the ocean or via a more complicated route: the land surface or soil. When precipitation reaches the surface of the land, it can

either collect and form surface runoff or infiltrate into the soil.

- Infiltration is the entering of water into the pore space of unsaturated soil. When precipitation infiltrates into the soil, it becomes part of the groundwater. The speed of infiltration depends on the permeability of the soil. After infiltration, the water percolates through the unsaturated soil layer to the saturated soil layer or water table.
- Runoff. This is the water that flows along the surface of the earth to a water body (lake or ocean). Runoff happens when the rate of precipitation is higher than the rate of infiltration. Runoff can collect and flow to the ocean in rivers. In the upper part of the river catchment, the headwaters are the small streams that form the river. Headwaters are generally characterized by low nutrient content, low temperatures and high flow velocities. Downstream in the floodplain, the flow rates can be lower, nutrient concentrations are higher due to accumulation and because of the lower altitude, temperatures are generally higher.
- Evapotranspiration. This is the sum of evaporation (movement of water from the liquid to the gas phase) and transpiration (loss of water from the stomata in the leaves of a plant).

Water is of crucial importance for all ecosystems but especially for aquatic ecosystems (wetlands, lakes, rivers etc.), and it is important to consider aquatic systems within the context of the complete hydrological cycle. For aquatic ecosystems to be wet, they need to receive water at least for a part of the year. The sources of water can be groundwater inflow, surface inflow (including runoff), and precipitation. The outflow of water can consist of evapotranspiration by the vegetation, surface outflow, groundwater outflow and, in case of a coastal system, the balance of tidal inflows and outflows. Often, aquatic ecosystems will have a combination of inflow sources but there are wetland types that have an exclusive inflow from one source. The water balance of a wetland can be described with the following equation:

$$\Delta V/\Delta t = Pn + Si + Gi - ET - So - Go + T \qquad (1)$$

in which

V	=	the volume of water stored in wetland;
$\Delta V/\Delta t$	=	the change in water storage volume in wetlands per unit of time t;
Pn	=	net precipitation;
Si	=	surface inflow, including flooding streams;
Gi	=	groundwater inflow;
ET	=	evapotranspiration;
So	=	surface outflow;
Go	=	groundwater outflow;
T	=	tidal inflows (+) or outflow (-) (in case of a coastal wetland)

Table 2.1. shows an example of a water balance/budget of Lake Naivasha, Kenya (IUCN/LNRA, 2005). Lake Naivasha has no surface outflow, so outflows must be through evaporation and sub-surface outflow. If evaporation would represent the main or only outflow out of the lake, an accumulation of salts in the lake would occur (this is what happens in the other lakes in the East African rift valley, such as e.g. Lake Nakuru). Because there is no buildup of salts in the water of Lake Naivasha, the sub-surface outflow must be considerable, as can be seen in the table. During the dry period the water balance was negative and the lake

was losing water. It can also be seen that water abstractions (by horticultural and other farms) represent a major part of the output of water from the lake.

Table 2.1. Annual water budget of Lake Naivasha in 10^6 m^3 per month (source: IUCN/LNRA, 2005).

	Wet conditions	Dry conditions
Inputs		
Rainfall	140.8	45.0
Surface inflow		
Malewa river	378.0	53.0
Gilgil river	74.0	3.2
Karati river	6.5	0.28
Ungauged watershed area	117.8	34.2
Seepage	54.0	32.0
Total input	771.1	167.7
Outputs		
Evapotranspiration	38.5	21.9
Evaporation	229.0	177.8
Seepage	54.0	32.0
Abstraction	33.8	53.2
Total	355.3	284.9
Balance	+415.8	-117.2

Groundwater moves through the soil slowly, at a speed in the order of a meter per year. The process by which the groundwater is replenished is called recharge. Recharge happens through infiltration from precipitation. Discharge is the upward movement of groundwater to the surface, e.g., to a lake, river or wetland. Discharge represents a loss of water from the groundwater. A spring is a place where groundwater flows to the surface naturally. Diffuse flows of groundwater to the surface, or surface water to the groundwater are called seepage. Wetlands are often located near a spring or near a place with seepage. Wetlands and lakes can also lose water to the groundwater by seepage. Aquifers are geologic formations that contain enough groundwater to be exploited commercially or for domestic or agricultural reasons. There are different types of aquifers: unconfined aquifers are permeable formations that can be recharged directly from the surface water or from infiltration of rainwater. Confined aquifers have a layer of rock or other impermeable material on top which means that they cannot be recharged by vertical infiltration (Figure 2.3).

2.1.2. Soil and soil processes

Soil originates from the bedrock of the earth by weathering and erosion. This is a process of millions of years. The eroded material is moved around by wind and water. Soils consist of a number of layers (the soil horizon) that include various components. The upper layer of the

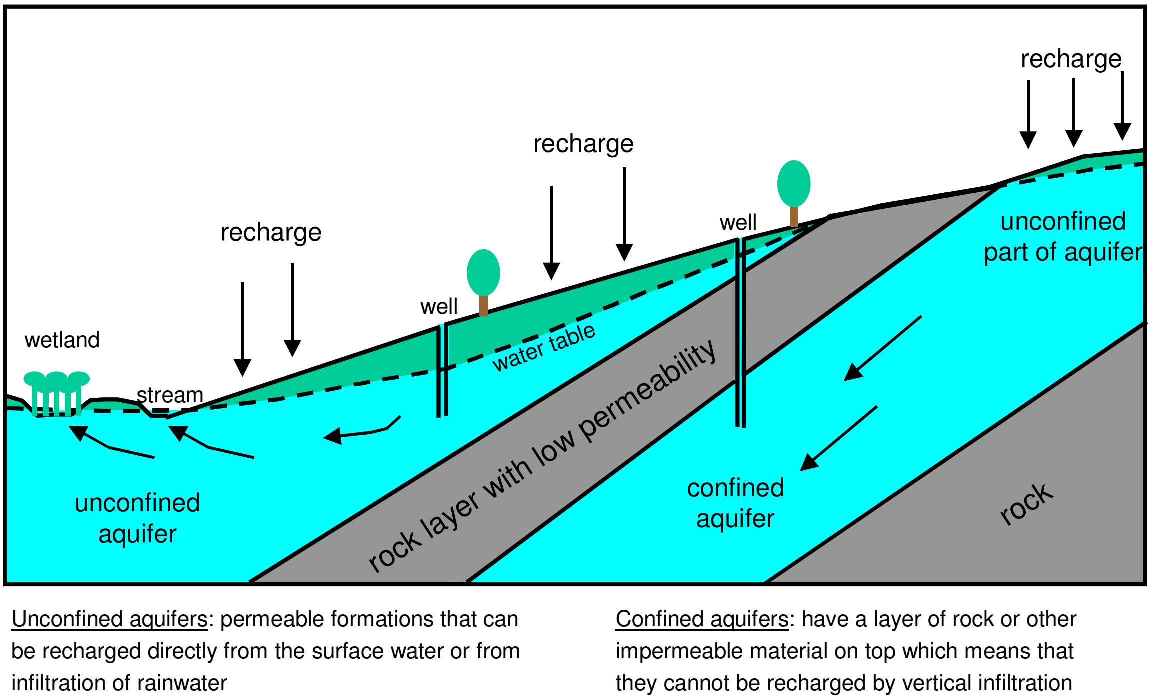


Figure 2.3. Aquifers are geological formation that contains enough groundwater to be exploited commercially or for domestic or agricultural reasons.

soil (topsoil) often contains a lot of litter of vegetation and other debris. Underneath the topsoil are various layers of subsoil, which is composed of a mixture of weathered rock material and organic material from decomposed plants. Near the surface, the organic matter content of the subsoil is higher. Towards the deeper horizon layers, the rock material becomes bigger (stones, rocks). Underneath the subsoil is the consolidated bedrock layer.

Soils are characterized by the size distribution of their particles. The smallest particles are clay (<2 μm). Silt has an intermediate size (2-50 μm) and sand has the biggest particles (50 μm – 2mm). Depending on the relative abundance of these three particle types, the soil can be classified as sand, sandy loam, sandy clay loam, silt loam, clay etc.

The space between the soil particles is called the pore space of the soil. In the upper soil layers, this pore space is occupied by water and gases (including air). This is the aerated, non-saturated zone or the 'aeration zone'. Underneath the aeration zone is the capillary water zone, where the water is held by capillary forces between the soil particles. Below the capillary zone is the saturated zone. Groundwater is water in the saturated zone of the soil and the top of the groundwater layer is called the water table. There is a difference between groundwater and sub-surface water. The latter is water that stays in the cracks beneath the surface of an unsaturated soil.

The term “hydric soil” is important in relation to aquatic ecosystems and especially wetlands. A hydric soil is a soil that is saturated or flooded long enough during the growing season to develop anaerobic conditions in the upper part that support the growth of hydrophytic vegetation. The presence of hydric soil is often used to designate a certain area as ‘wetland’.

2.1.3. Plants and vegetation dynamics

Plants are the autotrophic component of the ecosystem. Their main function in the system is to use light energy from the sun, carbon dioxide from the air and nutrients from the soil and water to produce organic matter that can be used by other organisms in the system.

On of the characteristics of wetlands is the occurrence of hydrophytes. Hydrophytes are plants that grow in water or on a substrate that is (at least periodically) deficient in oxygen as a result of excessive water. Hydrophytes have special features that allow them to survive in water-saturated environments, such as the ability to respire anaerobically, anatomic and morphologic adaptations (e.g., special tissue to transport oxygen from the leaves to the roots, or special roots), and other adaptations.

In aquatic systems, generally, three types of aquatic plants can be distinguished: (1) emergent plant vegetation; (2) submerged and floating-leaved vegetation (Euhydrophytes); and (3) surface-floating vegetation.

Ecosystems are dynamic in space and in time. Changes can occur as a result of external influences (e.g., climate) or due to internal processes (changes in productivity). Changes can be short-term (seasonal) or long-term. Wetlands can be especially dynamic, and in the next sections we will have a look at the causes of vegetation dynamics in wetland ecosystems.

Short-term dynamics in time and space are mainly caused by hydrology and vegetation. E.g., herbaceous wetlands show a zonation of vegetation along a hydrological gradient from emergent plants at the water/land interface to rooted, floating-leaved and then submerged plants at the interface between the swamp and open water. The hydrology and ecology of wetlands are intimately related. The hydrology of the wetland affects all physical, chemical and biological processes; and in return, biological changes affect the hydrological characteristics of the wetland. It is not just the presence or absence of water that matters, but also the seasonal fluctuations that regulate many biological processes. Primary production by aquatic vegetation and their reproductive cycles and decomposition rates are also regulated by fluctuations in water quantity and quality. Herbaceous wetlands are typified by a zonation of vegetation along a hydrological gradient from emergent plants at the water/land interface to rooted, floating-leaved and then submerged plants at the interface between the swamp and open water. Even within each zone a zonation of species may be identified. One may see the wetland as a buffer or transition vegetation between two major ecosystems; the terrestrial and the aquatic systems. Certainly it is a connecting system between the two. The wetland zonation is an *ecotone*, i.e. *a zone where two ecosystems overlap, and which supports species from both ecosystems as well as containing its own specific biota*. In terms of plant species the transition between those species with predominantly terrestrial characteristics through to those that are truly aquatic - the *Euhydrophytes* – have been identified.

Long-term ecosystem dynamics are more related to a process called succession. Depending on the stage of ecosystem development, ecosystems can be in an early or more mature development stage. Early development stages are associated with high productivity, high growth rates and low biomass. Mature stages are associated with low growth and productivity, and high biomass. The gradual development from low maturity to high maturity in ecosystems is called ecological succession. Succession is a long-term change in vegetation and fauna that follows a sequence with one plant community replacing another. Primary succession occurs on bare sites like sand dunes, volcanic muds or newly formed islands. The first community that forms is called the pioneer community. Secondary successions follow the pioneer community. The last community in the succession is called the climax community. In lakes, succession, consisting of a combination of sediment accumulation and establishment of vegetation, can eventually lead to formation of a wetland.

2.1.4. Animals

Animals are among the most visible components of the ecosystem. They contribute a lot to the joy that humans derive from observing and experiencing nature. They also represent a lot of the staple food that ecosystems produce, e.g., in the form of fish from lakes and wetlands. Waterbirds and their migrations connect aquatic ecosystems in different parts of the world with each other. Despite the importance and visibility of larger animals, the importance of smaller and microscopic heterotrophs for the structure and functioning of ecosystems should not be forgotten. Many animal groups suffer from threats such as extinction, habitat degradation, over-expoitation and pollution.

Just like vegetation shows a zonation along the gradient from purely terrestrial to purely aquatic environment, there is a similar trend with animals. E.g., in East African wetlands rangeland herbivores such as gazelles, buffalo (*Syncerus caffer*) and elephant (*Loxodonta africana*) visit the wetlands to graze and/or wallow, as do many domesticated species. Within the wetland can be found mammals such as Nile letchwe (*Kobus megaceros*) and sitatunga (*Tragelaphus spekei*) and swamp fish; lungfish (*Protopterus aethiopicus*) and catfish (*Clarias* sp.), while visitors from the water include aquatic amphibians (e.g. frogs and toads), and littoral fish species that breed and feed at the swamp/lake interface. The rich diversity of bird species that live within swamps such as papyrus yellow warblers (*Chloropeta gracilirostris*) and shoebills (*Balaeniceps rex*), those that fish at the swamp/open water interface (e.g. kingfishers, cormorants and waders) and those that visit from the surrounding terrestrial landscape.

Animals can influence the hydrology of aquatic ecosystems. An often cited example are beavers that can build dams, change water levels and actually change portions of dry uplands into (temporary) wetlands. Muskrats and geese can consume large parts of the vegetation of wetlands.

Ecosystems are important for the provision of habitat. Habitat is an ecological concept that is defined as the place where a particular species lives and grows. It is the physical environment that is utilized by a population of a certain species and is also affected by that population. Sometime the term microhabitat or microenvironment is used. This is defined as the immediate surroundings and physical factors of an individual plant or animal within its habitat. The term habitat can also be used for assemblages of species. Different species can share a habitat. A habitat that is shared by many species is also called a biotope. Habitat destruction is on of the major dangers for species populations that can lead to reduction or even extinction of species. Ecosystems provide habitats for a multitude of species, and ecosystem degradation and destruction thus can lead to the extinction of animal and plant species.

2.1.5. Nutrients and nutrient cycles

For a good understanding of the productivity of ecosystems and of some of the problems related to their exploitation and management, it is important to know the basic features of the main nutrient cycles. Here, we will limit the discussion to the nitrogen and phosphorous cycles although other cycles (carbon, sulfur, silicon) are also important.

Nitrogen and phosphorous are both important because they are among the so-called macronutrients: they are needed to feed the autotrophs (plants) and are often limiting productivity in both terrestrial and aquatic systems. Because they are limiting, food production systems (agriculture, aquaculture) add nitrogen and phosphorous in the form of fertilizers to stimulate the production and increase yields. Large parts of the nutrients added as fertilizers are not taken up by crops but end up in the environment, leading to a process called

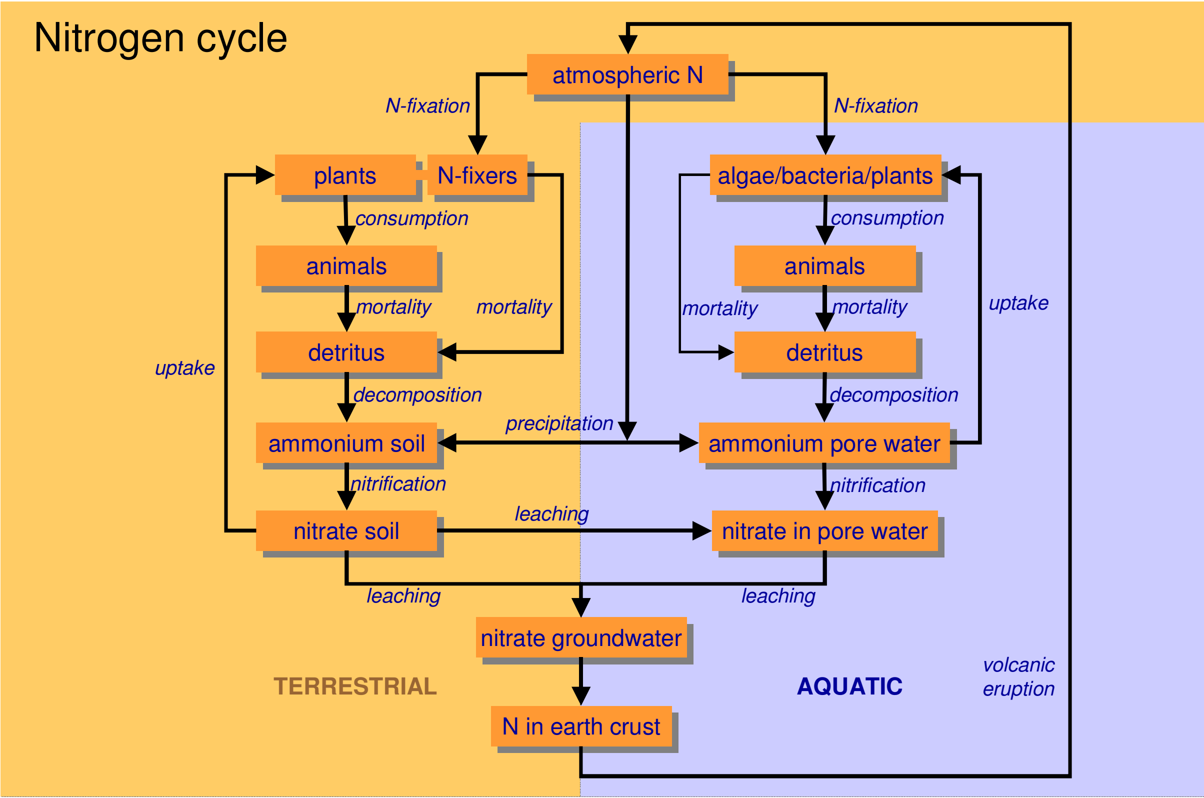


Figure 2.4. The nitrogen cycle.

eutrophication. Eutrophication involves a gradual rise in the concentrations of inorganic nutrients in aquatic ecosystems, a concomitant increase in the growth of algae and a number of related processes that lead to a deterioration of water and environmental quality.

Nitrogen is an important nutrient because it is needed for the formation of protein by all living organisms. Without nitrogen, plants and animals cannot grow, and without proteinaceous foods (legumes, fish, meat) humans cannot survive. At the same time, nitrogen is part of ammonia, a toxic substance that is produced when organic matter is decomposed. This happens naturally in ecosystems but also occurs when domestic and industrial waste decomposes. Ammonia can then become a threat to water quality.

Figure 2.4 shows the nitrogen cycle in more detail. The main reservoir of nitrogen is its molecular form in the atmosphere but only few organisms are capable of utilizing it in this form. Molecular nitrogen can be fixed by some algae and bacteria. In terrestrial systems, this is done by N-fixing bacteria in association with plants (e.g., Rhizobium with legumes). In aquatic systems, cyanobacteria (blue-green algae) can fix nitrogen. The organic nitrogen in the biomass of plants and algae is consumed by animals. Both plant and animal mortality and excretion lead to organic nitrogen in dead organic matter (detritus). This detritus is decomposed, resulting in inorganic N in the form of ammonia. In terrestrial systems, ammonia ends up in the soil where it can be converted to nitrate (through nitrification, an aerobic process). Nitrate can leach to the groundwater or be taken up by plants again. In aquatic systems, oxygen is less abundant making decomposition slower and nitrification less important. Organic N and ammonia therefore tend to accumulate more at the bottom of aquatic systems. Ammonia can however be utilized by algae. Eventually, nitrate from groundwater can end up in the Earth's crust and be recycled to the atmosphere through volcanic eruptions. In conclusion, it can be seen that the main sources of N are N-fixation from the atmosphere and recycling of N within the system. In natural waters, the amount of

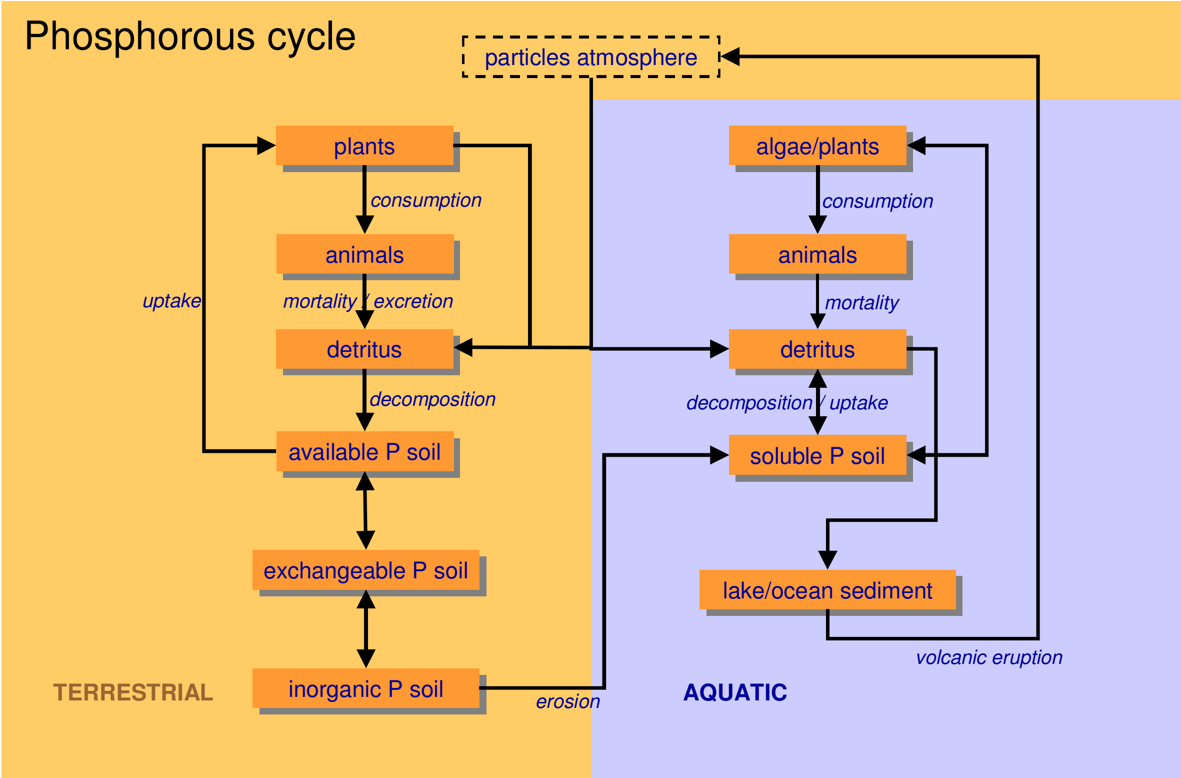


Figure 2.5. The phosphorous cycle.

nitrogen entering through N-fixation is a small fraction of that derived from other sources. In terrestrial systems, N-fixation (through legumes) is much more important.

Figure 2.5 shows the phosphorous cycle in more detail. The main difference with the nitrogen cycle is that P is not present in an atmospheric reservoir. The only form in which P appears in the atmosphere is attached to small particles. There is no gaseous form of P in the ecopshere. In terms of the utilization of phosphorous by plants and animals, there are few differences between the terrestrial and aquatic system. Soluble phosphorous in the water is taken up by plants (including phytoplankton) which in turn can be grazed by herbivorous animals. Mortality and excretion return P to the soluble pool. In terrestrial systems, this works in a similar way. Eventually, phosphorous ends up in the sediment where it is bound to soil particles. Depending on the availability of oxygen and on the pH of the soil, P can be bound or even precipitates making leaching of P from soils difficult. Lake and ocean sediments are important storage reservoirs for phosphorous. Under low oxygen conditions, such as encountered frequently in lake sediments, P is released and returned to the surface water. Phosphorous in the Earth's crust can be recycled to the atmosphere through volcanic eruptions.

Humans have intervened in the nutrient cycles in various ways. One example from the carbon cycle is the burning of fossil fuel which has contributed significantly to the rise of carbon dioxide in the air during the 20th century. For the nitrogen and phosphorous cycles, the use of fertilizers for agriculture has had serious implications for ecosystems. Application of fertilizers has intensified some of the flows in the nutrient cycle, leading to accumulation of nutrients in some reservoirs and increased process rates. Although intensive agriculture does not necessarily take place in wetlands, lakes and wetlands often end up suffering from increased nutrient loading because they collect all the runoff from a catchment. Both nitrogen (dissolved in water and particle-bound) and phosphorous (mostly particle-bound) are carried from the upstream parts of the catchment to the floodplains where they end up in wetlands and lakes. Apart from agriculture, deforestation and other unsustainable forms of land use contribute to the movement of nutrients into wetlands. The whole process is called eutrophication and leads to serious changes in the ecosystem. The main effects of eutrophication are:

- rising nutrient concentrations
- increased algal productivity
- risk of algal die-offs leading to sudden decomposition and oxygen shortage
- increased algal turbidity and therefore less light penetration
- changes in zooplankton and fish comunities

The availability of nutrients (notably nitrogen and phosphorous) determines the productivity of aquatic ecosystems to a large extent. Under natural conditions in the aquatic environment, nutrients are generated by the microbial decomposition of dead organic material and flow into and out of the wetland dissolved in water. Nutrients are absorbed by growing plants (algae and macrophytes) that take care of the primary productivity (using light energy from the sun). The rate of nutrient cycling in a wetland depends on the rates of productivity and decomposition. Primary productivity is enhanced by flowing water and reduced by stagnancy. In stagnant waters, the pore space of the soil is saturated and the dissolved oxygen us used up by microbial respiration and soil metabolism (hydric soil is formed). This causes a shift in redox potential, pH and change in cation exchange capacity of the soil and affects the availability of nutrients. Peatlands with flow-through have higher productivity than stagnant bogs. Hydrology controls the accumulation of organic matter in the wetland. High flow-through removes organic matter and prevents accumulation. Nutrient flows and cycling are determined by water flows.

Micro-organisms are crucial for the cycling of nutrients. Numerous conversion processes of nutrients are performed by microorganisms like bacteria, yeasts, phyroplankton, etc. This also means that temperature is an important governing environenmental factor.

Wetlands are often described as natural filters but they do not have an infinite capacity for nutrient removal and metal stripping. They can get overloaded with sediments till they become dry lands; binding sites for adsorption become saturated, the growth rates of the plants regulate absorption and accumulation, and if the living biomass is not harvested or grazed, minerals become re-cycled during die-off and decomposition. In other words the wetland ecosystem becomes saturated with minerals. The dynamics of the rate of loading to the system compared with the pathways for rates of loss from the system determines retention capacity. The retention capacity of a wetland can vary from one season to many hundreds of years depending upon conditions. That is why it is better to consider wetlands as buffers and reservoirs for minerals rather than sinks. During the first rains a strong surge of water through the wetland can flush out stored material including solutes, sediments, organic detritus and plants. There is evidence from studies on Lake Victoria wetlands that they are indeed buffer systems that are at least partially flushed of materials and minerals during the rains (Van Dam et al., in prep.; Mwanuzi et al., 2003).

2.1.6. Oxygen

Oxygen is an extremely important component of aquatic ecosystems. It is needed for important processes like nitrification (the conversion of toxic ammonia to nitrate) and the rapid decomposition of organic matter. The solubility of oxygen in water is much larger than in air, so seasonally flooded wetlands experience strong fluctutations in the availability of oxygen for decomposition. During the dry period, soils and detritus are exposed to air and the abundance of oxygen speeds up the decomposition process. During flooding, oxygen runs out and organic matter accumulates because decomposition is slowed down. Flooded soils are also deficient in oxygen and only hydrophytes with special adaptations to aerate their roots can survive there. The centre of wetlands tends to be anaerobic as microbiological decomposition at tropical temperatures is rapid and available oxygen is limited and quickly respired. The dense emergent vegetation shades the water from sunlight so photosynthesis and re-oxygenation in the water cannot occur.

Nutrients can be lost because of changes in aerobic state. Nitrification and denitrification depend strongly on the presence of oxygen. Nitrification is an aerobic process with nitrate as the end product. In aquatic systems under aerobic conditions, nitrate can accumulate. When conditions change to anaerobic and enough organic matter is present, denitrification can convert the nitrate into nitrogen gas which then escapes from the system to the atmosphere.

2.2. Processes of ecosystems

While the ecosystem components discussed in the previous section are the building blocks that make up the ecosystem, the processes are the links between these components. They often represent the flow of material or energy from one component to the other, or from outside the ecosystem to one of its components. In the following some of the main processes in ecosystems are discussed.

2.2.1. Primary production

Primary production is the production of organic matter from inorganic matter by autotrophs. Autotrophs take up inorganic nutrients from the soil or the water (nitrogen, phosphorous) and combine these with carbon from carbon dioxide in the air to produce organic matter (carbohydrates, proteins and fats that make up their biomass).

2.2.2. Consumption

Consumption is a process in which heterotrophic organisms consume the biomass of the autotrophs and other heterotrophs and produce their own biomass. This involves digesting the organic matter of the autotrophs and recombining this to produce their own body tissue.

2.2.3. Mortality

Mortality is the process in which both autotrophic and heterotrophic organisms eventually die (if they are not consumed before they die). Their dead biomass contributes to the pool of detritus in the ecosystem. Detritus usually ends up on the surface layer of the soil and is gradually incorporated into the soil by decomposers and by physical processes.

2.2.4. Exretion and egestion

Excretion and egestion are processes that contribute a lot to the recycling of matter in ecosystems. Heterotrophs (animals) are not 100% efficient. A large part of the nutrients they consume do not end up in their body tissue but are excreted in the form of urine or faeces. These excreted nutrients are released into the water (in aquatic systems) where they dissolve or settle to the detritus on the bottom sediment.

2.2.5. Decomposition

Decomposition is the conversion of dead organic material to inorganic nutrients. This is done by heterotrophic organisms (decomposers), ranging from bacteria to a variety of larger animals that can utilize detritus. Because most heterotrophs need oxygen, decomposition is an oxygen-consuming process. Once oxygen runs out, the decomposition is left to anaerobic organisms. Anaerobic decomposition is much slower than aerobic decomposition, and detritus tends to accumulate in anaerobic conditions.

2.2.6. Sedimentation and resuspension

Sedimentation and resuspension are important processes in aquatic systems. In terrestrial systems, dead material (animals that die or excreta) falls on the surface of the soil where it is decomposed by a variety of small decomposers. In aquatic systems, soluble materials dissolve in the water. Solid materials settle to the bottom where they are also subject to decomposers. There are however two important differences with the terrestrial environment. First of all, oxygen is scarce in the aquatic environment, and decomposition in the aquatic environment soon leads to anaerobic conditions which slow down decomposition. Secondly, material that has settled can be resuspended into the water column by wave action or by browsing animals (e.g. by bottom-feeding fish).

2.3. Some important system characteristics

2.3.1. Maturity

Depending on the stage of ecosystem development, ecosystems can be in an early or more mature development stage. Early development stages are associated with high productivity, high growth rates and low biomass. Mature stages are associated with low growth and productivity, and high biomass.

2.3.2. Carrying capacity

An important ecological concept in relation to sustainability is carrying capacity (often referred to as K). In the ecological sense, carrying capacity is defined as "the maximum population size of a given species that an area can support without reducing its ability to support the same species in the future". K is thus a function of both the area and the organism. K is a somewhat difficult concept in the context of an ecoystem approach since it only refers to one species whereas in the ecosystem approach we like to look at all the elements of the system. Another complication is that for populations of humans, the carrying capacity, apart from biological requirements, depends strongly on cultural and economic factors. A distinction is therefore made between the biophysical carrying capacity (the maximum population size that can be sustained biophysically under a given level of technology) and the social carrying capacity (the maximum population that can be sustained under a particular social system and welfare level). For a particular level of technological development, the social carrying capacity is always lower than the biophysical carrying capacity because of inefficiencies and wastefulness associated with certain lifestyles. If we would all be prepared to accept walking as the sole means of transportation, wear simple clothes and eat simple

vegetarian food, we could support many more people on this planet. This is not a realistic option.
Technology can serve to increase the carrying capacity for human populations. Often, this increase in the carrying capacity in one place is at the expense of depletion or pollution of resources elsewhere. A typical example is the pork industry in the Netherlands, which is based on imports of cassava meal from Thailand and Brazil as the main feed ingredient. This is used to maintain extremely dense populations of pigs in some parts of The Netherlands that are far beyond the natural carrying capacity. The manure production of these pigs causes environmental problems after application of the manure to the surrounding land, mainly in the form of contamination of groundwater with nitrates and eutrophication of the surface water. Thus, the increase in the local carrying capacity for the pig population is at the expense of a strong export of nutrients in another part of the world, and pollution of surface and groundwater water resources in other parts of The Netherlands.
Typical examples of exceeding the carrying capacity are (1) waste flows that are larger than the assimilation capacity of an ecosystem (e.g., in eutrophication); (2) emissions of biodegradable susbstances that are larger than the degradation rate in the system; and (3) emission of persistent pollutants (that are cannot be degraded and therefore remain in the system.

2.3.3. Resilience

Resilience is the ability of an ecosystem to absorb and still persist (Holling 1973). Resilience is an indication of the amount of disturbance (kind, rate, intensity) a system can absorb before it changes to another structure or behaviour. Resilient systems can absorb a lot of stress. Systems that are not resilient can easily be disturbed and will not recover easily from disturbances. Changes in system behaviour or structure can cause changes in the services that the system delivers. E.g., the productivity of the system may change, the supply of water may change, or there may be more uncertainty in economic activities that rely on the ecosystem. It is not easy to measure or estimate resilience because experimenting with systems to test their resilience is often not desirable.

2.3.4. Fragility and stability

Stability can be defined as the ability of an ecosystem to maintain some form of equilibrium in the presence of a disturbance. Fragility is considered the inverse of stability. The difference between stability and fragility is the distance from equilibrium: a stable system stays close to its equilibrium, even in the presence of a disturbance, whereas a resilient system moves away from equilibrium under a disturbance but does not collapse. Stable systems can stay in equilibrium for a long time under a disturbance, fragile systems are easily brought out of equilibrium. Inertia, persistance, resistance, conservatism and endurance are also terms that have been used to indicate stability. Elasticity and resiliency are terms that are used to indicate the speed at which a system returns to equilibrium after a disturbance.

2.3.5. Diversity/complexity

How diversity is defined depends on the scale level that is observed. Diversity can refer to the number of species present in a certain habitat, but it can also refer to different habitats in a landscape. In an ecosystem model, diversity can refer to the number of functional groups that are included in the model.

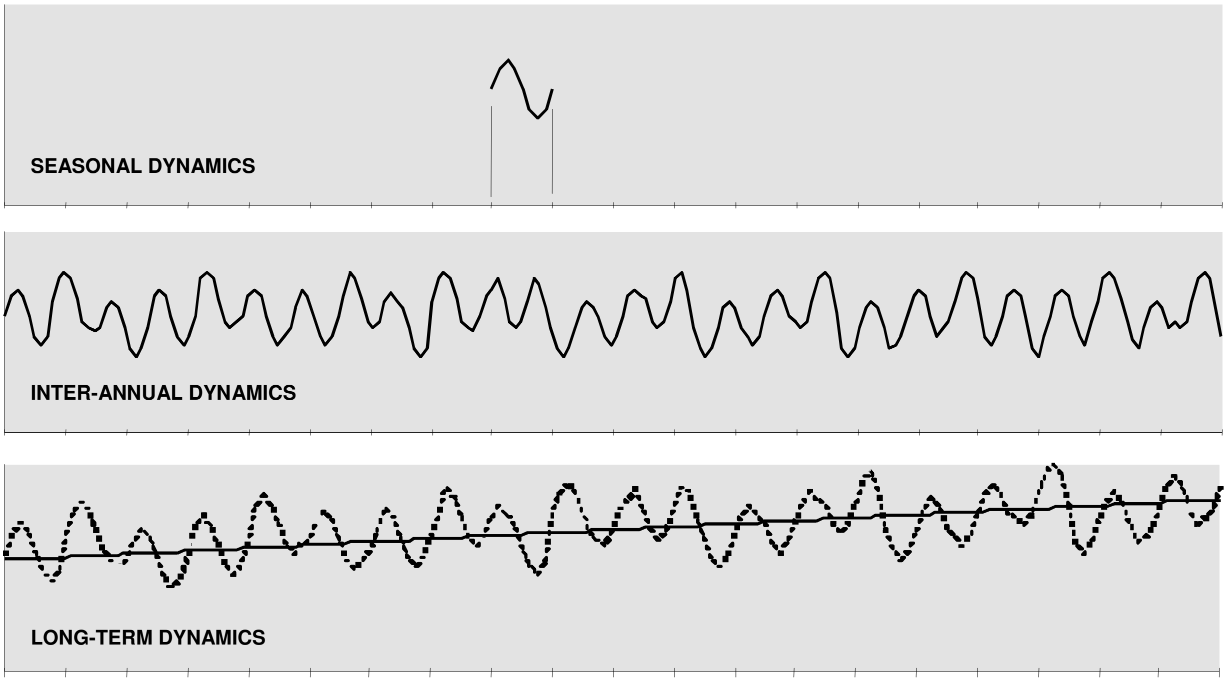


Figure 2.6. Different types of system dynamics.

2.3.6. System boundaries and spatial and time scales

In dealing with the analysis of environmental systems, it is important to consider the boundaries of the system, both in terms of the biophysical and the socio-economic parts of the system. Questions to be asked are: what are the boundaries of the area? What is the time horizon of the various processes? What are the natural processes to consider? Which human activities are important? Who are the stakeholders?

The system boundaries define which elements are considered part of the system (and therefore can change as a result of things happening within the system) and which elements are outside the system (and therefore act as driving forces for the system but are not affected by what happens in the system). E.g., meteorological conditions are often considered driving forces, determining the rate of natural processes in the system (e.g., temperature, rainfall). For a farming system, the national economic conditions can be a driving force (e.g., the prices of certain agricultural products or inputs).
With regard to time, it is good to look out for changes in the rate of change of processes. Perturbation of environmental systems often is shown by an increase in the rate of change of some of the processes. E.g., sudden increases in migration rates, or changes in the productivity of vegetation or crops (e.g., eutrophication leading to higher algal concentrations), or changes in the average size of the fish caught (as often happens when overexploitation in fisheries occurs). Changes in rates can be derived from accumulation or depletion of materials in the system (e.g., depletion of nutrients in the soil and therefore diminishing soil fertility, accumulation of algae or weeds, deoxygenation of surface water, etc.). The dynamics of a system can be sub-divided in seasonal dynamics (variations within one year due to difference in season), inter-annual dynamics (differences between years but no change in the average over many years) and long-term dynamics (gradual decrease or increase over many years) (see Figure 2.6).

2.4. References and further study

Bullock, A. and M. Acreman (2003) The role of wetlands in the hydrological cycle. Hydrology and Earth System Sciences 7, 358-389.

CBD/Ramsar (2006) Guidelines for the rapid ecological assessment of biodiversity in inland water, coastal and marine areas. Convention on Biological Diversity and Ramsar Convention, CBD Technical Report Series 22 and Ramsar Technical Report 1, Montreal/Gland.

Holling, C.S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4, 1-23.

IUCN/LNRA (2005) Lake Naivasha, local management of a Kenyan Ramsar site. IUCN Eastern Africa Regional Programme, Nairobi and Lake Naivasha Riparian Association, Naivasha. 78 pp.

MEA (2005) Ecosystems and well-being: wetlands and water synthesis. Millennium Ecosystem Assessment, World Resources Institute, Washington DC.

Mwanuzi, F., Aalderink, H. and Mdamo, L. 2003.Simulation of pollution buffering capacity of wetlands fringing the Lake Victoria. Environment International 29, 95-103.

Ramsar (2005) A Conceptual Framework for the wise use of wetlands and the maintenance of their ecological character. The Ramsar Convention on Wetlands, (Resolution IX.1 Annex A). http://www.ramsar.org/key_guide_framework_wiseuse_e.htm.

Unit 3. Ecosystem services, livelihoods and stakeholders

3.1. Ecosystem services and exploitation

Ecosystems provide a wide range of services that support the well-being and livelihoods of people. These services are based on the functions that are performed by the components (soil, water, nutrients, plants, animals) and processes of ecosystems. While the livelihoods of human communities that live near or in these ecosystems can depend completely on these services, some of the services extend far beyond the ecosystem itself and can even contribute to global processes. The Millenium Ecosystem Assessment distinguishes four main categories of services that are provided by or derived from ecosystems. These are:

- Provisioning services
- Regulating services
- Cultural services
- Supporting services

Provisioning services are often the most directly and easily visible services from which human populations benefit. They include all the products and materials that people derive from the ecosystem. E.g., in wetlands this can be the supply of fish, plants, game, fruits etc. that can be used for human consumption. They also include other materials that can be used as fuel or for construction purposes. Perhaps most importantly, water supply is among these services, both for direct consumption (drinking water) and for agricultural and industrial use. Wetlands do not only supply water, they can also store water for later use.

The regulating services include the regulation of processes related to water, sediment and climate. Taking wetlands again as an example, they play a role in groundwater recharge and discharge, can purify water from nutrients and pollutants, can trap sediments, can form a buffer against floods, etc. Although extremely important, the regulating services are sometimes more difficult to observe, especially to people who do not depend on the wetland directly. Modifications made to the wetland system often direcltly impact on the effectiveness of its regulatory services.

The cultural services provided by ecosystems include spiritual and inspirational, recreational and educational services. Ecosystems provide people with opportunities to experience nature, to learn about nature, and to generally increase their well-being by knowing that natural ecosystems are there and having the opportunity to visit them.

Finally, supporting services include soil formation (accumulation of sediment and organic matter) and nutrient cycling. These are processes that are fundamental to the functioning of ecosystems and of the wider ecosphere to which they belong. These services are vital even for people living far away from the ecosystem.

For management and policy making purposes, it is important to recognize and value all ecosystem service categories and not just one or two. Economic development projects often emphasize the benefits of the project for the provisioning services. An example is a project that will drain a papyrus wetland and convert it to rice culture. The yield of rice and its value in the market are often used to convince policy makers that the project will produce more value than the former wetland which did not produce much food. However, conversion of the wetland also means the loss of the many other wetland services, such as the water purification and buffering services. Proper valuation of all these services often shows that development projects decrease rather than increase the total value of wetlands. The challenge is to look for development interventions that enhance the services that support people's livelihoods and can contribute to poverty alleviation without affecting the other important services that wetlands provide.

3.2. Livelihoods

Traditionally, a livelihood is defined as the means of earning an income. For example: capturing fish, harvesting raw materials, or making crafts and selling them to meet one's needs are all examples of livelihoods. Livelihoods do not necessarily mean work for payment. People engaged in productive activities may not earn any cash but still contribute to their own livelihoods as well as to the livelihoods of their households. Employment should be regarded as a part of a livelihood. The informal sector, by contributing to household and individual incomes, also contributes to livelihoods. In a more comprehensive definition, the term livelihoods therefore includes not only activities but also the means – the assets and entitlements. A livelihood comprises the capabilities, the assets (including both material and social resources) and activities required for a means of living.

Livelihoods consist of:

1. Activities, such as work, in the formal and informal sectors;
2. Assets, which can be divided into four categories:
   - Human capital: skills, knowledge, creativity and adaptive strategies
   - Social capital: governance structures, decision-making power, community and other institutions, culture and participatory processes
   - Natural capital: land, water, air, rivers, lagoon, ocean and forests/vegetation, wetlands
   - Human-made capital: buildings, roads, machinery and crops/livestock;
3. Entitlements, including: the support of family or clan members, rights enshrined in national constitutions and international treaties, technical assistance from extension workers, social security and unemployment insurance (if available);
4. Short-term coping mechanisms in response to shocks and stresses;
5. Adaptive strategies including the long-term changes and adjustments people make in their livelihood systems in order to respond to difficult circumstances.

Various development organizations have embraced a "sustainable livelihoods approach" and use a "sustainable livelihoods framework" as a guideline for working with communities. A sustainable livelihoods approach is an approach to development in which people's livelihoods are the focus of attention and which adopts the principles of the sustainable livelihoods approach (i.e., people-centered, holistic, dynamic, building on strengths rather than needs, multi-scale, and focused on sustainability). An example is the DFID (Department for International Development, UK) Sustainable Livelihoods (SL) framework (see e.g, www.livelihoods.org). The SL framework can be divided into five key components: the vulnerability context; livelihood assets; policy, institutions and processes; livelihood strategies and livelihood outcomes. The SL framework shows how these factors relate to each other (see Figure 3.1). It is important to realize that people can convert assets to activities, or how policies, institutions and process affect the key components. A livelihood (as a means, and an outcome) can be said to be sustainable if it satisfies five criteria, namely:

- An increase in real value between two time periods;
- Economic effectiveness or the use of minimum inputs to generate a given amount of outcome;

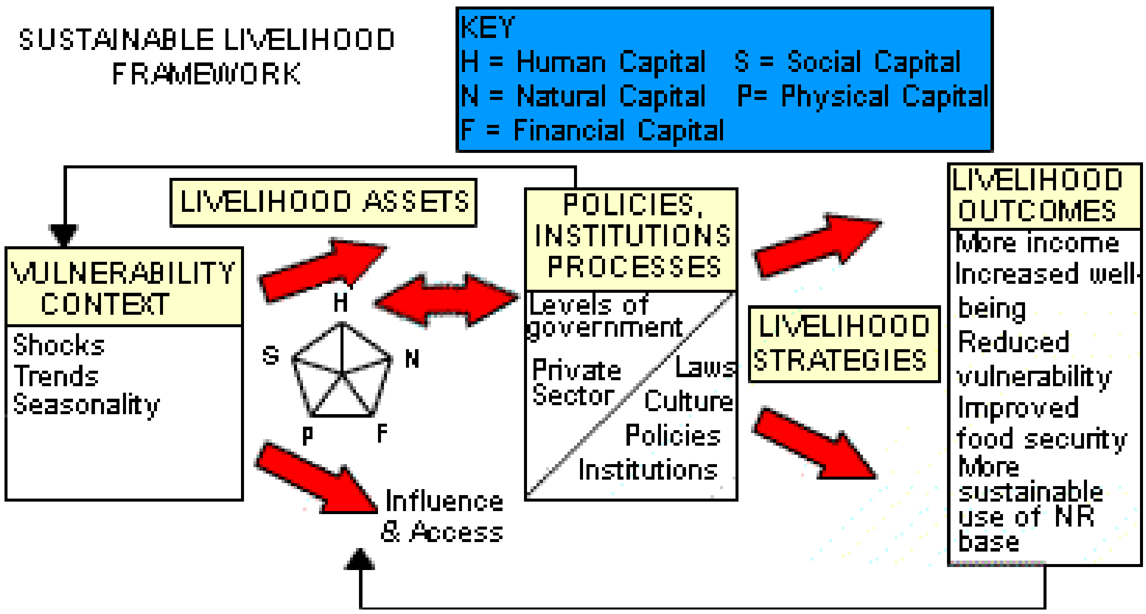


Figure 3.1. Sustainable livelihoods framework (source: IDS, http://www.livelihoods.org/info/guidance_sheets_rtfs/Sect2.rtf).

- Non-declining values of natural capital;
- Social equity, which suggests that promotion of livelihood opportunities for a household does not impose negative externalities on others, nor foreclose options for other groups either now or in the future;
- Ability to cope with and recover from vulnerability.

3.3. Stakeholders

3.3.1. What are stakeholders?

All people who have a stake (or share) in a particular issue or system are called stakeholders. Most of the time, we can define stakeholders as groups of people (e.g., communities, organisations or institutions) but sometimes also as individuals. Other terms that are often synonymous to stakeholders are "actors" (people are often involved in some activity that can have an impact on other stakeholders and on the environment) and "interest groups" (stakeholder usually have an interest in the system). Stakeholders can be at any level or position in society, from the international to the national, regional, community or household level. Stakeholders include all those who affect and are affected by policies, decisions or actions within a particular system. For Environmental Systems Analysis, it is important to consider stakeholders as they represent the human component of the environmental system and are always involved in both the cause and the solution of environmental problems.

Hannan and Freeman (1984) define stakeholders as 'any group or individual who can affect or is affected by the achievement of a corporation's purpose'. In the context of natural resources, Röling and Wagemaker (1998) define stakeholders as 'natural resource users and managers'. Examples of stakeholders in wetland management are: local communities living in the wetlands, communities living downstream of the wetland receiving water from the wetland, government agencies at various levels (local, district, national) involved in management of the wetland, non-governmental organizations involved in wetland conservation, etc. It can thus be concluded that communities are almost always stakeholders, but not all stakeholders are (part of) communities. Table 3.1 gives an example of stakeholders in a forestry project.

Table 3.1. Example of stakeholders in a forestry project (based on Grimble and Wellard, 1997).

Institutional level	Actors	Interests
Global / international	International agencies Donors Environmental lobbies	Biodiversity Conservation Climatic regulation
National	National governments NGOs	Timber extraction Tourism development
Regional	Forest departments Regional authorities	Forest productivity Soil conservation
Local off-site	Local communities Local authorities Logging companies	Access to timber supply Conflict avoidance
Local on-site	Forest dwellers, Livestock keepers, Agriculturists Women firewood collectors	Land for cultivation and grazing Cultural sites

3.3.2. Why is it important to identify and consider stakeholders in ESA?

Environmental management policies and sustainable development projects often fail. Many times, there has been lack of involvement of stakeholders in the various stages of policy or project development. Each stakeholder has a different perspective on the system and a different interest. The objective of stakeholder analysis is to incorporate the stakeholders' multiple and often conflicting views, interests and objectives in the analysis of the system (and also in the formulation and implementation of solutions). Stakeholder analysis looks at the interests, objectives, power and relationships (including conflicts) of stakeholders.The term stakeholder analysis was first used for identifying and addressing the interest of different stakeholders in business. In environmental analysis and management, stakeholder analysis is used for:

- understanding and analysing complex situations in natural resource management;
- policy formulation;
- project formulation;
- implementation and evaluation.

(i.e., in all stages of the environmental policy making cycle). Stakeholder analysis can help to improve the implementation of projects and policies by helping to identify trade-offs between different stakeholders objectives and the conflicts between them. As a result, the effectiveness and impact of policies can be improved. Stakeholder analysis can also support the evaluation of policy and project impacts, e.g. by looking at the distribution of the benefits of policies and their social and political impacts. It can highlight the needs and interest of people who might otherwise have been forgotten or left out by the policy or project. Stakeholder analysis is a tool in the search for efficient, equitable and environmentally sustainable development strategies (Grimble and Wellard, 1997).

3.3.3. What different kinds of stakeholders are there?

In projects, a distinction is often made between primary and secondary stakeholders.

Primary stakeholders are the intended beneficiaries of a project. This includes intended beneficiaries or those negatively affected. In most projects, primary stakeholders will be categorised according to social analysis. Thus, primary stakeholders should often be divided by gender, social or income classes, occupational or service user groups. In many projects, categories of primary stakeholders may overlap (eg. women and low-income groups; or minor forest users and ethnic minorities).
Secondary stakeholders are the (groups of) people who are intermediaries within a project. Secondary stakeholders can be divided into funding, implementing, monitoring and advocacy organisations, or simply governmental, NGO and private sector organisations. In many projects it will also be necessary to consider key individuals as specific stakeholders (e.g., heads of departments or other agencies, who have personal interests at stake as well as formal institutional objectives). Also note that there may be some informal groups of people who will act as intermediaries. For example, politicians, local leaders, respected persons with social or religious influence.

Another distinction is between key, active and passive stakeholders.

Key stakeholders are the stakeholders who are considered to have significant influence on the success of a project.
Active stakeholders are the stakeholders who affect or determine a decision or action in the project.
Passive stakeholders are the stakeholders who are affected by decisions or actions of others.

3.3.4. How can we identify stakeholders?

Identifying stakeholders is not always a straightforward process. Often, stakeholders are found after talking to other stakeholders. To avoid missing important stakeholders, it is important to review this regularly. Not all stakeholders are equally important throughout the whole systems/stakeholders analysis. Some may gain importance during the process, others may become less important. Criteria for identifying who should be considered stakeholders are:

- Degree of economic, social or cultural reliance on the system;
- Degree of effort and interest in the management of the system;
- Present or potential impact of the activities of the stakeholder on the system;
- Historical and cultural relationship with the system;
- Unique knowledge or skills for the management of the system or resources at stake;
- Existing rights to land or other natural resources.

Often, stakeholder analysis uses groups like communities, the government or the private sector. While this suggests that these groups are homogeneous, they are not. Individuals in communities are differentiated by gender, caste, wealth, age, occupation, etc. All these give social identity but divide people and cut across community boundaries.

Identification of stakeholders is not something that can be done by reading a few articles about the environmental system. Being on the ground, making field visits and having meetings and discussions are very much part of a thorough stakeholder analysis. Stakeholder analysis can be approached from different angles, depending on the specific objective of the analysis. Two main approaches are a strategic approach (which we will use in this exercise) and a participatory approach.

A strategic approach is primarily aimed at analyzing, designing, implementing and/or evaluating an environmental project or policy. In this type of stakeholder analysis a matrix or checklist of all stakeholders is formulated and the stakeholder's interests and other related characteristics (such as interrelationships, potential risks and conflicting interests) are listed. For the formulation of a project, the interests and risks can be related to project objectives and activities.

A participatory approach to stakeholder analysis is aimed more at faciliation of negotiation and dialogue between stakeholders. In this case, the stakeholders learn about the interests of other stakeholders by participating in the process of stakeholder analysis. There is a whole range of participatory methods and exercises that can be used for participatory stakeholder analysis.

3.4. References and further reading

Hannan, M.T. and Freeman, J. (1984) Structural inertia and organizational change. American Sociological Review 49, 149-164.

Grimble, R and Wellard, K 1997, "Stakeholder methodologies in natural resource management. A review of principles, contexts, experiences and opportunities," Agricultural Systems Journal 55(2): 173-193

Röling, N.G. and Wagemakers, M.A.E. (1998) A new practice: facilitating sustainable agriculture, pp. 3-22, In: Facilitating sustainable agriculture. Participatory learning and adaptive management in times of environmental uncertainty (ed. by N.G. Röling and M.A.E. Wagemakers). Cambridge University Press

ODA, 1995. Comprehensive guidance note on how to do stakeholder analysis of aid projects and programmes. Social Development Department, Overseas Development Administration, London (available at: http://www.euforic.org/gb/stake1.htm).

Unit 4. Drivers of change in environmental systems

See Chapter 4 of Ecosystems and Human Well-being: A Framework for Assessment (Millennium Ecosystem Assessment), available at http://www.maweb.org/en/Framework.aspx

Unit 5. Sustainable management of natural resources

5.1. Some definitions

Ecological character

"Ecological character is the combination of the ecosystem components, processes and services that characterize the wetland at a given point in time" (MEA, 2005)

Sustainable development

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987)

Sustainable use

"Sustainable use, both extractive and non-extractive, is a dynamic process toward which one strives in order to maintain biodiversity and enhance ecological and socio-economic services, recognizing that the greater the equity and degree of participation in governance, the greater the likelihood of achieving these objectives for present and future generations." (Zaccagnini et al., 2001)

Wise use of wetlands

"Wise use of wetlands is the maintenance of their ecological character within the context of sustainable development, and achieved through implementation of ecosystem approaches" (MEA, 2005).

Ecosystem approach

An ecosystem approach recognizes that "all components of an ecosystem (physical, chemical, biological) are interdependent. Therefore, resources must be managed as dynamic and integrative systems rather than as independent and distinct elements. The ecosystem approach means that all stakeholders understand the implications of their actions on the sustainability of ecosystems. The dynamics and complex nature of ecosystems requires that the ecosystem approach be flexible and adaptive. The complex nature of problems and issues within an ecosystem can be addressed only by integration of scientific, social and economic concerns. Environmental research, planning, reporting and management must be interdisciplinary." (CBD, 2002).

5.2. Concepts of sustainable management

Sustainable Use is a concept that has been developed with support from IUCN (IUCN Sustainable Use Initiative and later on the Sustainable Use Specialist Group). Its development was prompted by important questions about the sustainability of natural resources in the world in relation to population growth and poverty reduction. Prohibitive policies had proven to be ineffective because it is impossible to control all resource users. Many rural and peri-urban resource users depend directly on natural resources for their livelihoods. A combination of using resources and at the same time preserving them seems more viable in theory, but there

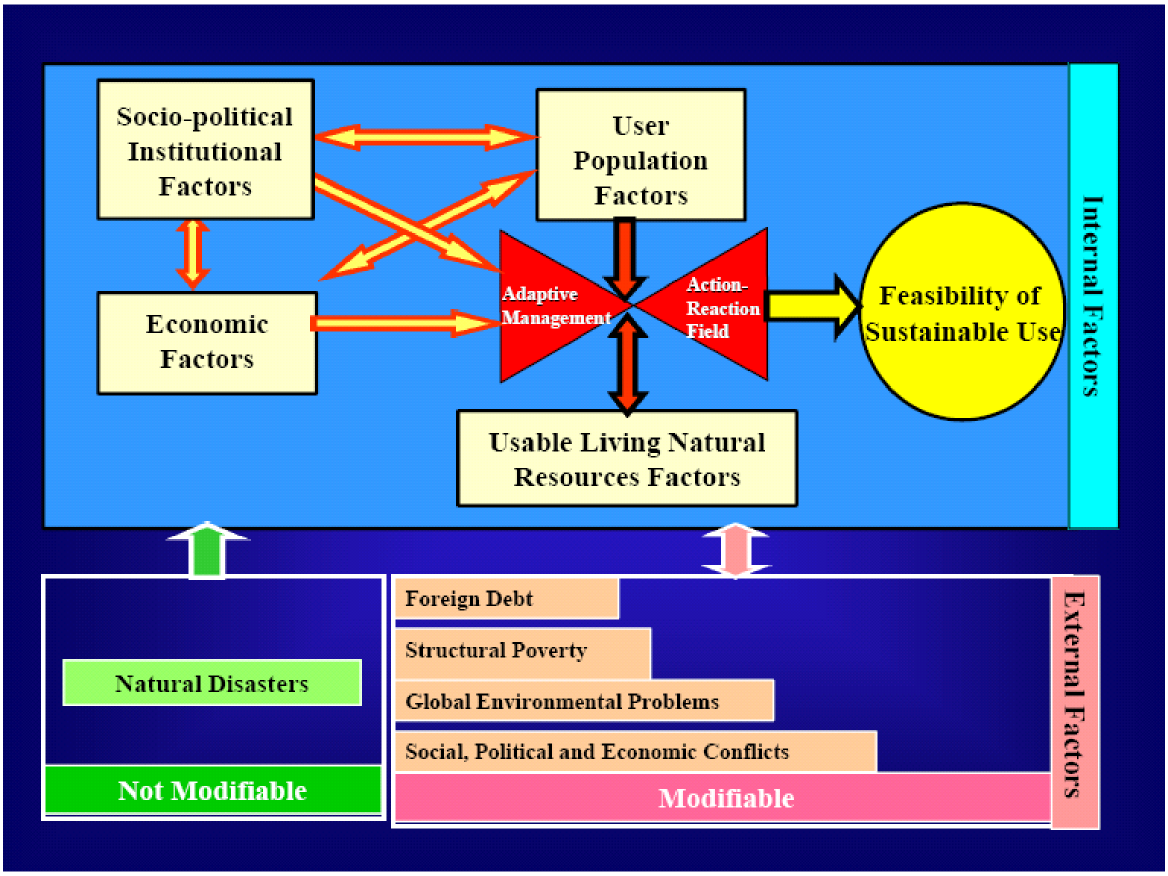


Figure 5.1. Conceptual framework of the Sustainable Use concept (from: Zaccagnini et al. 2001).

were many questions about how to implement programmes of sustainable use. IUCN attempted to develop an analytical framework for the concept of Sustainable Use. Such a framework can be used to evaluate the sustainability of certain resource systems and their management schemes or policy options. The framework contains indicators for ecological, economic, social and socio-political factors (the different dimensions of sustainability).

The concept is based on seven axioms and eight principles. The most important principles are that stakeholders should benefit equitably from the resource use, that adaptive management should be applied, that traditional knowledge should be taken into account and that institutional support should be given to the process of sustainable use (see Zaccagnini et al. 1991). Much emphasis is put on the multidisciplinary and dynamic character of the sustainable use. Ecological integrity itself is not sustainable when people are suffering from poverty, so all dimensions of sustainability should receive attention. The framework assumes that apart from the productive capacity and integrity of the ecological system, equitable sharing of the benefits and full participation of civil society in the management processs are important factors/criteria for sustainability.

The Ecosystem Approach was primarily developed as a framework for action of the Convention on Biological Diversity (CBD). In 1995, it was adopted by the CBD which recommended the application of the principles of the Ecosystem Approach to the countries who are party to the Convention. There are 12 principles that describe the Ecosystem Approach (see CBD 2002) and five operational guidelines. The main points of these principles are: (1) the Ecosystem Approach advocates the integrated management of land, water and living resources to promote conservation and sustainable use in an equitable way; (2) the Ecosystem Approach is based on scientific methodologies and focusses on the components and processes of ecosystems (i.e., the organisms and their environment), of which humans are often an integral part; (3) implementation of the Ecosystem Approach requires adaptive management, i.e., a "learning by doing" approach to management which takes into account that ecosystems have a high degree of uncertainty and non-linear behaviour, that there is lack of knowledge about these systems which makes prediction of their behaviour difficult, and that management should include continuous monitoring and subsequent adptation of management goals and actions.

The concept of sustainable development became important when it was introduced by the IUCN in the World Conservation Strategy in 1980. Main criticism of the terms "sustainability" and "sustainable development" are that there is a lack of consistency in their interpretation; that the formulation of objectives is weak; that the underlying problems of poverty and environmental degradation are not understood properly by people using the terms; and that all this leads to inadequate policy making on the basis of the terms. It is important to distinguish different forms of sustainability. These forms can be called the "dimensions" of sustainability. The three most often used dimensions of sustainability are:

- social sustainability
- ecological sustainability
- economic sustainability

These three dimensions have been translated popularly as "the three P's" (People, Planet, and Profit, respectively). Quantitative, rigorous indicators for each of these dimensions need to be defined in order to be able to use them for characterizing ecosystems or changes to ecosystems. To get a good indication of sustainability, indicators for the three dimensions of sustainability need to be evaluated simultaneously. Using a wetland for economic development may have a positive effect on one dimension of sustainability (economic dimension) but a negative effect on another (ecological dimension). In that case, the solution cannot be called sustainable. E.g., if degradation of a papyrus wetland because of seasonal agriculture and harvesting of papyrus is the problem, then we could define the following sustainability indicators:

- social: employment
- economic: household income
- ecological: diversity of wetland plant and bird species

If the degradation of the wetland is stopped by installing a fence around the wetland and restricting access for the riparian community, the ecological sustainability indicator will probably benefit with an increase in diversity of plant and birds. However, the social and economic indicators may suffer because the community loses its source of livelihood. Overall, the fence is not a sustainable solution. Alternatively, a solution could be proposed with environmentally friendly forms of agriculture or perhaps some form of ecotourism where the integrity of the wetland is maintained while at the same time the community can earn a livelihood from the wetland.

5.3. Exploitation of ecosystems

5.3.1. Exploitation, impact and feedback

Most environmental problems have their origin in the actions of humans. Humans want to exploit the natural environment to support their livelihoods. Three processes are of major importance (see Figure 5.2):

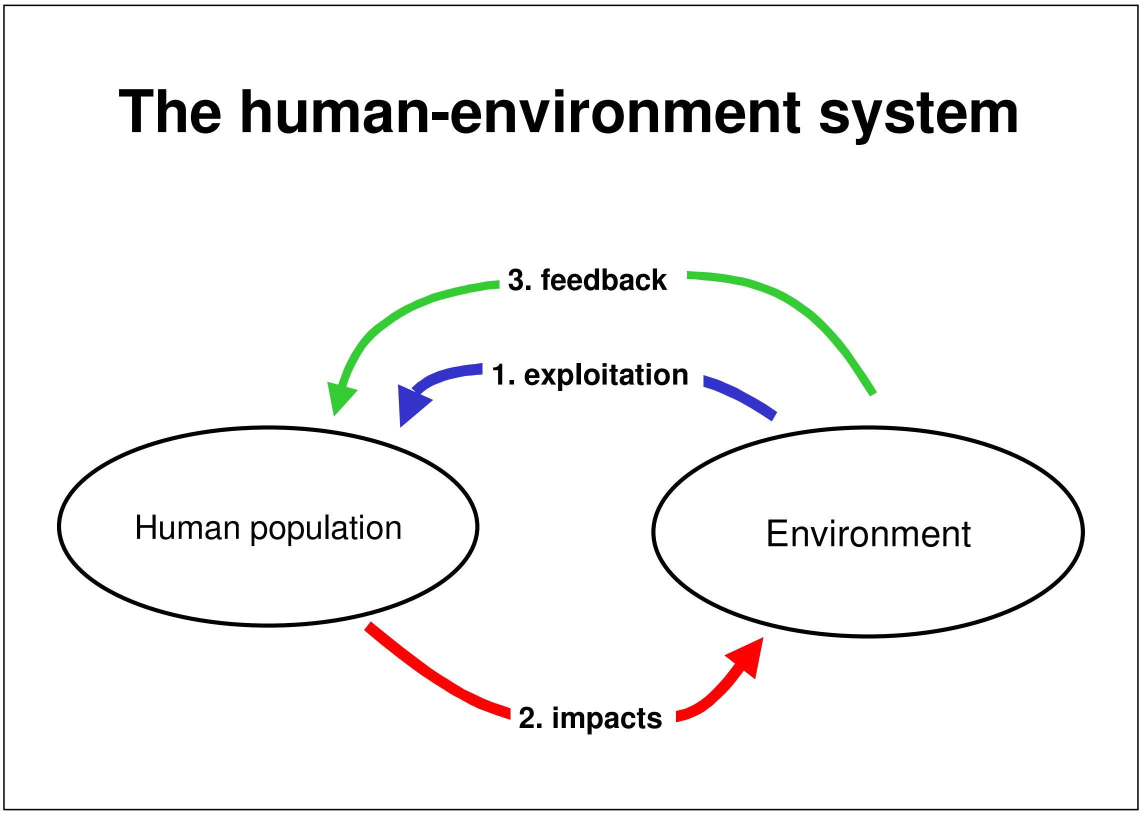


Figure 5.2. Exploitation, impact and feedback in environmental systems.

- Exploitation of the natural environment by humans. The exploited parts of the natural environment are the natural resources that provide services to humans. Examples of exploitation are agriculture (soil nutrients), fisheries, mining of sediments for brick making, hunting, etc.
- Impact of humans on the environment. The impact of a population depends on the population size, the per capita consumption and the environmental damage due to the use of technologies. The main forms of impact are pollution (air, water, soil), depletion (e.g., fish, minerals, fossil fuels) and degradation (biodiversity, wetlands, rain forest, etc.). In wetlands, the impact often consists of changes in the hydrology and damage to the vegetation (together causing reduction of habitat for natural populations), reduction of the biodiversity, introduction of exotic species, etc.

  The impact (I) of a population can be expressed as a product of population size (P), the per capita consumption (A) and the environmental damage due to the use of technologies (T) (Daily and Ehrlich 1992):

  $$I = PAT$$

  T is usually a function of P and A. Per capita consumption and environmental damage are generally higher in rich countries. Because 80% of the world population is in poor countries, the per capita impact is higher in very poor and in very rich countries.
- Feedback on humans. Negative effects of impact are felt by humans themselves. Because of the impact that human populations have on the environment, the structure and function of the natural environment may be affected. This leads to a reduction of the services to the human population. Examples are soil nutrient depletion leading to lower crop yields, fish stock depletion leading to lower catches, air pollution leading to respiratory diseases, etc.

5.3.2. Renewable and non-renewable resources

Natural resources can be classified as renewable or non-renewable, essential or substitutable, and necessarily or not necessarily degraded when used (see Table 5.1).

Table 5.1. Classification of resources: renewability and substitutability

Resource type		**Not necessarily degraded or dispersed in use**	**Necessarily degraded or dispersed in use**
Non-renewable	Essential	Ozone, tropical forests, biodiversity	Time, opportunity
	Substitutable	Some materials that supply services (e.g., gold, diamonds)	Fossil fuels, some minerals
Renewable	Essential	Ecosystem elements that supply services (e.g., soil microbes, pollinators)	Solar energy, fresh water, soil for agriculture
	Substitutable	Species that supply services (e.g., draught animals, insulin, vaccines, shade trees)	Wood for construction, plants and animals for food

Another way of thinking about renewability of resources is in terms of systems theory. The resource can be represented as a stock or state variable with one inflow (the renewal rate) and one outflow (the exploitation rate). In non-renewable resources, the renewal rate is very low or even zero. When the exploitation rate is high, the stock will be depleted relatively quickly and the resource will disappear. An example are fossil fuels that have taken millions of years to form (slow renewal rate) but might be depleted in 100-200 years (fast exploitation rate) (see Figure 5.3).

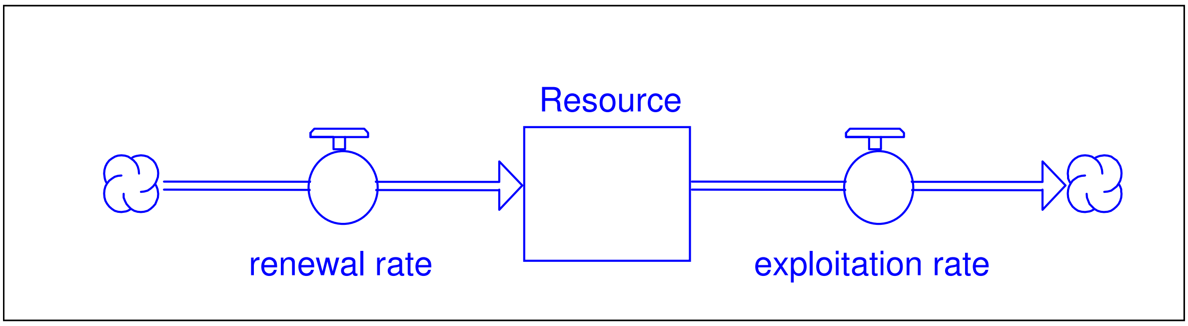


Figure 5.3. Systems dynamics representation of exploitation of natural resources.

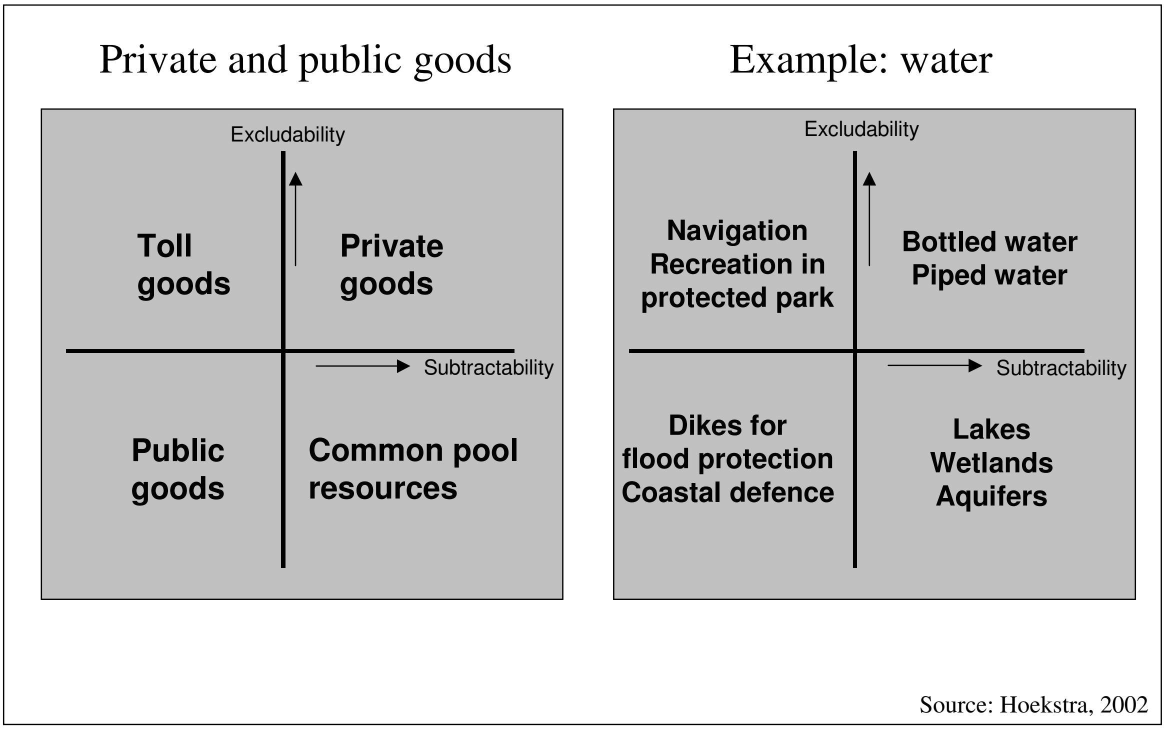


Figure 5.4. Private and public goods.

5.3.3. Excludability and substractability

Another way of looking at resources considers the excludability and subtractability of the resource:

- Excludability is the degree to which users can be excluded from the resource (denied access).
- Subtractability is the degree to which exploitation by one user reduces the possibility for exploitation by other users.

The concepts of excludability and subtractability allow the distinction of private and public goods (Figure 5.4). Wetlands in most cases are examples of public goods with a low excludability and high subtractibility.

5.3.4. Extractive and non-extractive use

Extractive use of ecosystems is based on their provisioning services. It involves the harvesting, capturing or culturing and ultimately the export of living or non-living ecosystem components. This includes a range of activities from harvesting of natural products to culturing of plants or animals. Examples of harvesting are fishing, drinking water abstraction, fuel production (wood or peat), harvesting of construction materials (clay for brick making, wood, other fibrous materials such as papyrus or reeds, etc.), medicinal plants, etc.

Natural ecosystems can also be used as an environment for culturing plants or animals. The most obvious example is the use of wetlands for agriculture. Wetlands contain large amounts of moisture and nutrients, important resources for agriculture. The availability of water also makes wetlands very attractive for aquaculture, the growing of aquatic organisms (e.g., fish). An example of this is the use of mangroves for shrimp culture.

Non-extractive use is based on the regulatory, cultural and supporting services of wetlands. Non-extractive use involves use of the functions of the ecosystem without the physical removal of ecosystem components. Examples of non-extractive use are the use of natural ecosystems for water purification, tourism, the use of wetlands for flood protection, the use of water bodies for shipping, etc.

Both extractive and non-extractive use create an impact on the ecosystem. Extractive use changes the levels of (bio)mass of the ecosystem components. When living components (organisms or biomass) are harvested, this can have implications for other organisms who are linked to the affected organisms through the food chain. Both extractive and non-extractive use can change the habitat of organisms. Removal of vegetation changes the habitat for animals. Waste loads and visitors put pressure on the natural system and can disturb the natural components and processes.

5.3.5. Species level use versus ecosystem level use

Examples of use at the species level can be found in several extractive uses of natural resources: fishery, forestry, agriculture. Sustainable use could be defined as a level of exploitation which ensures the continuous presence of the target species above a certain abundance threshold that guarantees its future viability. Viability should be both demographically (i.e., in terms of numbers of the species itself) but also ecologically (i.e., in terms of the ecotrophic links of the target species with other species as predators or prey).

Use at the ecosystem level can range from recreational activities to activities that use the ecosystem's functions or services. Examples of use at the ecosystem level are: water regulation by wetlands; carbon sequestration by forests; or the role of tropical forests as reservoirs of genetic material.

5.4. Impact of use on ecosystems

5.4.1. Types of impact

The impact of exploitation on ecosystems can be evaluated in terms of their components and processes, and ultimately of the services they provide. Three general categories of impact can be distinguished:

Pollution: the activity leads to increased concentrations of nutrients, toxicants or microorganisms in the water, soil or air of the ecosystem. The natural processes of the ecosystem cannot reduce these concentrations to levels that are considered acceptable. The change in concentrations has a negative effect on other components of the system, e.g., it causes mortality among plant or animal species, it causes extreme changes in processes that lead to imbalance in the system, it gives aesthetic problems, etc. Examples: excessive discharge of wastewater into wetlands, leading to eutrophication with algal blooms, oxygen depletion and fish kills.

Depletion: the activity leads to reduction in the abundance of certain components. This will eventually lead to the activity to be terminated because a depleted resource can no longer be exploited. Examples: overfishing, abstraction of water for irrigation.

Degradation: the activity alters the ecosystem to such and extent that it can no longer provide some or all of its services. Typical examples are: the draining of wetlands for conversion into agricultural land. Although not all of the wetland is converted, the changed hydrology leads to degradation of the whole wetland. Upstream construction of a dam leads to degradation of the downstream floodplain wetlands.

5.4.2. Example: impact of agriculture on wetlands

Wetlands provide important services to humans. While all four categories of services discussed in the previous sections contribute to human livelihoods, those types of wetland use that can contribute directly to the economic development of rural communities in developing countries is most important for this course. Economic activities of rural communities are widely varying, and rural livelihoods are often supported by both local economic activity and remittances from workers who have migrated to urban areas. Food production is still the basis of many rural livelihoods as it provides food security as well as opportunities to generate cash to buy goods and services elsewhere. Agriculture therefore features prominently among the potential enterprises that can be set up in or around wetlands.

It is important to specify the term agriculture here. Agricultural production systems can range from rainfed extensive smallholder plots without any external inputs producing a variety of crops to supply food for one household to large-scale, irrigated, mechanized, industrial-style agriculture producing large quantities of one single crop for the world market. A major effort to boost food production in developing countries was the so-called "Green Revolution" which consisted of a combination of genetically improved crops (e.g., rice and wheat) and increased fertilizer and pesticide inputs. While the Green Revolution did increase the production of food, it also created problems because many resource-poor farmers could not adopt the new technologies because they were too expensive and risky or because their land was unsuitable. There are also serious questions about the impact of modern agricultural practices on the integrity of the environment.

Many rural households depend on food and income from agricultural production systems in sub-optimal and even marginal environments. Often, wetlands are attractive environments for growing crops because of the accumulated nutrients and the residual moisture in the dry season. There is a need to develop agricultural technologies that do not destroy the natural biodiversity of ecosystems, that make use of traditional knowledge of environmentally friendly agriculture, but at the same do not destroy large areas of natural ecosystems such as wetlands.

New approaches to agricultural development are Agroecology and Integrated Natural Resource Management (INRM). Whereas traditional agronomy and animal science are focused on specific commodities (crops or animal products), Agroecology and INRM are multidisciplinary approaches that aim to increase productivity of the whole system, conserve the natural resource base and develop economically viable systems that fit in the culture of the people and are socially just.

An agroecosystem is a community of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fibre, fuel and otehr products for human consumption and processing. The processes in agroecoystems are the same processes that can be found in natural ecosystems: nutrient cycling, predator-prey relationships, competition, symbiosis, succession, etc. Knowledge and understanding of the components of the agroecosystem and its processes make it possible to manipulate the system and improve production. Knowledge of the ecological principles for the study, design and management of agroecosystems is the aim of the scientific discpline called agroecology.

The subjects of Agroecology and INRM are traditional farming systems that are diverse, complex, adapted to loal conditions, use limited amounts of chemical fertilizers and pesticides, use traditional soil and water management techniques that have developed over centuries (e.g., raised fields, terraces, mulching), and use polycultures and integrated cultures. These traditional systems are knowledge-intensive rather than input-intensive. One of the objectives of agroecology is to make use of this knowledge and build on it to develop more productive contemporary agroecosystems by modifying and adapting the traditional sytems. INRM is defined as responsible and broad based management of land, water, forest and biological resource base (including genes) needed to sustain agricultural productivity and avert degradation of potential productivity (CGIAR 2000). INRM is an approach to research that aims at improving livelihoods, agroecosystem resilience, agricultural productivity and environmental services. In other words, it aims to augment social, physical, human, natural and financial capital. It does this by helping solve complex real-world problems affecting natural resources in agroecosystems .

In INRM and agroecology it is important to take an integrated approach to ecosystem management. This means, e.g. for research, that the focus is not on one particular crop or species but on crop, water, soil and pest management simultaneously. Instead of offering one particular technique for increasing production of one commodity, research is aimed at exploring a range of different strategies for manipulating agroecosystems from which the most suitable strategy can be selected by farmers based on their particular environmental and socio-economic constraints. There is now more and more awareness of the interrelatedness of the components of systems. E.g., pest management and soil fertility management are strongly linked and should not be developed separately. The technologies developed based on agroecological and INRM principles should make use of, enhance and conserve the natural functions and biodiversity of the environment. Such technologies are based on cover crops, green manures, intercropping, agroforestry, crop-livestock mixtures, etc. General characteristics of such technology are (Altieri 2002):

- recycling of biomass and balancing of nutrient flows
- securing favorable soil conditions for plant growth, through enhanced organic matter and soil biotic activity
- minimizing losses of solar radiation, air, water and nutrients by way of microclimate management, water harvesting and soil cover
- Enhancing species and genetic diversification of the agroecosystem in time and space
- Enhancing beneficial biological interactions and synergisms among agrobiodiversity components resulting in the promotion of key ecological processes and services.

Agriculture and aquaculture in wetlands should be developed along the principles of agroecology and INRM. This means that agricultural practices should aim at the multiple objectives of food production and income for the farmers and environmental integrity of the wetland ecosystem. In this sense, Agroecology and INRM are based on the same principles as Sustainable Use and the Ecosystem Approach. A lot of research on how to achieve sustainable wetland production systems is still needed. Unfortunately, agricultural research and wetland research have been mostly separate worlds with different objectives. A more integrated, multi-disciplinary approach with strong cooperation between the agriculture, aquaculture and wetland sectors is needed.

With regard to agriculture, a number of potential impacts can be distinguished. The main impact of conventional agriculture on wetlands has been the conversion of wetlands to agriculture. This usually consists of draining the wetland and removing the natural wetland vegetation. This essentially eliminates the characteristic features of wetlands. Other impacts of agriculture on wetlands are:

- surplus of nutrients (e.g., nitrogen and phosphorous) in adjacent rivers and lakes because of fertilizer and manure use leading to eutrophication

- detrimental effects of herbicides, fungicides and insecticides
- reduction of biodiversity
- soil erosion
- depletion of soil minerals
- air pollution because of ammonia volatilization
- soil salination

5.5. Decision making and trade-offs in the use of ecosystems

5.5.1. Introduction

the decision making about the possible exploitation and use of wetlands, the current status of the wetland needs to be addressed. What are its components, processes and services? Is the wetland pristine, does it have a high natural value? Or is it already affected a lot by human interference? Is the wetland important for people already? Another important consideration is the nature of the proposed exploitation/activities. What exactly will be done, what are the benefits and to whom do they accrue, is the wetland suitable for these activities? Finally, the impact of the proposed exploitation is also important. What will happen to the ecological character of the wetland when the proposed development is implemented? And what will happen to the people who are involved (economically, in terms of equity, etc.)? The final decision is based on a trade-off between between the benefits of exploiting the wetland (generally consisting of some service to the human population like food, income, water purification, etc.) and the costs/disadvantages/impact associated with the use (often consisting of the degradation of the ecosystem components and processes, and as a results, often also of other services provided by the wetland). In the wetland management programme of Uganda, the so-called "Kampala matrix" is used (Figure 5.5) (WID/IUCN, 2005).

The Kampala Matrix: prioritizing wetland management in Uganda

		STATUS		
		threatened	***not threatened***	***destroyed***
IMPORTANCE	***vital***	restore	monitor strictly	restore
	valuable	ensure wise use	monitor	restore?
	dispens-able	encourage wise use	monitor?	forget for the time being

Figure 5.5. The Kampala matrix (source: WID/IUCN, 2005).

5.5.2. Example of a method for determing trade-offs: Working wetlands (McCartney et al., 2005)

A simple and pragmatic method for explicit and systematic consideration of opportunities and consequences of agricultural development in a wetland was developed by McCartney et al. (2005). The method comprises 6 steps:

1. Classification of the present ecological condition of the wetland (five classes from "natural" to "extensively modified"). This will be based on expert knowledge, comparison with similar wetlands in the region that are undisturbed, and historical knowledge of wetland users and local communities.
2. Classification of the current contribution of the wetland to social welfare (five classes from "no or negative contribution" to "major contribution"). This includes people's reliance on the wetland for water and food resources and other products; the current dependence of people's livelihoods on the wetland (agriculture, aquaculture, etc.); the extent to which socio-economic characteristics affect the benefits people derive from wetlands (i.e., equity); benefits on catchment scale (e.g., flood control for downstream users); benefits on a global scale (e.g., important habitat for migratory birds). Information on all these issues can come from secondary data sources (reports, publications, etc.) but also from participatory assessments involving local stakeholders.
3. Determination of the development pressure for the wetland. This is done in consultation with the stakeholders and includes dertermining what ecological condition is desired in the working wetland, exactly which uses and activities will be undertaken in the wetland, and which benefits are expected from these activities and who will enjoy these benefits. This step results in a list of aims and objectives of the stakeholders and should allow a prioritization of these aims.
4. Determination of the suitability of the wetland for a specific agricultural activity based on biophysical suitability and socioeconomic suitability (Class 1-5 from "not suitable" to "highly suitable"). The biophysical suitability has to be evaluated in relation to the planned uses as defined in Step 3. The socioeconomic suitability is related to the benefits that are expected, both for local users and more generally, and to institutional and gender issues.
5. Identification of hazard potential of specific agricultural activity based on the possible impact on the ecological condition and on the social welfare (Class 1-5, from "high" to "none"). For the ecological condition, featurs like uniqueness and naturalness are important. For the social welfare, health and equity of those directly involved are important but also impact on traditional livelihoods and on people living downstream should be considered.
6. Classification of the Working Wetland Potential by combination of suitability and hazard potentials. The potential as calculated as the product of the values determined in the suitability assessment (Step 4) and the hazard assessment (Step 5). This results in values between 1 and 25, where higher values indicate a higher potential and suitability for with low risk. Five WPP classes are defined. The four dimensions of the WPP (biophysical suitability, socio-economic suitability, ecological hazard and socioeconomic hazard) can be graphically represented using a polygon.

Problems related to trade-offs:

– Lack of knowledge. We do not know enough about wetlands to know exactly all their components, processes and services. Management interventions imply venturing into unknown areas. The response of wetlands to certain types of interventions cannot always be predicted. More knowledge about the response of wetlands is needed.
– Quantitative monetary valuation of a number of services is still difficult so cost-benefit analysis is not always possible or does not always give the correct picture.
– Costs and benefits of using a wetland may not be synchronized in time or in place. Maybe the negative effects are felt in a place far away or a long time from now, making the trade-off less clear because only the immediate benefits are clear.
– As soon as there is a change in conditions which may affect the evaluation of the suitability or hazard assessments, the evaluation of the WWP should be done again. Also, the WWP evaluation of one wetland should not be applied to another wetland. The whole procedure should be followed for each wetland that is considered for agricultural activities.

5.6. References and further study

Altieri, M.A. (2002) Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems and Environment 93, 1–24.

CBD (2002) 'Ecosystem Approach'. Availabe at http://www.biodiv.org/programmes/cross-cutting/ecosystem/default.shtml.

Daily, G.C. and Ehrlich, P.R. (1992) Population, sustainability and Earth's carrying capacity. BioScience 42, 761-771.

Halwart, M. and A.A. van Dam (2006) Integrated irrigation and aquaculture in West Africa: concepts, practices and potential. Food and Agriculture Organization of the United Nations, Rome, 181 pp. (available at http://www.fao.org/docrep/009/a0444e/a0444e00.htm).

Hartje, V., Klaphake, A. & Schliep, R. (2003) 'The international debate on the ecosystem approach: Critical Review, international actors, obstacles and challenges'. BfN Skripten 80 (availabe at http://www.biodiv.org/doc/meetings/esa/ecosys-01/information/ecosys-01-inf-03-en.pdf).

Hollis, G.E. 1990. Environmental impacts of development on wetlands in arid and semi-arid lands. Hydrological Science Journal 35(4), 411-428.

McCartney, M.P., Masiyandima, M., Houghton-Carr, H.A. (2005) Working wetlands: classifying wetland potential for agriculture. Research Report 90. Colombo, Sri Lanka: International Water Management Institute (IWMI).

MEA (2005) Ecosystems and human well-being: wetlands and water synthesis. Millennium Ecosystem Assessment, World Resources Institute, Washington DC (available at http://www.maweb.org//en/Products.Synthesis.aspx).

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: wetlands and water Synthesis. World Resources Institute, Washington, DC.

Prein, M. (2002) Integration of aquaculture into crop–animal systems in Asia. Agricultural Systems 71, 127–146.

Ramsar (2004) Wise us of wetlands. Ramsar Handbooks for the Wise Use of Wetlands No. 1, 2nd edition. Ramsar Convention Secretariat, Gland, Switzerland.

WID/IUCN (2005) From conversion to conservation - fifteen years of managing wetlands for people and the environment in Uganda. WID, Kampala and IUCN Eastern Africa Regional Programme, Nairobi, Kenya.

Zaccagnini, M.E., S. Cloquell, E. Fernandez, C. González, G. Lichtenstein, A. Novaro, J.L. Panigati, J. Rabinovich and D. Tomasini (2001) Analytic Framework for Assessing Factors that Influence Sustainability of Uses of Wild Living Natural Resources. IUCN, Gland, Switzerland (also available as http://www.iucn.org/themes/ssc/susg/docs/analytic_framework_nov01.PDF).

Unit 6. Tools for Environmental Systems Analysis

6.1. Introduction

As mentioned in the introduction, ESA consists of:

(1) describing and understanding both the socio-economic (human) and biophysical (natural) components the environmental system;
(2) understanding the resource systems and their exploitation;
(3) applying systems analysis tools for describing and understanding the environmental system.

This unit focuses on the last of these three points: tools for Environmental Systems Analysis. A large variety of tools for ESA activites are used. Tools vary according to the environmental system under study and also depend on the disciplinary background of the people who developed them. A distinction can be made between conceptual tools and computational tools.

Conceptual tools are used for describing and understanding the processes and stakeholders in the system. Examples are flow diagrams, transects, seasonal calendars, and maps. Some tools consist of procedures to collect specific information about the system, stakeholder analysis and problem analysis. For a lot of these tools, participation of the stakeholders in the analysis is important to make sure that no important information is missed. Participation is a way to include traditional and indigenous knowledge in the description of the system and to ensure the active envolvement of the stakeholders in the ESA process. It also facilitates participation of stakeholders in later stages of policy formulation, implementation and evaluation (see also Unit 4).

Computational tools are mostly related to modelling of the system. Again, a variety of tools is available. The main objective of modelling is to obtain a quantitative analysis of the system and to produce quantitative estimates of system indicators. Eventually, this can lead to estimates of sustainability of different policy options from which decision-makers can choose. Models are needed in this process to deal with the complexity of the system and to simultaneously calculate indicators for the social, ecological and economic dimensions of the system. These indicators can be included in a goal function that is maximized or optimised. Models can be used for forecasting (based on the present situation, what will happen in the future) or backcasting (based on a desired situation, what should we do to arrive there from the present situation). Often, models are used for the formulation of scenarios.

In this ESA module, emphasis is on the use of dynamics modelling. Dynamic modelling (using Stella as the modelling tool) is used for the case studies in groups (see below in these module materials). The reason for the emphasis on dynamic modelling is that an understanding of dynamic modelling provides a lot of insight in system dynamics and in modelling in general. Dynamic models can also be used for scenario analysis and the calculation of indicators. However, many other useful tools are available and may be considered for application within the framework of an environmental systems analysis. This unit will address briefly the following tools: participatory environmental assessment methods; dynamic modelling; environmental indicators (including sustainability indicators); multi-criteria analysis (MCA).

6.2. Participatory environmental assessment methods

Traditional methods for learning about rural communities and their natural resources include conventional social science methods, usually with questionnaire surveys, and field visits by technical experts. Surveys often suffer from problems with selection of people to be interviewed, lack of attention for the local context, bias introduced by the enumerators, etc. Field visits are also problematic and suffer from considerable bias. There are four main bias types (Pretty and Vodouhe 1997):

1. spatial bias, in which people living near roads and services are visited, while poorer people in more remote areas are left out;
2. time bias, e.g. by making visits in the dry season when remote areas are accessible or during the day when few people are available because everyone else is working;
3. people biases, in which the experts only speak to rural leaders and other elites, usually the dominant and wealthy groups;
4. project biases, in which a showcase village or technology is repeatedly shown to outsiders, who get the impression that this is typical of all efforts.

To overcome these biases and get a better picture of the situation in a certain area, more participatory techniques and approaches were developed in which rural people themselves are an active partner in the investigation, presentation, analysis, planning and dissemination stages of the management process. These methods were developed in the late 1970s and 1980s and draw on some traditions from applied anthropology, combined with farming systems research methods. There is a host of names and acronyms for various techniques or groups of techniques that all have overlapping objectives and tools. Here we mention three: rapid rural appraisal (RRA), participatory rural appraisal (PRA) and participatory action research (PAR). A general acronym that is also used regularly is PLA (participatory learning and action). What these techniques have in common is that they all put more emphasis than the traditional methods on local knowledge and that they attempt to enable development practitioners, government officers and local people to work together in natural resource planning and management. They are a response to the top-down planning and formal social science research methods, and try to obtain more relevant and context-related information. These participatory techniques are an attempt to find out "what is really going on". They are based on principles of empowerment (local knowledge is valued which leads to confidence in the community) and respect (researchers and local community are equal partners in the process). Another important principle is that they should be interesting and fun for people to be involved in (as opposed to answering long questionnaires that can be quite boring and even annoying).

Rapid Rural Appraisal (RRA)

The main objective of RRA is to get a quick, big picture of what is going in a certain area. In this sense RRA is really driven by the agenda of the outsiders and not by the community itself. It uses tools like:

- review of secondary sources, including aerial photos, even brief aerial observation
- direct observation, familiarization, participation in activities. Physical aspects, socio-economic or cultural, political, etc. E.g. histories of cropping patterns, changes in customs and practices, changes and trends in the population, migration, fuel used, education, health. Causes of these changes.

- interviews with key informants, group interviews, workshops. Who are the local experts? Semi-structured interviewing: interviewer has a mental or written checklist, but is open to new aspects and follows up on new and unexpected issues. Sequence or chains of interviews: from group to key informant, to other informants; or with a series of key informants.
- foot transects, mapping, diagramming: systematic walks with key informants through an area, observing, asking, listening, discussing, identifying different zones, local and introduced technologies, identifying problems, solutions, opportunities, and mapping and/or diagramming resources and findings
- biographies, local histories, case studies
- ranking and scoring
- time lines
- short simple questionnaires: only used at the end, if at all, and should be light, precise and tight.
- informal interactions, e.g. at social gatherings
- rapid report writing in the field

Participatory rural appraisal (PRA)

PRA was the next step in development of participatory techniques. It is less extractive than RRA and pays more attention to the role of the community. Many of the tools used are the same as in RRA (see above) but group discussions and community workshops are important parts of the PRA process. Depending on the size of the area, a PRA exercise can take 2-3 weeks or longer. When done properly, PRA empowers participants through their actual involvement in the investigation, mapping, modeling, diagramming, ranking and scoring, quantification, analysis, planning and presentation/sharing of the outcomes. PRA results in building of rapport and ownership of the information about the social and ecological systems. PRA requires a culture of sharing: information, methods, food, field experience between all the stakeholders. The attitude and behaviour of the facilitators are important in PRA. Facilitators should be open about doubts, embrace errors and learn from them, and integrate beneficial experiences into the process.

Participatory action research (PAR)

PAR goes a step further than PRA in the sense that it involves the actual work with communities. It is not only about learning and planning, but eventually also implementing plans to create improvements in livelihoods and natural resource management.

Although participatory methods certainly have advantages over traditional methods, there are also risks and problems associated with them. Some of these are:

- Wrong identification of target groups
- Lecturing by the researchers instead of listening to and learning from the community
- Rushing and imposing own ideas, categories and values without realizing it, thus hindering the joint learning process and making the local community appear ignorant.
- Finding the questions to ask.
- Ignoring gender issues/angles

Some people have questioned and criticized participatory methods. There are doubts about whether methods like PRA can really empower communities and promote sustainable development. Often it is difficult to find good, truly independent facilitators and trainers who have the trust of all stakeholders. The methods used sometimes lack analytical clarity due to the focus on participation during the appraisal phase without ensuring collective planning in the longer term. Although the process generates a lot of information, it is not always clear what can be done with all this information and how it should be analyzed. Often, participatory exercises are done in a rigid way, simply following protocols. Flexibility and imagination and a belief in the importance of the participatory process are important aspects of these approaches.

6.3. Dynamic modelling

The principles of dynamic modelling are subject of the course "Environmental modelling" in Module 4 of the Environmental Science programme. Reference is made to the lecture notes of that course. In the ESA module, environmental modelling is applied in the group case studies (see B. below in these lecture notes).

6.4. Environmental indicators

by Chiung-Ting Chang

6.4.1. Learning goals

The goal of this lecture is to present an overview of environmental indicators. After studying this part of the course, the student should be able to:

- Distinguish between indicators and index;
- Identify the functions of environmental indicators;
- Select a proper environmental indicators according to the criteria provided;
- List different types of environmental indicators;
- Explain how an indicator works, given examples, to serve environmental management;
- List some problems with indicators.

Figure 1 shows a summary of this lecture in the form of a mind map.

6.4.2. Definition of Indicator and Index

- An *indicator* is a measurement that describes the state of a social, economic or environmental system. Indicators are often calculated based on raw data or statistics and used for for policy analysis. Indicators are often expressed relative to a reference value.
- An *index* is a set of weighted or aggregated indicators.

6.4.3. Functions of Environmental Indicators

An `ideal' indicator would have the following functions:
- Clarification: clarifying and defning policy targets.
- Inter-temporal comparison: assessing present conditions and trends over time.
- Intra-temporal comparison: comparing situations or regions.
- Linking causes and impacts:
  - Assessing conditions and trends in relation to policy targets.
  - Determining impacts of policy programmes.
- Prediction:
  - Providing early warning information.
  - Anticipating future conditions and trends.

6.4.4. Criteria for Obtaining Proper Environmental Indicators

Indicators should be relevant for policy making, easy to use, analytically sound and easy to measure. The criteria for obtaining proper environmental indicators are summarized in Table 1 (adapted from OECD, 1993). These criteria describe the `ideal' indicators and not all of them will be met in practice.

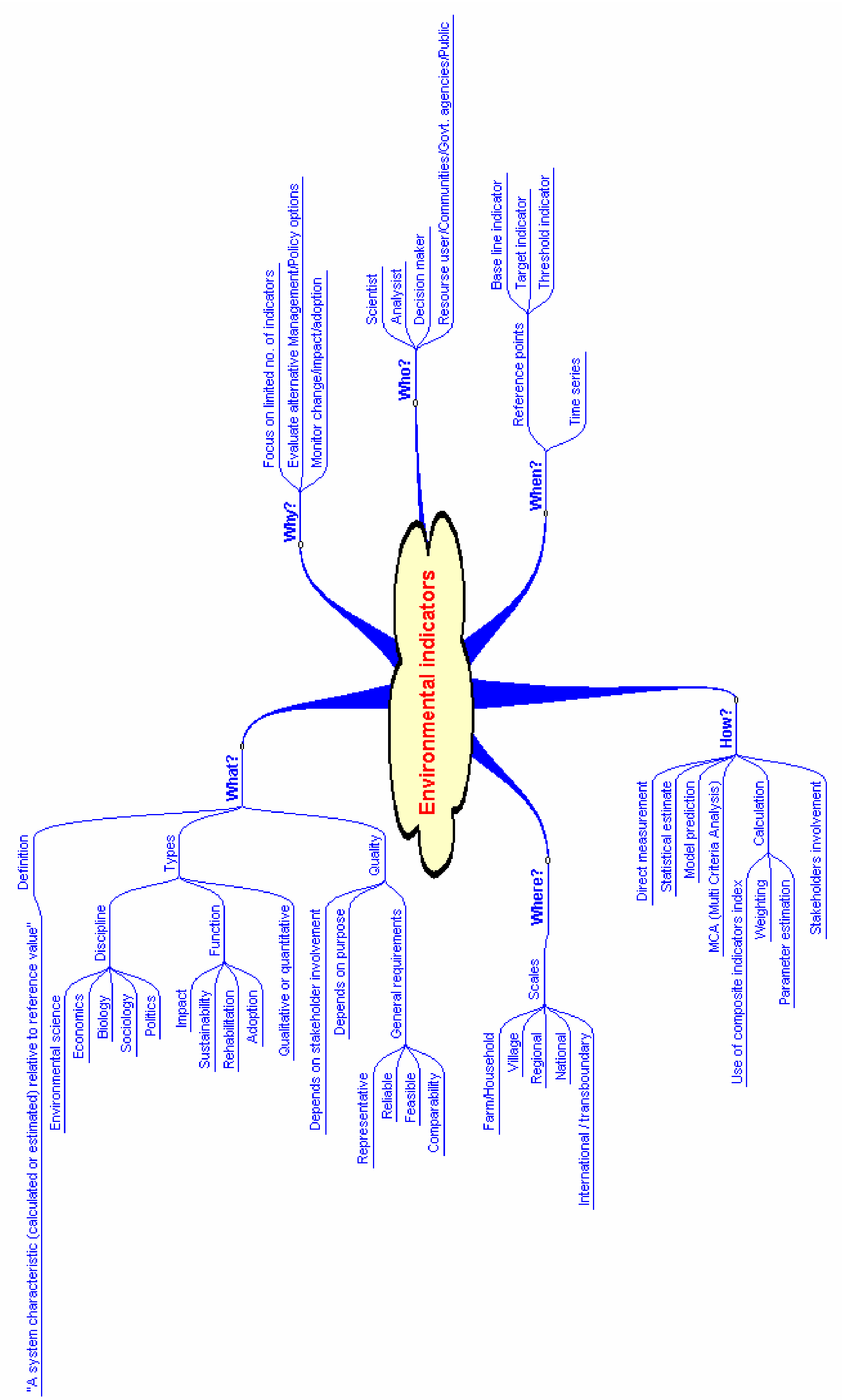


Figure 6.1. Mind map showing main features of environmental indicators.

Table 1: Criteria for obtaining proper environmental indicators (adapted from OECD, 1993)

POLICY RELEVANCE AND UTILITY FOR USERS
• Providing a representative picture of environmental conditions, pressures on the environment or society's responses. • Being easy to interpret and being able to how trends over time. • Being responsive to changes in the environment and related human activities. • Providing a basis for regional or international comparisons. • Being either national in scope or applicable to regional environmental issues of national signifcance. • Having a threshold or reference value against which to compare it so that users are able to assess the significance of the values associated with it.
ANALYTICAL SOUNDNESS
• Being theoretically well-founded in technical and scientific terms. • Lending itself to being linked to economic models, forecasting and information systems. • (Being based on international standards and international consensus about its validity, especially for transboundary environmental issues.)
MEASURABILITY
• Being readily available or made available at a reasonable cost/benefit ratio. • Being adequately documented or of known quality. • Being updated at regular intervals in accordance with reliable procedures.

6.4.5. Types of Environmental Indicators

There are several ways to classify environmental indicators. Here we first introduce the OECD Pressure-State-Response framework as a base. Then we elaborate the framework based on Riley (2001) and on experience. Environmental indicators are then classified according to disciplines, functions, and the quantitative or qualitative feature.

a. The OECD Pressure-State-Response Framework

According to the `Pressure-State-Response' framework used by OECD, there are three types of environmental indicators. These are presented here with application to the example of biodiversity (OECD, 2004).

- Indicators of <u>environmental pressures</u>. For biodiversity: habitat alteration, land conversion from natural state, road network density, change in land cover, etc.
- Indicators of <u>environmental conditions</u>. For biodiversity: threatened or extinct species as share of total species assessed, area of key ecosystems, etc.
- Indicators of <u>societal responses</u>. For biodiversity: protected areas as % of national territory and by type of ecosystem, protected species, etc.

This set of indicators captures the procedure of pressure-state-response and offers a way to present the information concerning trade-offs between environmental and economic concerns.

b. Discipline-wise

Indicators can be produced from different disciplines concerning environmental management.

- Environmental science: e.g., ecological footprint;
- Economics: e.g., per capita income;
- Biology: e.g., level of habitat fragmentation;
- Sociology: e.g., average educational level;
- Politics: e.g., numbers of identification and planning meetings held with local stakeholders.

c. Function-wise

There are four types of indicators in terms of their functions (Riley, 2001):

- <u>Impact indicators</u> usually reflect change from a baseline. They may be observed directly (e.g., an increase in income) or indirectly through a proxy indicator (e.g., the purchase of a car).
- <u>Sustainability indicators</u> relates to patterns of change over time and is portrayed by the successive measurement of the chosen impact indicators. It is only measurable if a sufficient period of time is monitored and should be observed for each of its component indicators.
- <u>Rehabilitation indicators</u> may be applied to monitor the improvement of interventions introduced to reverse the non-sustainable trends.
- <u>Indicators of adoption</u> measure the extent of the dissemination of policy recommendations. Typically, these are counts of farmers or consumers using the recommendation.

d. Quantitative vs Qualitative

Indicators can be in in either quantitative or qualitative form. A quantitative indicator is often preferable.

e. Time-wise

There are two types of time-wise indicators.

- <u>Time series indicators</u>, e.g., annual GDP over a specific period of time is commonly applied.
- <u>Reference points indicators</u>.
  - Baseline indicators. E.g., the IPCC uses global temperature in 1990 as a baseline and predicts the temperature would increase 1:4 to 5:8 by 2100.
  - Target indicators. E.g., halve [percentage: measurable], by 2015 [time], the proportion of people without sustainable access to safe drinking water and

sanitation. (Target 10 in the Millennium Development Goals to achieve the goal of environmental sustainability. More information is given in the following section [Where is the baseline?]).
- Threshold indicators. E.g., carrying capacity is the population level that can be supported for an organism, given the quantity of food, habitat and other life infrastructure present.

6.4.6. Examples

a. Sustainability

`Sustainability' is measured according to the international efforts following up UN Millennium Development Goals (MDGs).
Definition in UN MDGs (Goal: Ensure environmental sustainability)

- Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
- Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation
- Target 11: By 2020, to have achieved a signi_cant improvement in the lives of at least 100 million slum dwellers

International efforts

Indicators are developed to measure whether the economy moves toward sustainability. Using the indicators, one would be able to point out below which point is unsustainable while above which is sustainable. Here is the list of international efforts on obtaining these three targets.

- Target 9: Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
  - Proportion of land area covered by forest (FAO)
  - Ratio of area protected to maintain biological diversity to surface area (UNEP-WCMC)
  - Energy use (kg oil equivalent) per $1,000 GDP (PPP) (IEA, World Bank)
  - Carbon dioxide emissions per capita (UNFCCC, UNSD) and consumption of ozone-depleting CFCs (ODP tons) (UNEP-Ozone Secretariat)
  - Proportion of population using solid fuels (WHO)
- Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation
  - Proportion of population with sustainable access to an improved water source, urban and rural (UNICEF-WHO)
  - Proportion of population with access to improved sanitation, urban and rural (UNICEF-WHO)
- Target 11: By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers
  - Proportion of households with access to secure tenure (UN-HABITAT)

Other research efforts

Next we will show you how other research efforts on the indicators concerning sustainability.

- One in which resources are managed so as to maintain production opportunities for the future (Solow, 1986)
- Non-declining capital stock (Atkinson and Pearce, 1993)
- Sustainable yield (Perman et al., 1999)
- One which satisfies minimum conditions of ecosystem stability and resilience through time (Ciriacy-Wantrup, 1968; Costanza et al., 1991)
- Measuring the impacts of environmental degradation on human welfare
- Some attempts: wealth, green GNP, genuine savings (Pearce and Barbier, 2000)
- Measuring either the overall state of the environment or the health of specific ecosystems
- Estimates of species loss, carrying capacity, ecological footprints, indicators of ecosystem stability (Pearce and Barbier, 2000)

b. Indicators for Freshwater Resources

OECD (2004) suggests the following set of indicators, corresponding to the pressure-state-response framework, for measuring freshwater quality. Examples are shown in the report. The measurability of each indicator is reviewed.

- Intensity of use of water resources: It can be derived from water resource accounts and is available for most OECD countries.
- Frequency, duration and extent of water shortages: More work is needed to improve the completeness and historical consistency of the data, and to further improve estimation methods.
- Water prices and user charges for sewage treatment: More work is needed to mobilise data at sub-national level, and to reect the spatial distribution of resource use intensity.

c. Roads and Floods Project

The 'Roads and floods' project, run by Delft Cluster (including UNESCO-IHE) in collaboration with MRC & WWF, applies a stakeholder-based step-wise procedure of identifying indicators concerning options and criteria for decision-making.

Summary of procedure

Here is the summary of procedure that relates to generating appropriate indicators tailor-made by the case.

- Step I. Decision-makers identify concrete and more tangible objectives, criteria and constrains; Experts identify criteria and (technical) options.
- Step II. On basis of constraints and options, the project analyst makes the first list of options.
- Step III. The analyst informs the experts of the results from step II and provides framework of an effect table (including options).
- Step IV. The analyst updates the effect table based on the results from Step II (options) and III (criteria).

Results

The indicators applied to measure whether objects are obtained or not are shown below (partially) in Table 2.

Table 2: Examples of indicators generated from stakeholder-based step-wise procedure (Source: Roads and Floods project, UNESCO-IHE)

Objectives	Indicators
Enhancing regional transport	Travel time
Reducing flood vulnerability	Damage of flooding on housing, infrastructure (excl. roads), agriculture and casualties
Maintaining fisheries & agriculture harvest	Fisheries & agricultural harvest
Minimising infrastructure investment & maintenance	Initial investment cost Maintenance cost
Maintaining floodplains hydraulics & ecology	Flood pattern & dynamics (within the zone) Flood pattern & dynamics (beyond the zone) Habitat area loss Habitat fragmentation

d. A Lesson to Learn

Ogle (2001) demonstrates an unsuccessful soil conservation programme in which progress could be made by improving its indicator system.

The Environmental Situations & Problems

Pressure from environmental concerns - from modest to strong measures
In 1973, a soil conservation programme was introduced in central Tanzania with the main objective of arresting land degradation in a rapidly deteriorating area through physical soil conservation measures. However, it did not have the desired effect, mainly due to the destruction by grazing livestock and uncontrolled water runoff from higher slopes denuded by overgrazing. In 1979, the most severely affected area of over 1,200 km^2, which involved the eviction of over 85,000 cattle, was closed as a political decision.
This decision caused severe hardship to the agro-pastoral societies in the region, as mortality in some of the evicted herds that were moved to the surrounding plains was around 50% or more (Ogle, 2001; Ostberg, 1986). Under pressure from these economic concerns, the government decided in 1989 to allow the introduction in the closed areas of some form of stall-feeding system as the only real alternative.
The problem of a non-robust system remains. Because of the withdrawal of donor funding, there is once again the danger of imminent collapse of the ecosystem in the Kondoa Closed Area.

The problems of the indicators in the project are the following:

- Lack of baseline data.
- Failure to systematically monitor the effects of the intervention using adequate socio-economic and environmental indicators. E.g., the research focused on the biophyisical inputs to, and outputs from the system, with relatively little emphasis on the collection of socio-economic data.

Indication of Solutions

Concerning the indicators, a proposed scheme for participatory collection of socio-economic and environmental indicators.

- An initial discussion workshop should be arranged with all involved stakeholders. The key is to ensure that farmers suggest issues and indicators, both so that they feel part of the whole process and so that they can continue monitoring the scheme after funding has been withdrawn.
- Examples of socio-economic data that might be suggested for regular collection both before and after the evictions and the introduction of zero-grazing on parameters are frequency of school attendance, children's milk and meet consumption patterns and weight-for-age data, together with qualitative farmer-generated information on changes in their children's health.

6.4.7. Problems with Indicators

Gaps and inconsistencies are the major problems with indicators. The following description is adapted from UN (1999) that presents an overview on the topic at the international level.

a. Lack of data

Problems related to gaps are often caused by the following reasons:
- Lack of data at the national or regional level.
- Non-response by countries or regions.
- Absence of a systematic international/national/catchment-wise effort to compile indicators and statistics on specific topics, which may exist at the national/regional level.

b. Inconsistencies of indicators

Problems related to inconsistencies are often caused by the following reasons:
- Indicators may in fact reect distinct phenomena. E.g., per capita GDP in US dollars. The market exchange rate-based indicators and the `purchasing power parity'(PPP)-based indicators serve two different purposes. Careful labelling of the indicators in question helps to avoid confusion or misinterpretation.
- Different definition may be applied to the same indicator. E.g., for the measurement of `access' to drinking water, some use time while others use distance walking from household to water source.
- Data discrepancies may have been inherited from the lower level. E.g., concerning the international level, national accounts figures could come from the national statistics or from the central bank.

- Different compilation or estimation techniques are used (at the international level). E.g., international organisations often make their own estimates of country indicators because the case information is either simply not available, or not available in sufficient detail or because it needs to be standardised to ensure international comparability or to derive regional and global aggregates.
- Base data may come from different points in time of the processing cycle. E.g., the country data may refer to provisional estimates or final estimates for a given reference period, depending on when the international organisation requested the country data.

Q: How to avoid these problems?

6.5. References and further study

Atkinson, G. and Pearce, D. (1993). Measuring sustainable development. The Globe, 13. UK GER Office, Swindon.

Ciriacy-Wantrup, S. v. (1968). Resources Conservation: Economics and Politics (2nd ed.). University of California Press, Berkeley.

Costanza, R., Daly, H., and Bartholomew, J. (1991). Goals, Agenda and Policy Recommendations for Ecological Economics. Columbia University Press, New York.

Jørgensen, S.E., R.. Costanza and Fu-Liu Xu (2005) Handbook of ecological indicators for assessment of ecosystem health. CRC Press, Boca Raton, Florida. 439 pp.

Lundberg, C. (2005) Conceptualizing the Baltic Sea ecosystem: an interdisciplinary tool for environmental decision making. Ambio 34, 433-439.

OECD (1993). OECD Core Set of Indicators for Environmental Performance Reviews. Technical report, OECD, http://lead.virtualcentre.org/en/dec/toolbox/Refer/dg93179.pdf. Accessed on-line in January 2007.

OECD (2004). OECD Key Environmental Indicators. Technical report, OECD, http://www.oecd.org/dataoecd/32/20/31558547.pdf. Accessed on- line in January 2007.

Ogle, R. B. (2001). The need for socio-economic and environmental indicators to monitor degraded ecosystem rehabilation: A case study from tanzania. Agriculture, Ecosystems and Environment, 87:151{157.

Ostberg, W. (1986). The Kondoa Transformation: Coming to Grips with Soil Erosion in Central Tanzania. Technical report, Scandinavian Insitute of African Studies, Uppsala. Res. Rep. No.76.

Pearce, D. and Barbier, E. (2000). Blueprint: For A Sustainable Economy. Earthscan, London.

Perman, R., Ma, Y., McGilvray, J., and Common, M. (1999). Natural Resource and Environmental Economics. Pearson Education Limited, Essex.

Riley, J. (2001). Multidisciplinary indicators of impact and change: Key issues for indentifiation and summary. Agriculture, Ecosystems and Environment, 87:245{259.

Solow, R. (1986). On the intergenerational allocation of natural resources. Scandanavian Journal of Economics, 88(1):141{149.

UN (1999). A critical review on the development of indicators. Technical report, UN, http://unstats.un.org/unsd/statcom/doc00/99-11.pdf. Accessed on-line in January 2007.

Unit 7. Case study Lake Victoria, East Africa: shrinking fish stocks and decreasing lake levels[1,2]

The Lake Victoria basin, measuring 263,000 km^2, provides a home to some 33 million people and intersects with the territories of five countries (Burundi, Kenya, Rwanda, Tanzania and Uganda). It is also known as the Kagera basin and forms part of the larger Nile basin. Lake Victoria is the world's largest tropical lake and second largest freshwater body. It is shared by Kenya, Uganda and Tanzania who hold 6%, 43%, and 51%, respectively of its 68,800 km^2 surface area. The lake was formed some 400,000 years ago and is the shallowest of the African Rift Valley lakes with an average depth of 40 m. The last 50 years have been characterized by dramatic changes in the lake environment due to various anthropogenic and climatic impacts.

Two anthropogenic impacts were clearly marked in time, both in 1954: the commissioning of the Owen Falls Dam (now called Nalubaale Dam); and the introduction of the Nile perch from Lakes Albert and Turkana. The Nalubaale Dam added power generation to the services supplied by the lake to its riparian communities and effectively turned the natural lake into a reservoir with regulated water depth. While the introduction of the Nile perch was clearly marked, the resulting ecological impact of this introduced species and the overall increase of the fisheries industry (both artesian and commercial) developed gradually over the next 25 years. The fishing industry reached a peak in the 1980s and 1990s and attracting thousands of people in search of an improved livelihood.

Fishing has always been important on the lake. Before the Second World War, the fish population was dominated by some 300 species of haplochromine cichlids and 14 cyprinids (*Barbus* spp.). The principle target species for the fishery were the tilapias *Oreochromis esculentus* and *O. variabilis*, and *Labeo victorianus*. The introduction of the Nile perch (*Lates niloticus*) and non-indigenous tilapia species (*O. niloticus*, *O. leucostictus* and *Tilapia zillii*) was considered necessary to boost the production of depleted indigenous populations. The changes triggered by the introduction of non-native species in the local fish populations only became apparent in the 1970s, when catches of Nile perch increased dramatically and attracted increased numbers of fishing boats, the development of a fish processing industry and the entrance of the three countries on the global fish market through the export of Nile perch products. In the process, the demersal haplochromine fish stocks were decimated and presently the fishery is dominated by only three species: the Nile perch, the non-indigenous tilapia *O. niloticus* and the small native pelagic cyprinid *Rastrineobola argentea* which is important for the fish meal industry and as an inexpensive fish for local consumption. Overfishing remains a problem and catch per unit effort continues to decline, mainly because of still increasing numbers of boats and stabilization of the Nile perch landings. (Figure 7.1).

The decline of the original haplochromine stocks has often been attributed to the voracious predation by the Nile perch, but the lake also underwent considerable changes in nutrient input composition and as a result water quality which may have also affected the fish populations. Additionally, increased population led to an expansion of agricultural and industrial developments, and, in turn an unpredictable flux in the composition of the waste stream chemical, microbiological and nutrient pollution) into the lake.

[1] Based on Bootsma and Hecky, 1993; Balirwa, 1995; Kassenga, 1997; Fuggle, 2002; Odada et al., 2004.
[2] Excerpt from van der Zaag, P., A.A. van Dam and R.A. Meganck (2006) Looking in the mirror: how societies learn from their dependence on large lakes. Invited paper, special session 'Large lakes as drivers for regional development', Stockholm World Water Week, 20-26 August 2006.

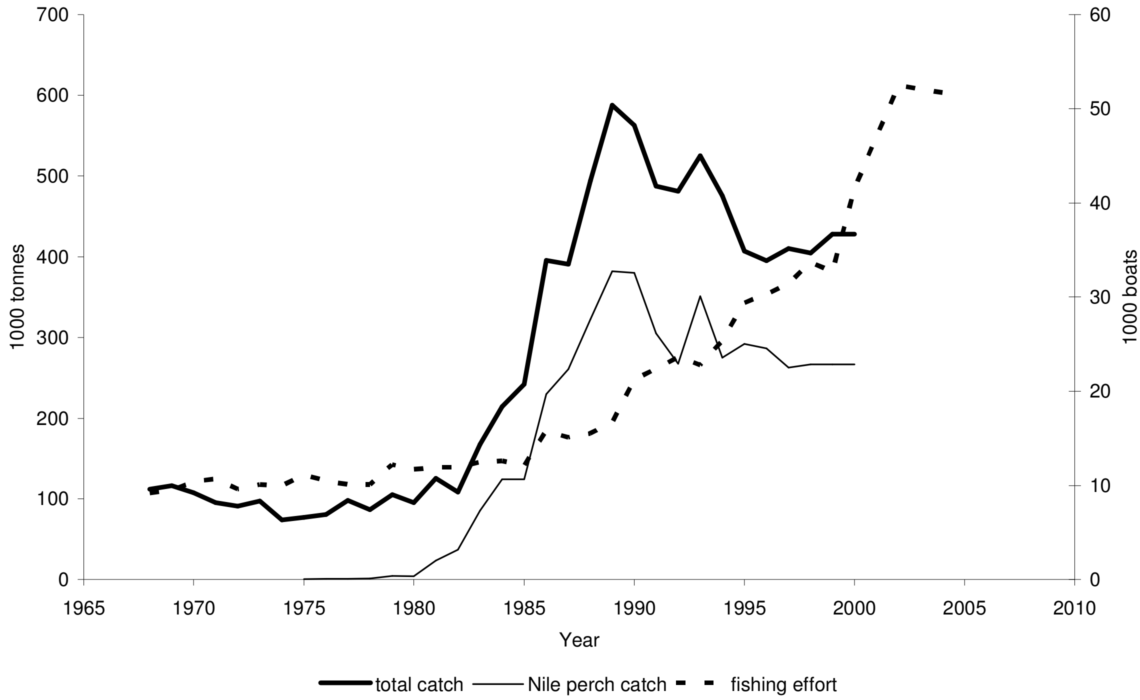


Figure 7.1: Fish catch (total and Nile perch) and fishing effort (no. of boats) in Lake Victoria, 1968-2004 (Sources: Kenya Marine and Fisheries Research Institute; van der Knaap, 2006)

Weak natural resources management institutions hampered development of an integrated approach (policy and enforcement) to address this complex of issues impacting the lake. Increased and unregulated deforestation and wetland degradation were two of the most prominent impacts hampering integrated management of the lake basin. Deforestation is catalyzed by the need for firewood for charcoal production and the conversion of upland forests to crop land. The results are increased sediment loads into the rivers, and ultimately siltation and high turbidity in the lake. Wetlands are extremely important for the lake environment because they act as buffers (regulating the release of nutrients and sediments into the lake) and have an important nursery function for the fish populations. They also harbor a large biodiversity in birds, game and other organisms. Wetlands are also important for riparian communities, providing food (including fish), fiber and fuel products. During dry periods, rain-fed agriculture yields decline and many people turn to the post-flood residual moisture in the seasonal wetlands for production of yam, banana, sugarcane and other crops. Increasingly, papyrus wetlands are being exploited for papyrus culms or converted to cropland. In addition to subsistence agriculture, in some places large-scale commercial agricultural companies have obtained permission to drain wetlands and convert them into irrigated agriculture land. An example is the Yala swamp in Kenya, where the development scheme is still in progress and hotly debated by the various stakeholders (Kenya Times, 2006).

The effects of population growth, urban and rural development, deforestation and wetland degradation on the water quality in the lake have been severe. Nutrient concentrations and phytoplankton production have been steadily increasing since the 1930s as evidenced by sediment core data (Verschuren et al., 2002). Nutrient input into the lake from deposition, runoff have reached levels impacting overall water quality and phytoplankton concentration is reported to be five times greater now than it was in the 1960s. The concentration of silica has declined sharply, accompanied by a shift in algal species from diatoms to cyanobacteria in the late 1980s. Frequent anoxia in the lake has resulted in fish kills.

One of the problems related to the water quality is the proliferation of the water hyacinth (*Eichornia crassipes*), a floating macrophyte which was introduced in the early 1980s. In 1995, about 80% of the lake's shoreline was covered by the plant forming floating mats that extend about 15 m out from the shore. These mats create difficulties in water extraction and affect the quality of drinking water, block irrigation canals, waterways and landing sites, increase the costs of transportation, reduce fish catches and disrupt hydroelectric power generation. Among the measures to control the water hyacinth were mechanical and chemical control (herbicides), and biological control with weevils (*Neochetina* spp.) introduced at the end of 1996. By 1998, the hyacinth infestation was under control. Although some have attributed this reduction to the weevils, recent research suggests that the 1997-1998 El Nino period, with its high rainfall and accompanying cloud cover, led to light limitation and therefore reduced production in the water hyacinth. While nutrient concentrations in the lake remain high and water hyacinth continues to be imported into the lake from the Kagera River, a return of the hyacinth infestation is possible (Williams et al., 2005).

Current water levels of Lake Victoria are at there lowest since the 1950s. Total lake evaporation (around 2 m a^{-1}) amounts to a staggering 140,000 Mm^3a^{-1}, four times the net total supply of water to the lake (inflows plus precipitation on the lake minus evaporation from the lake), estimated at 30,000 Mm^3a^{-1}. This means that minor changes in precipitation and evaporation rates on the lake strongly influence lake levels, since a dry year will not only result in lower precipitation but also in higher evaporation rates. Lake levels are also affected by human activities. The amount of water generated in the Kagera basin and flowing into the lake depends on rainfall patterns, land use practices and water abstractions upstream. The amount of water released from the lake into the White Nile can be influenced by the operation of the Nalubaale and the new Kiira (commissioned in 2000) hydropower dams at Jinja. This was acknowledged by Egypt when the Owen Falls dam was being constructed. Agreement was reached between Uganda and Egypt (in 1949 and 1953) to ensure that the amount of water flowing through the dam's turbines would mimic the old natural flow over the weir, based on a formula known as the "agreed curve". Up to 1997 the Nalubaale dam was indeed operated in accordance with the agreed curve. However due to excessive rainfall in 1997 it was decided to reduce the release of water from the lake to protect downstream communities from further flooding, explaining the surge in the lake level in 1998 (Figure 7.2). Thereafter, however, more water was released than would have been allowed by the agreement due to Uganda's increasing need for electricity. This may explain more than half of the drop in water levels since 1998. The rest may be explained by decreased rainfall in the basin during the last few years (Kull, 2006).

The lower water levels have affected many people in downstream portions of Tanzania, Kenya and Uganda, especially the transport and fishery sectors since ships have difficulty in reaching landing sites, and the towns whose water intakes are often exposed. Fierce debates emerged about the causes of the decreasing water levels, particularly between riparian countries. Talks between water officials from the Kagera basin countries were initiated in November 2005 (Daily Nation, 15 November 2005), which led to a commissioned report by the International Rivers Network in February 2006 (Kull, 2006). The question centers on whether to optimize hydropower production by better utilizing the storage capacity of the lake (which could result in larger fluctuations in lake levels), or to minimize lake level fluctuations (which may affect the electricity generation from the dams) which would benefit some users such as farmers and the shipping industry.

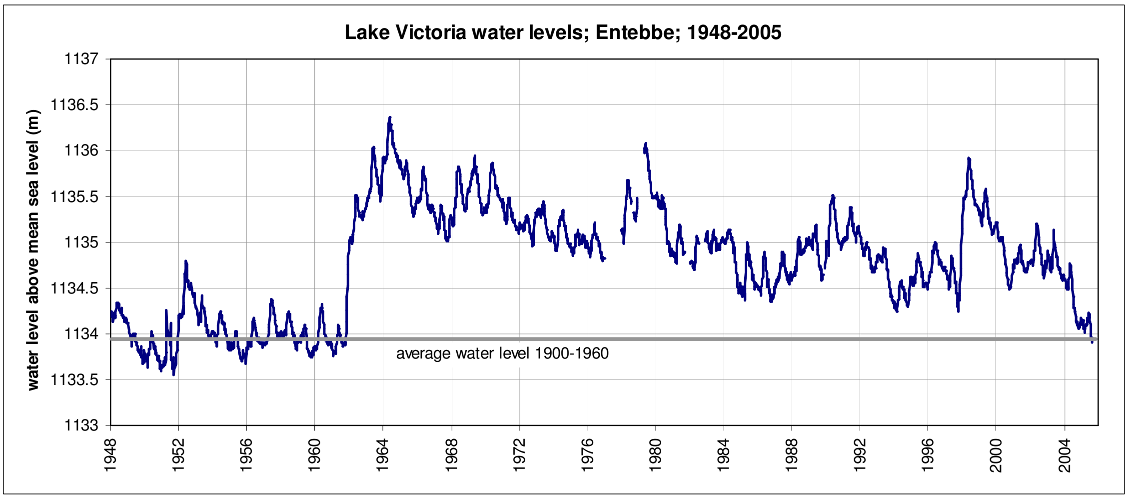


Figure 2: Water levels of Lake Victoria, 1948-2005

The effects of the environmental changes on the riparian communities have been profound. Traditionally, the rural lake communities depended on agriculture, livestock herding and fishing. Inhabitants alternated between agriculture and fishing depending on the rains, although livestock has traditionally served as a savings account that could be used for large expenditures or in times of need. With a growing population and some periods of drought, the pressure on the fishery increased. In the 1980s the Nile perch stocks in the lake allowed a tremendous increase in fishing effort (including new inhabitants from outside the lake basin), and farming was neglected. Now that the fishery is in decline, a return to farming poses various problems. Soil degradation in the catchment and drought make rain-fed agriculture difficult, and communities are turning to seasonal agriculture in communal wetlands. Land ownership is also problematic, with farm plot sizes decreasing as the generations pass. Risk reduction through diversification of livelihoods seems to be the strategy of most communities to deal with this situation (Geheb & Binns, 1997).

Urban populations around the lake (Kampala, Jinja, Kisumu, Mwanza), have also been affected by the changes in Lake Victoria. Changes in fish catch and food production are felt immediately in the urban markets. Moreover, cities depend on the lake for their drinking water and the low water levels in the lake impact intake of sufficient quantities of quality water for domestic use. In Uganda, the low water levels are also the cause of frequent power cuts.

The foregoing discussion gives an indication of the intimate and delicate relationship existing between Lake Victoria and its riparian communities While it is obvious that fishing effort needs to be regulated, fluxes of nutrients and pollutants reduced, a new balance established between inflows and outflows of the lake, the formulation and implementation of policies for integrated land and water management have been hindered by a combination of political instability, absence of funds, weak enforcement, transboundary disputes and short-term economic priorities. There seems to be agreement that a top-down, centralized approach by individual countries does not work. This realization has led to attempts at co-management that while complicated by the reluctance of governments to transfer power to communities or decentralize; render more benefits to local communities (Geheb and Crean, 2003). Additionally, participatory processes with involvement of all stakeholders (including the state), sensitive to local cultural conditions and with sufficient institutional support is vital for the success of any planning process (Geheb et al., 2002).

Transboundary cooperation has been a major issue in the Lake Victoria basin since pre-independence days. In 1999 the East African Community (EAC) was formally established; the main objectives of which include economic (take advantage of economies of scale, protect and expand markets, harmonize internal and adopt common external tariffs, take common position in world trade negotiations, etc.), cultural, political, legal and environmental (promote common transboundary projects in water and environmental management) issues and policies.

There are several examples of projects aimed at tackling Lake Victoria's environmental problems on a regional level. The EAC coordinated the World Bank/GEF – funded Lake Victoria Environmental Management Project (LVEMP) between 1997 and 2005. A second phase of the project (LVEMP-II) is scheduled to start at the end of 2006 and will include a regional programme of applied research. Another important transboundary initiative is the Nile Basin Initiative (NBI) under which several basin-wide and country/region-specific projects are being implemented. Other examples of important regional collaborative arrangements are the Lake Victoria Fisheries Organization (LVFO), the Inter University Council of East Africa (IUCEA) and the recently established East African Water Association (EAWA), with membership from East African and European academics and funding from the Austrian government. These regional projects and programmes demonstrate an increased awareness that progress in the lake basin can only be made by taking a broad, transboundary, integrated and collaborative approach.

References and further study

Balirwa, J.S., 1995. The Lake Victoria environment: its fisheries and wetlands – a review. Wetlands Ecology and Management 3, 209-224.

Bootsma, H.A. and R.E. Hecky, 1993. Conservation of the African Great Lakes: a limnological perspective. Conservation Biology 7, 644-656.

Fuggle, R.F. (2002) Lake Victoria: a case study of complex interrelationships. Available at: http://africa.unep.net/casestudies/pdf/Lake_Victoria.pdf.

Geheb, K. and K. Crean, 2003. Community-level access and control in the management of Lake Victoria's fisheries. Journal of Environmental Management 67, 99-106.

Geheb, K. and T. Binns, 1997. 'Fishing farmers' or 'Farming fishermen'? The quest for household income and nutritional security on the Kenyan shores of Lake Victoria. African Affairs 96, 73-93.

Geheb, K., K. Crean, M. Medard, M. Kyangwa, C. Lwenya and P. Onyango, 2002. On pitfalls and building blocks: towards the management of Lake Victoria's fisheries, pp. 142-173, In: Geheb, K. and Sarch, M.T. (eds.) Africa's Inland Fisheries. Fountain Publishers, Kampala, Uganda. 280 pp.

Gichuki, J., F. Dahdouh Guebas, J. Mugo, C.O. Rabuor, L. Triest and F. Dehairs, 2001. Species inventory and the local uses of the plants and fishes of the Lower Sondu Miriu wetland of Lake Victoria, Kenya. Hydrobiologia 458, 99-106.

Gichuki, N., 2003. Wetland research in the Lake Victoria Basin, Kenya part: Analysis and Synthesis Report. Lake Victoria Research Initiative(VicRes), The Inter-University Council for East Africa, Kampala, Uganda. 58 pp.

ILEC, 2005. Managing lakes and their basins for sustainable use: a report for lake basin managers and stakeholders. International Lake Environment Commission Foundation: Kusatsu, Japan.

Kassenga, G.R., 1997. A descriptive assessment of the wetlands of the Lake Victoria basin in Tanzania. Resource, Conservation and Recycling 20, 127-141.

Kenya Times, 2006. Storm in Yala swamp. Kenya Times Magazine, 19 April 2006. Available at: http://www.timesnews.co.ke/19apr06/index.html.

Kull, D., 2006. Connections between recent water level drops in Lake Victoria, dam operations and droughts. Unpublished report. International Rivers Network IRN, Berkeley. URL http://www.irn.org/programs/nile/

Odada, E.O., D.O. Olago, K. Kulindwa, M. Ntiba and S. Wandiga, 2004. Mitigatin of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses. Ambio 33, 13-23.

Scheren, P.A.G.M., H.A. Zanting and A.M.C. Lemmens, 2000. Estimation of water pollution sources in Lake Victoria, East Africa: application and elaboration of the rapid assessment methodology. Journal of Environmental Management 58, 235-248.

Tusasirwe, B., 2003. The East African Community (EAC) and constitutional development in 2002. Kituo Cha Katiba (East African Center for Constitutional Development), Faculty of Law, Makerere University, Uganda (available at http://www.kituochakatiba.co.ug/Constm%202002%20Tusasire%20EAC.pdf).

Van der Knaap, M. 2006. Analyse sociale en economische effecten van westerse consumptie van Nijlbaars uit het Victoriameer (Analysis of the social and economic effects of consumption of Lake Victoria Nile perch by Western countries). Consultancy Report, Milieu en Natuurplanbureau, Bilthoven, The Netherlands, 58 pp. (in Dutch).

Verschuren, D., T.C. Johnson, H.J. Kling, D.N. Edgington, P.R. Leavitt, E.T. Brown, M.R. Talbot and R.E. Hecky, 2002. History and timing of human impact on Lake Victoria, East Africa. Proceedings of the Royal Society, Lond. B. 269, 289-294.

WID/IUCN, 2005. From conversion to conservation – fifteen years of managing wetlands for people and the environment. Wetlands Inspection Division, Kampala, Uganda and IUCN Eastern Africa Regional Programme, Nairobi, Kenya.

Williams, A.E., H.C. Duthie and R.E. Hecky, 2005. Water hyacinth in Lake Victoria: why did it vanish so quickly and will it return? Aquatic Botany 81, 300-314.

Unit 8. Case study: Mangrove rice production and water management of the Diola in Basse Casamance, Senegal

(by P. van der Zaag)

Mangrove rice production in Basse Casamance, southern Senegal, is an example of a very old agricultural production system with remarkable technical sophistication. The Diola have developed infrastructural works and a technology with which they have made the reclaimed mangrove clays suitable for permanent rice cultivation, and have maintained soil fertility through the years. Central to this rice production system is water management, and the control of salt and fresh water by means of dykes and ponds.

The article focuses on one small village in Basse Casamance, Niomoun. It starts with a description of its spatial organisation (section 1), including the layout of the agricultural complex (the rice fields and the associated ponds and dykes). Section 2 deals with the technical features of the agricultural complex and how it is managed. Section 3 turns to the changes that have occurred in Niomoun during the last 25 years, and tries to understand why rice production has declined from surplus production to subsistence level. How best can this decline be redressed?

8.1. The spatial organisation

The village layout

Niomoun is a small village with approximately 1,500 inhabitants which lies hidden in the delta of the Casamance river, only some 20 kilometres from the Atlantic Ocean. It is surrounded by extensive mangrove woods which fall dry with low tide, a river-arm and a number of creeks, their salty waters always flowing with the tide. The only way to reach the village is over water, and it takes at least one hour to reach the nearest village by motorised dug-out canoe. The journey to the region's capital city, Ziguinchor (60 km.), takes some six hours.

The spatial organisation of Niomoun is highly structured: it has four quarters or neighbourhoods which are situated on higher sandy plateaux, separated from one another by the lower-lying rice fields and ponds, which are protected from the tidal river waters by dykes (Figure 8.1). Each village quarter (*kalol*) consists of four or five extended families, with adjoining compounds. Each compound (*hank*) has between 6 and 15 houses, in which the 50 to 70 members of the patrilineal group live. Each house (*eloup*) is inhabited by a nuclear family (father, mother, their unmarried children and other dependants), sometimes completed with the father's parent(s).

The layout of the agricultural complex

The quarters of Niomoun are surrounded by rice fields (*utama*), with the typical ridges on top of which the rice is planted; the dykes (*kudunk*, between 0.5 and 1.5 metres high) with sluices, and the water ponds, which form the buffer between the rice fields and the unreclaimed mangrove soils. With these elements, Diola farmers know how to manage water flows so that rice can be grown, and the soil quality maintained.

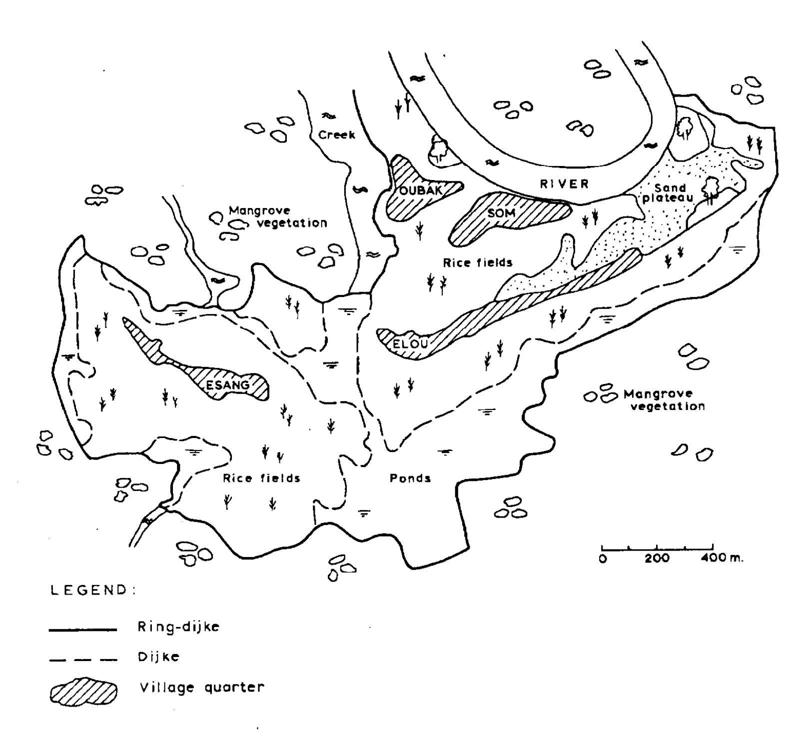


Figure 8.1: The four quarters of Niomoun

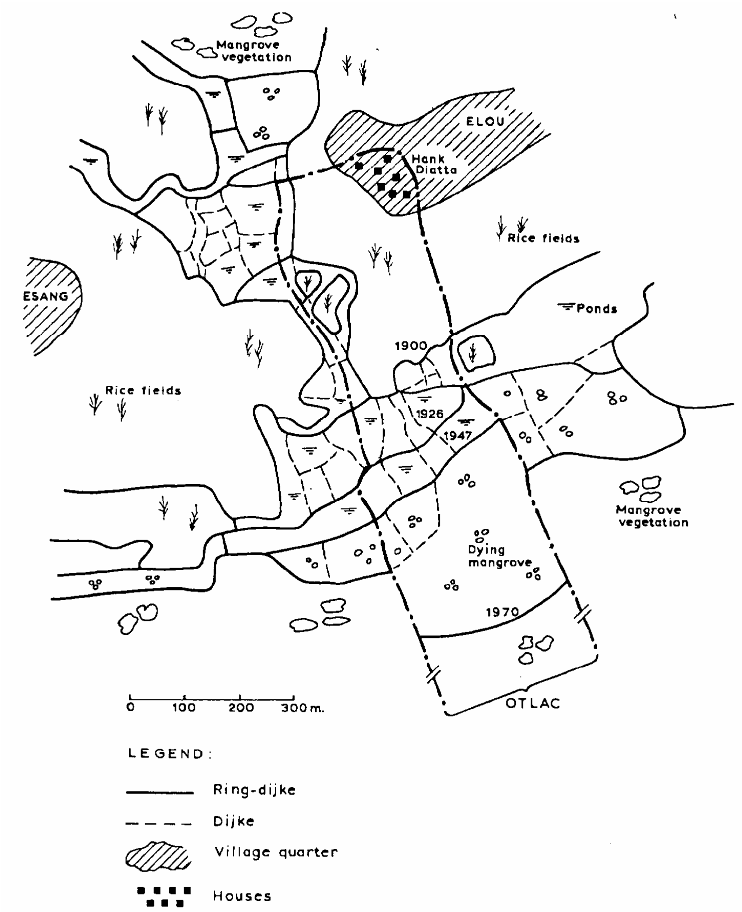


Figure 8.2: The group of rice fields, dykes and ponds (*otlac*) belonging to the compound of the extended family Diatta, in the Elou quarter

The dykes form several irregular concentric lines around the village quarters, which indicate that the villagers only gradually reclaimed the mangrove soils and transformed them into fertile rice lands. The dyke nearest to the Elou quarter was said to have been constructed around the turn of the century. The most recent dyke, 1,000 metres away towards the mangrove wood, was constructed around 1970 and borders the untouched mangrove and the tidal waters.

Each extended family owns a slice of the agricultural complex, namely the part which borders their compound or *hank* and which extends into the mangroves. This slice is known as the *otlac*. The *otlac* of a particular *hank* may be 200 to 500 metres wide and as much as 1,000 metres long (20-50 hectares). The part nearest to the quarter (between 5 and 15 hectares), contains the rice fields measuring between 0.02 and 0.2 hectares. Further down and bordering the rice fields are the water ponds, which produce fish and salt. Then finally there is the recently reclaimed land with the dying mangrove bushes which provide firewood and construction materials, and the many shells which are used for house construction (making floors) and paint. (Figure 8.2)

The *otlac* or agricultural complex, then, is the most important human-made resource or means of production for the *hank*. The *otlac* is divided into a number of smaller slices, the *katjale*, owned by the heads of the *hank*'s households. In this way each household has access to rice fields with different soil characteristics (low-high; wet-dry; heavy-light; fresh-salty), ponds, newly reclaimed soils, and part of the outer ring-dyke, and thus access to the tidal water. (Figure 8.3)

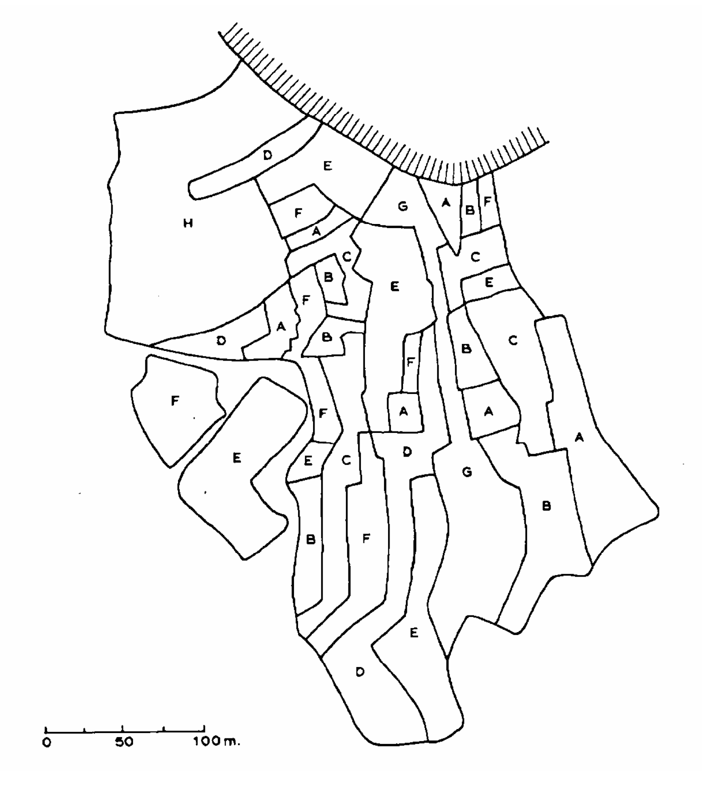


Figure 8.3: The *katjale* pattern of ownership of rice lands, of the extended family Diatta, Elou quarter of Niomoun (each letter indicates ownership by one of the eight heads of the households of the Diatta extended family)

8.2. Managing the agricultural complex

Mangrove soils are normally very salty, but upon reclamation these soils are drained, dry up and may become acid and turn into so-called acid-sulphate soils. Once a soil has developed acidic properties, it is very difficult, and often impossible to get rid of them, because of a series of chemical processes influencing the physical soil characteristics. Mangrove soils require a particular and very strict water management regime in order to stay suitable for agriculture (Dent, 1986; Beye, 1973). Apart from proper soils, rice needs enough fresh water. For the Diola, by far the most important source of fresh water is provided by the rain: during the rainy season, June - October, average precipitation is 1150 mm (at Ziguinchor, 1971-1985).

In the dry season, when the rice fields lie fallow, farmers consciously keep the water table very high, through maintaining the water level in the surrounding ponds to its maximum. This is not difficult: by high tide, salt river water is let in through the sluices in the outer ring-dykes. Through the high water table, the rice soils do not completely dry up, and acidification is forestalled. At the same time, however, the soils become salty.

With the first rains, rice nurseries are planted on the higher sandy soils near the homesteads. In Niomoun, farmers grow about 15 different rice cultivars, most of which belong to the *Oryza glaberrima* species ('African rice'), which differ from the Asiatic *Oryza sativa* species. On the lower rice fields the first rains are used to wash out the salts from the ridges. The salts are collected in the furrows (in between the ridges) and through a system of small canals this waste water is drained towards the ponds. This is possible because at that time, water levels in the ponds are maintained at their lowest level, and excess water is drained at low tide through the sluices in the outer ring-dyke. After this first washing of the rice fields, the ridges are turned over by the men using the typical Diola spade or *kayendo*.(Figure 8.4). With the following rains the fields are again completely submerged with fresh water, part of the remaining salt in the ridges is washed out, and the waste water is again drained off. With subsequent rains the fields again submerge and then the women can start transplanting the rice.

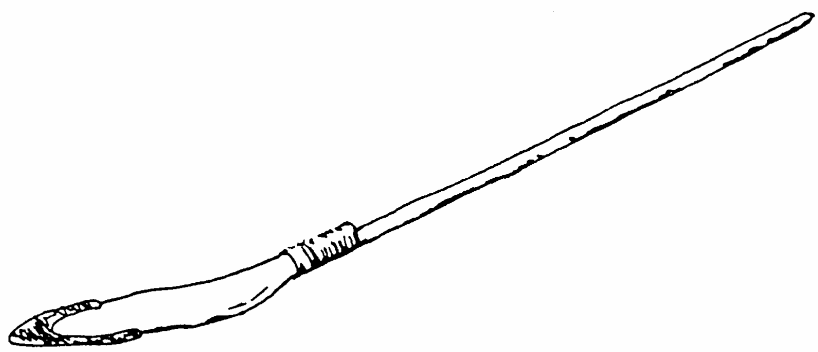


Figure 8.4: The *kayendo*

Now it is crucial to zealously guard the fresh water collected on the rice fields, because more than half of all the rain has already fallen, and with the rains to come the crop has to be raised. The fresh water can be contained through maintaining a high water table in the fields, and this is possible through keeping a high water level in the fish ponds. The result is fresh water standing on the fields, and a shallow fresh water table in the soil, below which the salty ground water is found. In the soil, and in the furrows, then, the fresh water is standing ('floating') on the (heavier) salty water. This phenomenon is known as *mou lamalamak* by the farmers of Niomoun. It ensures that no fresh water can seep away[i] (Figure 8.5).

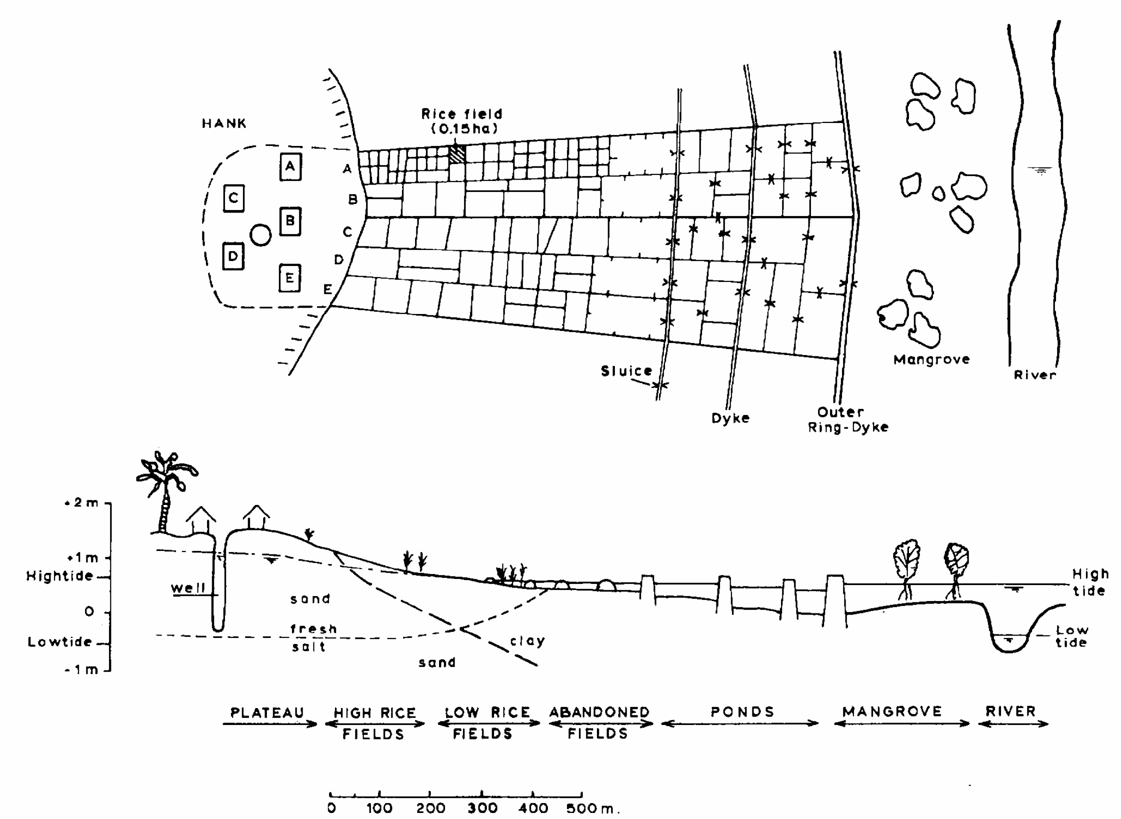


Figure 8.5: The agricultural complex, with its water management features

As we have seen, each village quarter has its own agricultural complex, consisting of the different adjoining *otlac*, which are bound together by the dykes. The extended families depend on each other for the adequate maintenance of the dykes. At the level of the *hank*, each *otlac* can follow its own type of water and salt management according to the specific local conditions, which may differ from the management practices of neighbouring families. Within the *otlac*, the distinctive *katjale* can also substantially differentiate water management. This is important for adapting water management to micro-variations in ground level and soil properties. A homogenous water management regime for the entire *otlac*, would imply that certain fields have too low a water table, and others too high, which would result in lower yields.

The temporal dimension: the rhythm of rice cultivation

The clockwork of the rice complex is formed by both the tide of the water and the coming and going of the seasons. Apart from the tidal movement (*katah du kalab*), there is the monthly cycle of spring tides, governed by the moon. Some days before a spring tide, most men are busy repairing the dykes, restoring them to a proper level again (dykes on mangrove clays are prone to subsidence). A longer cycle is formed by the annual rainy season, a cycle which determines the rhythm of activities such as ploughing, sowing, transplanting, harvesting, dyke-repair and new reclamations.[ii]

Finally there is the long-wave cycle over the years, which is characterised by the gradual expansion of the rice polders when rainfall has been good in a number of successive years; and enough labour is available.

As the foregoing has attempted to show, rice cultivation on mangrove soils in Niomoun is technically advanced. This is exemplified by the permanent character of agriculture. Part of Niomoun's rice fields have been under cultivation for over 100 years. The sustained application of natural fertilizers has ensured that crop yields remain between 1 and 2 tons per hectare. This results in a labour productivity of around 10 kg paddy per day.[iii] Another feature is formed by the genotypic variety of rice cultivars available, and the way farmers make use of this variety in order to cope with the different soil qualities and hydrologic conditions of their plots. Also, the infrastructural works of the complex, including the dykes and sluices, demonstrate an aspect of the system's technical sophistication. In the foregoing section it was shown that the layout of the agricultural complex is a sheer necessity in order to use the mangrove soils productively, and keep them suitable for agriculture. The complex is multi-functional, as it not only enables rice cultivation, but fish raising and salt production as well. In addition, it provides construction materials and fire-wood. In short, the Niomoun agricultural complex is highly developed, given the natural circumstances which agronomists would classify as marginal.

8.3. From surplus to subsistence

The above description of agricultural production in Niomoun, and how it relates to the social structure, suggests that Niomoun's society is self-contained, inward-looking, and closed off from the wider social, economic and political environment. This is not the case, however.

In pre-colonial times, the Diola used to barter rice with the neighbouring Mandinko for cattle. In this way, the Diola elders accumulated their most important prestige good, a big herd of cattle (Roche, 1985: 46; van der Klei, 1989: 202-208). By the time the French had finally succeeded in 'pacifying' the Casamance (around 1920), rice trade with the Diola had diminished considerably. The Mandinko now dealt with European traders, gradually becoming part of the colonial structure. The French trading companies were not interested in rice or cattle, but in ground nuts. The Mandinko sold these to the French, with the proceeds of which they bought rice imported by the French from Indo-China. The market value of Diola rice decreased quickly, forcing the Diola out of the market. Consequently, the Diola's need for cash for the purchase of cattle increased (van der Klei, 1989: 211-216; Snyder, 1981: 116).

The Diola elders reacted by urging the younger generation to sell their labour during the dry season in cash crop production (notably ground nuts) in nearby Gambia. Part of the money earned their elders quickly converted into goods, especially cattle bought now from the Fulani pastoralists in Haute Casamance. In this way the broken chain was restored.

The overall effect of these trends has been that Niomoun has not become poorer, but that rice production has declined, and that seasonal migration, especially of youngsters (both male and female) has predominated at least since the 1960s.[iv] The place of Niomoun's agricultural complex changed from a major economic resource with which a surplus could be produced, to a resource which secured the subsistence needs of the villagers. As a result, the need to produce rice has diminished considerably (corresponding to some 85% of the original production level in the 1960s). In addition, due to the regular absence of many villagers, the demand for rice for subsistence decreased by a further 25% or more. It is no surprise, then, that the annual rice production of Basse Casamance has fallen steadily from 46,000 tons in 1960-62 to 28,000 tons in 1975-1977 (Carvalho, 1983), and that for instance in Niomoun, some 40% of the rice fields were not cultivated during the 1980s. Figure 8.6 compares the fields cultivated in 1969 by the hank Diatta, Elou quarter (based on the interpretation of a 1969 aerial photograph, scale 1:10,000), with the situation in 1985.[v]

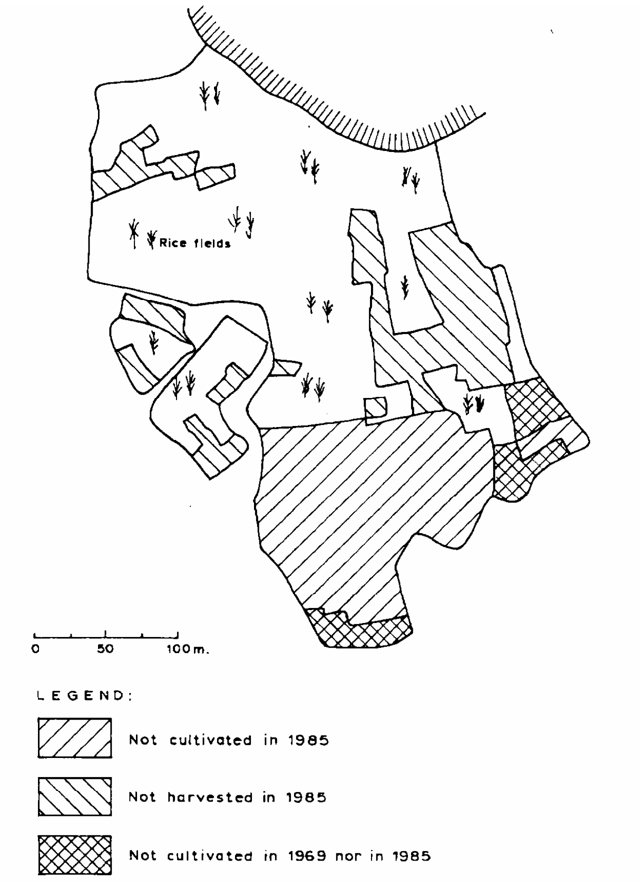


Figure 8.6: Rice fields cultivated by *hank* Diatta, Elou, in 1969 and 1985

Declining rice production is the awe of the European agronomist and the Senegalese planner, but not for most villagers of Niomoun: villagers are richer now than in former times. Developments of the last 25 years, then, has led to the major source of surplus shifting from agriculture to seasonal migration. The Diola thus produce less rice, but this has not harmed the economy of Niomoun or changed its social structure fundamentally. Nevertheless, this economic transformation implies that Niomoun society has become more closely linked to the wider world-market system, and consequently, more dependent of it.

Rice production in Niomoun is in decline. From a source of surplus it is now merely a means of subsistence. Demand for rice has diminished in the village, and labour for maintaining dykes and for new reclamations (during the dry season) is in short supply due to the seasonal migration of a quarter or so of the total population. Contrary to what most people seem to think, the Sahel drought which has affected the Casamance region since 1970, is not the main cause of the declining rice production.[vi] It has, of course, made rice production on mangrove soils more precarious, which is why the *hank* Diatta for instance, in 1970, still constructed a huge dyke in order to better protect the fields against salt intrusion (see Figure 8.2). It is the Diola need for rice which has diminished, which is one of the reasons why modern rice projects have not lived up to their expectations (Spijkerman and van Schagen, 1986; van der Klei, 1988; 1989: 132-134).

The Niomoun case shows how Diola land reclamation technology is intertwined with the social structure of the village. The *kayendo* spade and the dykes, for instance, have much to do with gender and age, the basic dimensions along which Diola society is stratified. The social, economic and political relations found in Diola society have been structured on the basis of the physical conditions of rice cultivation on mangrove soils, and thus are rooted in the technology of land reclamation and in the artefacts which the Diola developed.

8.4. Conclusion

This article has attempted to show that the Diola have developed the appropriate technologies as well as the institutional arrangements to manage the fragile mangrove soils, and salt and fresh water, such that these soils produce sustainable yields of rice. Rice production has declined principally because its market was undercut since late colonial times. Diola need for cash is now satisfied through migrant labour. Hence less labour is invested in maintaining the rice polders.

To revive their interest in rice as a surplus crop, the Diola need a concrete incentive, such as a fair price for the superb rice they produce. Even then, they might prefer the modernity of migration to turning the mangrove mud.

References

Albrecht, D., M. Diagayette, D. Millar, R.J. Scheer, and O. Serrant, 1983, *Les systèmes de la production agricole dans la région des Kalounayes en Basse Casamance, Senegal*. ICRA Bulletin 12, Wageningen: ICRA

Beye, G., 1973, Acidification of Mangrove soils after empoldering in Lower Casamance. In H. Dost (ed.), *Proceedings of the international symposium on acid sulphate soils, 13-20 August 1972, Wageningen*, ILRI Publication 18, Wageningen: ILRI; vol.2, pp.359-372

Boivin, P., en B. Barry, 1986, Secheresse et evolution des conditions d'amenagement des zones fluvio-marines en Basse Casamance. Paper presented at the Third International Symposium on Acid Sulphate Soils, January 6-11, 1986, Dakar

Carvalho, A.F., 1983, Sectoral policy and regional development: rice farming policy implementation and its impact on Casamance and Fleuve (Senegal). Ph.D. thesis, Amsterdam: University of Amsterdam

Dent, D, 1986, *Acid sulphate soils: a baseline for research and development*. ILRI Publication 39, Wageningen: ILRI

FAO, 1984, Development of mangrove lands for rice cultivation in Tombali and Quinará (formerly Buba) regions. Mission findings and recommendations, Rome: FAO

Hykoop. S., 1983, De funktie van runderen bij de Diola. M.A. thesis, Amsterdam: Department of Cultural Anthropology, Free University

Korfker, D., 1983, De funktie van de vroedvrouw (matrone) in Niomoun. M.A. thesis, Amsterdam: Department of Cultural Anthropology, Free University

Linares Sapir, O., 1970, Agriculture and Diola society, In P.F. McLoughlin (ed.), *African food production systems, cases and theory*. Baltimore and London: The John Hopkins Press; pp.193-227

Linares, O.F., 1981, From tidal swamp to inland valley: on the social organization of wet rice cultivation among the Diola in Senegal. *Africa* 51(1981):563

Loquay, A., 1981, Formes d'approvisionnement et de consommation de l'énergie dans un village de Basse Casamance au Sénégal, In *L'énergie dans les communautés rurales des pays du tiers monde*. Travaux et documents de géographie tropical, 43. Bordeaux: Domaine Universitaire; pp.83-119

Roche, C., 1985, *Histoire de la Casamance, conquête et résistance 1850-1920*. Paris: Editions Karthala (2nd ed.)

Snyder, F.G., 1981, *Capitalism and legal change, and African transformation*. New York: Academic Press

Spijkerman, A.J.C., en R.H. van Schagen, 1986, The growing of wetland rice on potential acid-sulphate soils in the Lower Casamance area in Senegal, Paper presented at the Third International Symposium on Acid Sulphate Soils, January 6-11, 1986, Dakar

Thomas, Louis-Vincent, 1965, Bukut chez les Diola - Niomoun. *Notes Africaines* 108: 97-116

Thomas, Louis-Vincent, 1967, L'habitat des Blis-Karon et des Niomoun (Basse Casamance Maritime). *Notes Africaines* 114: 33-48

Tuluy, A.H., 1981, Cost and incentives in rice cultivation in Senegal. In: S.R. Pearson et al. (eds.), *Rice in West Africa, policy and economics*. Stanford: Stanford University Press; pp.263-293

Van der Klei, Jos, 1988, Soil reclamation: a technical or a socio-economic problem? Reclaiming the acid-sulphate soils in the tidal swamps of Basse Casamance, In H. Dost (ed.), *Selected papers of the Dakar Symposium on Acid Sulphate Soils, Dakar, January 1986*. ILRI Publication 44. Wageningen: ILRI; pp.229-237

Van der Klei, Jos, 1989, *Trekarbeid en de roep van het heilige bos, het gezag van de oudste en moderne veranderingen bij de Diola van Zuid-Senegal*. Nijmegen: IKEN

Van der Ploeg, J.D., 1981, Guiné-Bissau: over landbouw en verborgen klassenstrijd. *Marquetalia* 2:67-115, Wageningen: De Uitbuyt

World Bank, 1975, Senegal; agricultural sector survey, volume 2, Regional Projects Department, Western Africa Regional Office, February 1975

Notes

i. Diola are well aware of the only source of fresh water, surrounded as they are with the brackish tidal waters in the mangrove creeks: rain, used not only for rice cultivation but also for domestic purposes. It is more than illustrative that the Diola word for rain, *emitey*, via the word for the sky, *emit*, is linked to their highest deity, *Ata emit*.

ii. The Diola word for year, *kadjan*, the 'space' between the rainy seasons, reveals that our distinction between time and space is theoretical. The Diola use more of an undivided time-space concept.

iii. Cultivating one hectare requires a labour input of between 100 and 200 days, without counting the initial investment in labour and without counting the annual repair works of dykes (see Linares, 1981; Loquay, 1981; Albrecht et al., 1983; World Bank, 1975; and Tuluy, 1981 on Diola rice cultivation in Casamance; compare with Van der Ploeg, 1981, and FAO, 1984 for Balanta rice cultivation in neighbouring Guinée Bissau).

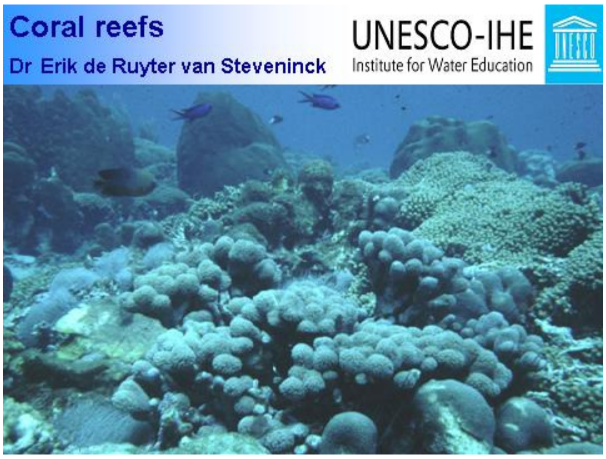
iv. Compare with Linares Sapir (1970:224). Hykoop (1983) found that the number of cattle owned by the Diola in 1975 was three times the number of cattle owned in 1920. During the dry season of 1967 in Niomoun, half of all boys and girls between 15 and 30 years migrated during the dry season (Thomas, 1967). In 1982 total seasonal migration involved 27% of all inhabitants of Niomoun (Korfker, 1983). On top of this, between 1964 and 1982 some 10% of all the villagers permanently migrated out of the village and settled in Ziguinchor, Dakar or other places (Thomas, 1965: 117; Korfker, 1983: 26). They however maintain contact with Niomoun, and return for important events, such as the initiation ceremony of young males (*bukut*) that is being held only once every twenty years.

v. The hank Diatta in the Elou quarter cultivated 7 hectares in 1969, and only 4.13 hectares in 1985.

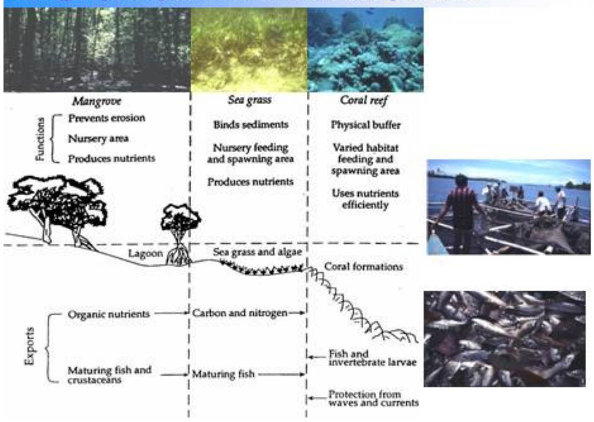
For its subsistence this hank, with 57 persons (20 of them children under the age of 12), needs slightly less than 10 tons of paddy rice, or equivalent to 0.5 kg of white rice per adult per day present in Niomoun. In 1985, the 37 persons above the age of 12, resided in total 335 months out of 444 (37x12) months possible, in Niomoun, or 75% of the time. The 4.13 hectares cultivated and harvested produced only an estimated 6 or 7 ton of paddy. The low production of 1985 may be partly attributed to the bukut ceremony celebrated that year. Rice production from the 7 hectares cultivated in 1969 must have ranged well above 10 tons of paddy.

vi. See e.g. Boivin and Barry (1986). Average annual rainfall over the period 1921-1970 was 1558 mm, the same figure for the period 1971-1985 was 1150 mm (data for Ziguinchor).

Unit 9. Coral reefs (by E.D. de Ruyter van Steveninck)



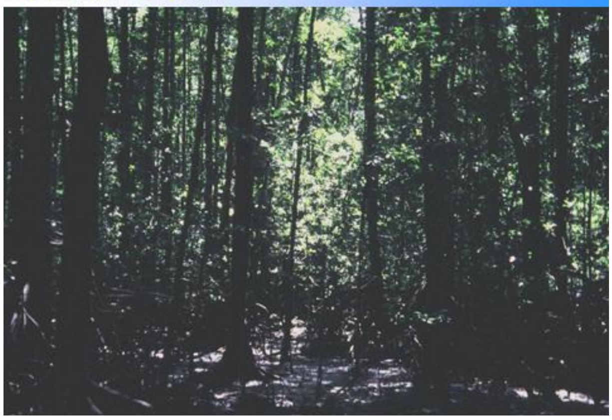
Integrity tropical coastal ecosystems



Mangroves

- Salt-tolerant plant species (mangrove tree)
- Community (mangrove forest) = mangal
- About 68 species of trees, shrubs, bushes, including:
  - *Rhizophora* (red mangrove type)
  - *Avicennia* (black mangrove type)
  - *Nypa* (palm)
- (Sub)tropical intertidal regions

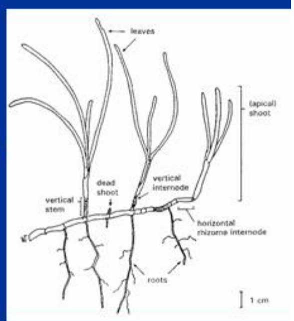
Mangrove forest



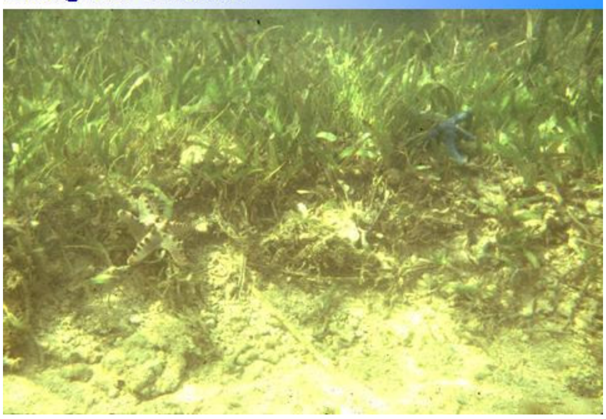
Mangrove inhabitants

Seagrasses

- Submerged or intertidal flowering plants
- About 58 species
- Terrestrial ancestors, which migrated back into the sea
- Horizontal rhizomes, erect shoots with leaves
- Occur world-wide, most abundant in tropics



Sea grass meadow



Seagrass inhabitants

Coral reef

- Bank-like limestone ($CaCO_3$) structure
- Limestone secreted by living organisms (a.o. corals)
- Upper surface near the level of the sea (at least during formation)
- Reef-building corals restricted to tropics

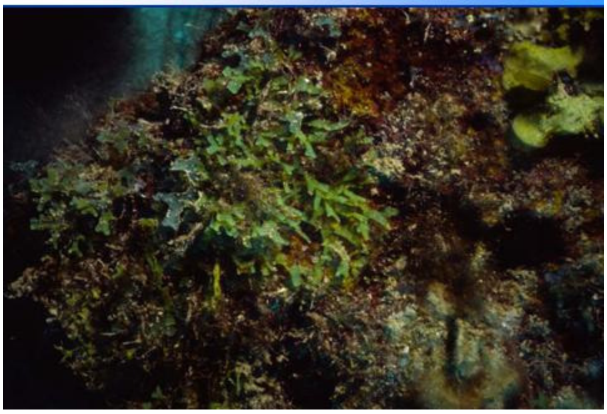
Coral reef

Brain coral

Fire coral

Sponges

Benthic algae



Crustose coralline

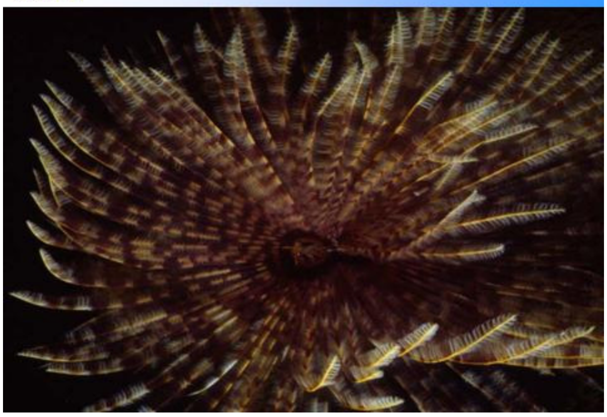
Sea turtle

French angel fish

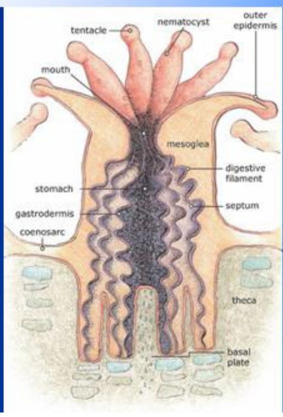
Coffin fish

Lobster

Quiz?



Coral polyp



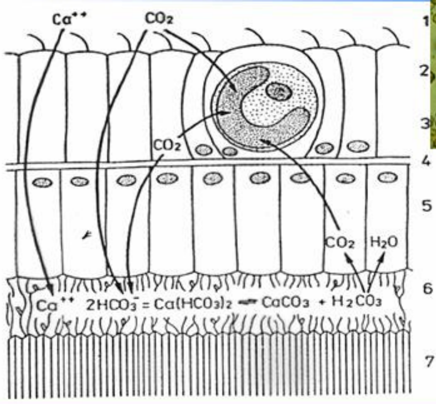
Coral with polyps

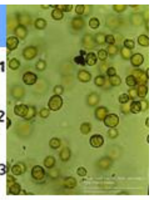
Two groups of stony corals

Hermatypic:
- + zooxanthellae
- fast growth and limestone deposition

Ahermatypic
- - zooxanthellae
- slow growth

Zooxanthellae: symbiotic algae



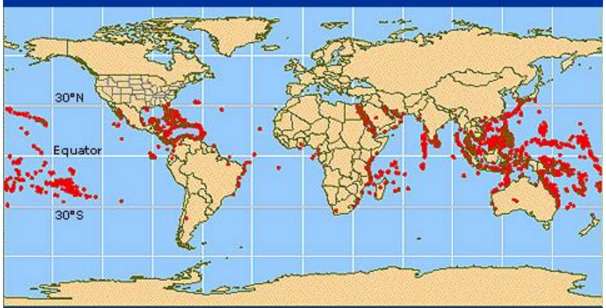


Hermatypic corals

- Autotrophs or heterotrophs?
- Tight recycling of nutrients and photosynthetic products, but also feeding on zooplankton, detritus and bacteria
- Algae find protection
- Need light: well adapted to nutrient-poor, clear oceans
- Algae responsible for colours

Coral bleaching

Global distribution coral reefs

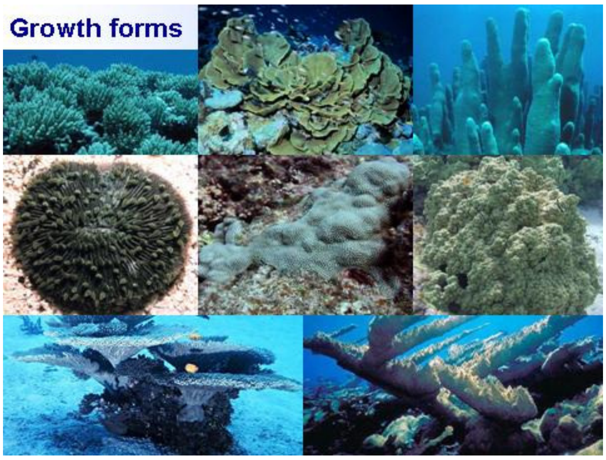


Coral reefs: production

Calcium carbonate budget:
- reef formation

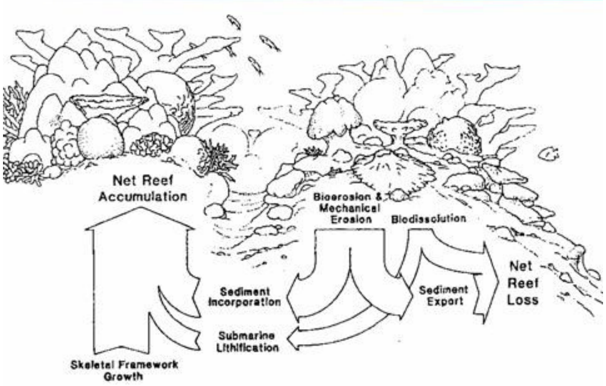
Primary production:
- food webs
- biodiversity

Growth forms

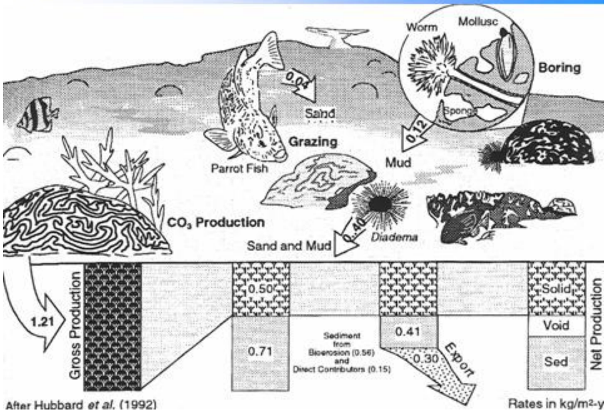


Shallow vs deep reef

Reef formation processes



Calciumcarbonate budget



Bio-erosion by parrotfish

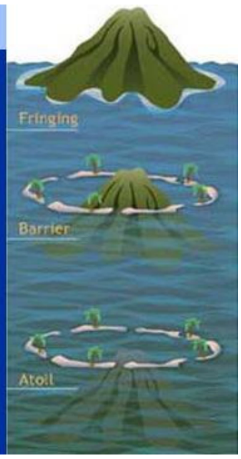
How do coral reefs form?

Growth rates corals:

0.3 - 2 (massive) up to 10 cm y^{-1} (branching)

Formation of fully developed reefs:

100,000 - 30,000,000 y



High coverage and diversity

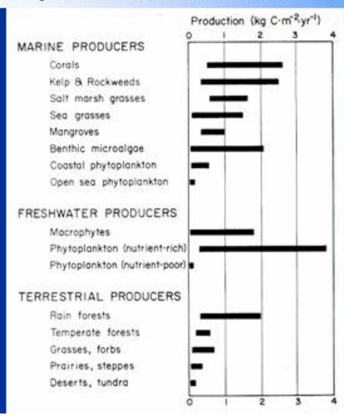
Tunicate overgrowing coral

Allelopathy by sea anemone

Coral-algae interaction

Impact of heavy grazing pressure

Annual net production rates (Valiela 1995)



High organic production in nutrient-poor tropical ocean

High surface area:

- three dimensional structure
- zooxanthellae in many species
- algae on and in ´bare´substrata

Tight recycling nutrients:

- symbiotic relations in many species
- high grazing pressure and turn-over

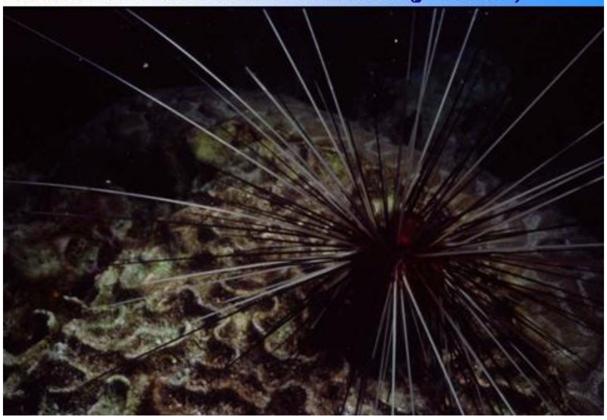
Role of grazing by herbivores

Maintaining the reef structure by:

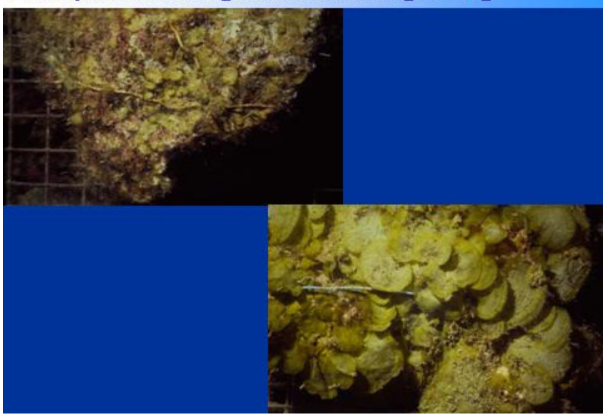
- Preventing overgrowth corals
- Keeping substrata open for settlement

Grazing parrotfish

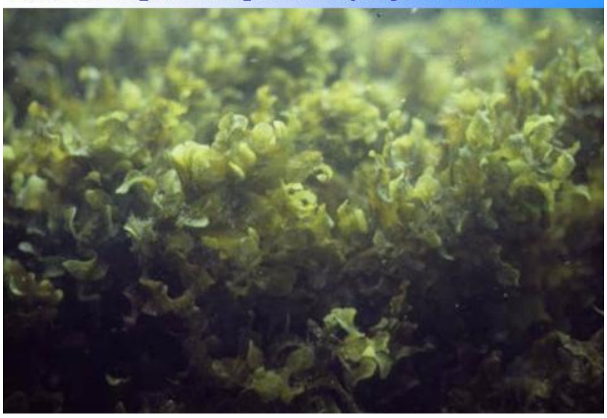
Sea urchin *Diadema antillarum* (juvenile)



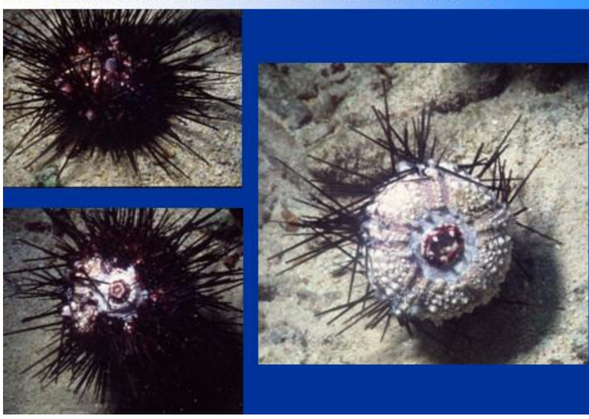
Lobophora variegata: effect of grazing



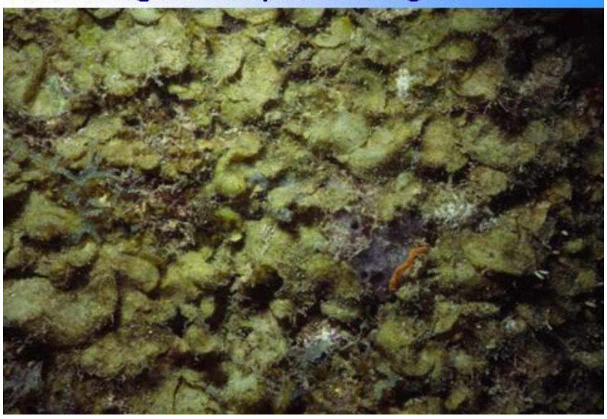
Benthic algae: *Sargassum polyceratium*



Infected sea urchin: *Diadema antillarum*



Benthic algae: *Lobophora variegata*



Depth distribution *Diadema antillarum* and *Lobophora variegata* (Curacao, 1983-1985)

Depth (m)		Before mortality		2 yr after mortality	
		Diadema	*Lobophora*	*Diadema*	*Lobophora*
Site 1	5	+++	-	-	-
	12	+	-	-	+
	20	-	+++	-	+++
	25	-	+++	-	+++
	30	-	+++	-	+++
Site 2	5	+++	-	-	-
	12	+++	-	-	-
	20	+	-	-	-
	25	+	+	-	++
	30	+	+	-	++
	35	-	++	-	++

Change in algal cover/biomass after mass mortality *Diadema antillarum* in 1983

Location	Depth (m)	Period of increase (mo)	New level persisted for at least (mo)	Increase algal cover (%)
Curacao	3	2	11	118-146
	15	4	3	32-35
	27	7	5	60
St.Croix	1.5-2	7	3	245
Jamaica	7	3	8	275-400

Curacao vs Jamaica

Reefs in Jamaica overgrown by algae (catastrophic shift).

Some possible causes:

- Overfished: grazing by *Diadema* not compensated by fish
- Nutrient input
- Combination

Natural threats to coral reefs

- Hurricanes, cyclones
- Tidal emersions
- Increased water temperature
- Predation (Crown-of-thorns starfish)

Limitations to recovery:

- Numerous and sustained stresses
- Overgrowth by algae

Anthropogenic stresses to corals

- Pollution (sediments, nutrients, toxicants, debris, oil)
- Overfishing
- Destructive fishing practices
- Mining, collection
- Swimmers, divers
- Global warming (sea level and temperature rise)

Interesting link

http://nos.noaa.gov/education/corals/welcome.html

B. EXERCISES AND GROUP WORK MODELLING CASE STUDIES

EXERCISES

Exercise 1. Conceptual models and problem analysis

(after Lundberg, 2005)

1. Design a conceptual model as in the example of the Baltic Sea (Lundberg 2005).

In the model, distinguish the following compartments:

causes / primary effects / secondary effects / social responses / management options

Use the information from the articles on Lake Victoria (see case study in Unit 7)to put together the conceptual model. Each of the five compartments can be further sub-divided into categories (e.g., physical, chemical, biological). You can use colours to indicate different categories.

2. Draw the model on a large sheet of paper and discuss it with another group.

References

Fuggle, R.F. (2002) Lake Victoria: a case study of complex interrelationships. Available at: http://africa.unep.net/casestudies/pdf/Lake_Victoria.pdf.

Lundberg, C. (2005) Conceptualizing the Baltic Sea ecosystem: an interdisciplinary too for environmental decision making. Ambio 34, 433-439.

Odada, E.O., D.O. Olago, K. Kulindwa, M. Ntiba and S. Wandiga (2004) Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options. Ambio 33, 13-23.

Exercise 2. Drawing a stakeholder table/matrix

(based on ODA, 1995)

Use the information in the case study in Unit 7.

1. **Identify and list all potential stakeholders.**

Stakeholders can be listed and categorised in various ways. One starting point is to divide a list into primary and secondary stakeholders. A checklist to help draw up a list:

- have all primary and secondary stakeholders been listed?
- have all potential supporters and opponents of the project been identified?
- has gender analysis been used to identify different types of female stakeholders (at both primary and secondary levels)?
- have primary stakeholders been divided into user/occupational groups, or income groups?
- have the interests of vulnerable groups (especially the poor) been identified?
- are there any new primary or secondary stakeholders that are likely to emerge as a result of the project?

2. **Identify their interests (overt and hidden) in relation to the problems being addressed by the project and its objectives. Note that each stakeholder may have several interests.**

The list of stakeholders forms the basis of a tabulation of each stakeholder's interests in the project, and the project's likely impact on them. A checklist to help think about the possible interests of a stakeholder:

- what are the stakeholder's expectations of the project?
- what benefits are there likely to be for the stakeholders?
- what resources will the stakeholder wish to commit (or avoid committing) to the project?
- what other interests does the stakeholder have whch may conflict with the project?
- how does the stakeholder regard others in the list?

3. **Briefly assess the likely impact of the project on each of these interests (positive, negative, or unknown).**

The likely or actual impact of the project on these interests should also be assessed (only in simple terms). Expected project impacts on various stakeholders' interests can be classified into positive, negative, uncertain and unknown.

4. **Write your table on a large sheet of paper and discuss with another group.**

Stakeholder Table/Matrix

Lake Victoria Case Study Project:		
Stakeholder	Interests	Project impact
Primary (possibly subdivided into groups)		+ – +/– ?
Secondary		
Others?		

Note: Additional steps in the stakeholder analysis which we will not pursue are:
1. Assessing the influence and "importance" of stakeholders;
2. Drawing out assumptions and risks affecting project design and participation.

References

Fuggle, R.F. (2002) Lake Victoria: a case study of complex interrelationships. Available at: http://africa.unep.net/casestudies/pdf/Lake_Victoria.pdf.

Lundberg, C. (2005) Conceptualizing the Baltic Sea ecosystem: an interdisciplinary too for environmental decision making. Ambio 34, 433-439.

ODA, 1995. Comprehensive guidance note on how to do stakeholder analysis of aid projects and programmes. Social Development Department, Overseas Development Administration, London (available at: http://www.euforic.org/gb/stake1.htm).

Odada, E.O., D.O. Olago, K. Kulindwa, M. Ntiba and S. Wandiga (2004) Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options. Ambio 33, 13-23.

Exercise 3: Algal blooms on coral reefs (with Unit 9)

1. System and model description

Lapointe (1997) describes a research site at Discovery Bay, Jamaica. The site covers an area of about 1.5 km^2. We assume that the average depth is about 1 m. The adjacent upland drainage basin is porous limestone and contains fissures and fractures that provide an input of groundwater-borne nitrate to the site. There is considerable debate about which mechanism controls the growth of macroalgae on coral reefs. Some researchers think that a bottom-up control mechanism, through the supply of nutrients to the algae, is most important. Others think that the density of macroalgae is primarily determined by the intensity of grazing by e.g., herbivorous fish and invertabrate grazers like sea urchins. It is proposed to investigate this problem by constructing a model of the system. The main objective of the model is to see which factor is most important for the development of macroalgae on the reef.

Consider the following model of this coral reef system. The model has three state variables:

1. DIN (dissolved inorganic nitrogen), in g
2. Macroalgae, in g dry matter
3. A grazer, in g fresh weight

In the model, we assume that the groundwater input into the system (Groundwater_discharge) is a percentage of the total volume per day. The inflowing groundwater has a fixed concentration of inorganic nitrogen (DIN). The outflowing current is equal to the inflow (resulting in a constant volume of water in the area) but the amount of nitrogen flowing out of the area is determined by the mean DIN concentration in the area.

In the model, we consider two types of surface areas. Water_Surface is the surface area of the site, in m^2 of water surface. This surface is used to calculate the densities of grazers and to calculate the volume of the water body. Reef_Surface_Area is the surface area of the reef, which is used to calculate the density of the macroalgae growing on the reef.

Dissolved inorganic nitrogen

DIN is taken up by macroalgae growing on the coral rock. The uptake of DIN by the algae is modeled using a Holling type II relationship:

DIN uptake = U_{max} * (DIN_conc / (DIN_conc + K_s)) * Macroalgae

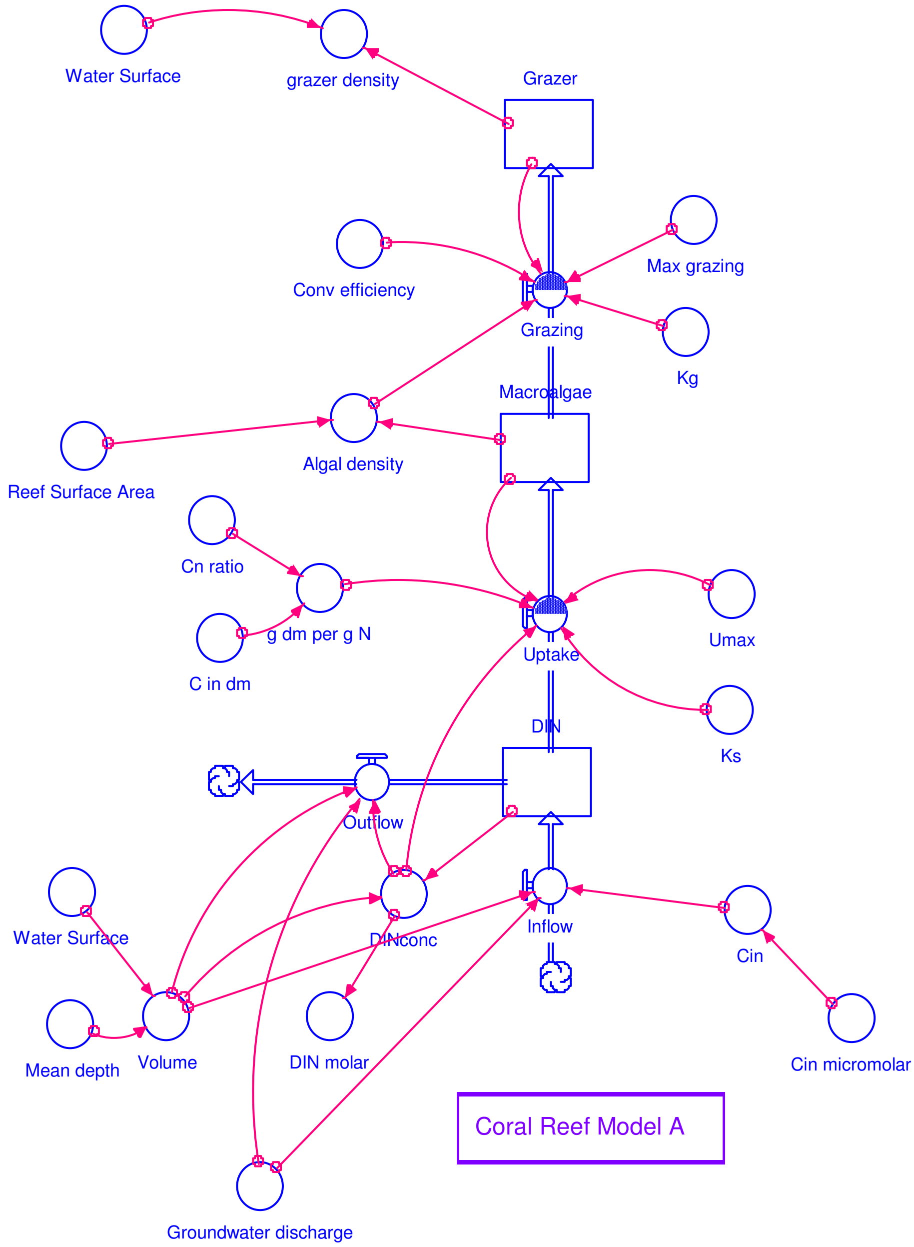
Macroalgae and grazers

Macroalgae are consumed by a grazer, and this grazing is also modelled using a Holling type II relationship:

Grazing = Max_grazing * (Algal_density / (Algal_density + K_g) * Grazer

2. Questions

PART A



1. Open the Stella-file "Coral Reef Model A.STM". Save the file on your own hard disk and rename it.

2. Make a list of all the variables in the model and write down the units for each variable. Check that the conversion of variables (e.g., from micromolar to g m^{-3} for DIN) is correct.

3. Note the "Unit Conversion" in the uptake rate and find out how the conversion of DIN to macroalgae is formulated in Stella.

4. Write fully the equation for the rate of change in Macroalgae biomass.

5. Create graph and table output which shows the relevant variables (decide which variables you want to show in the graph).

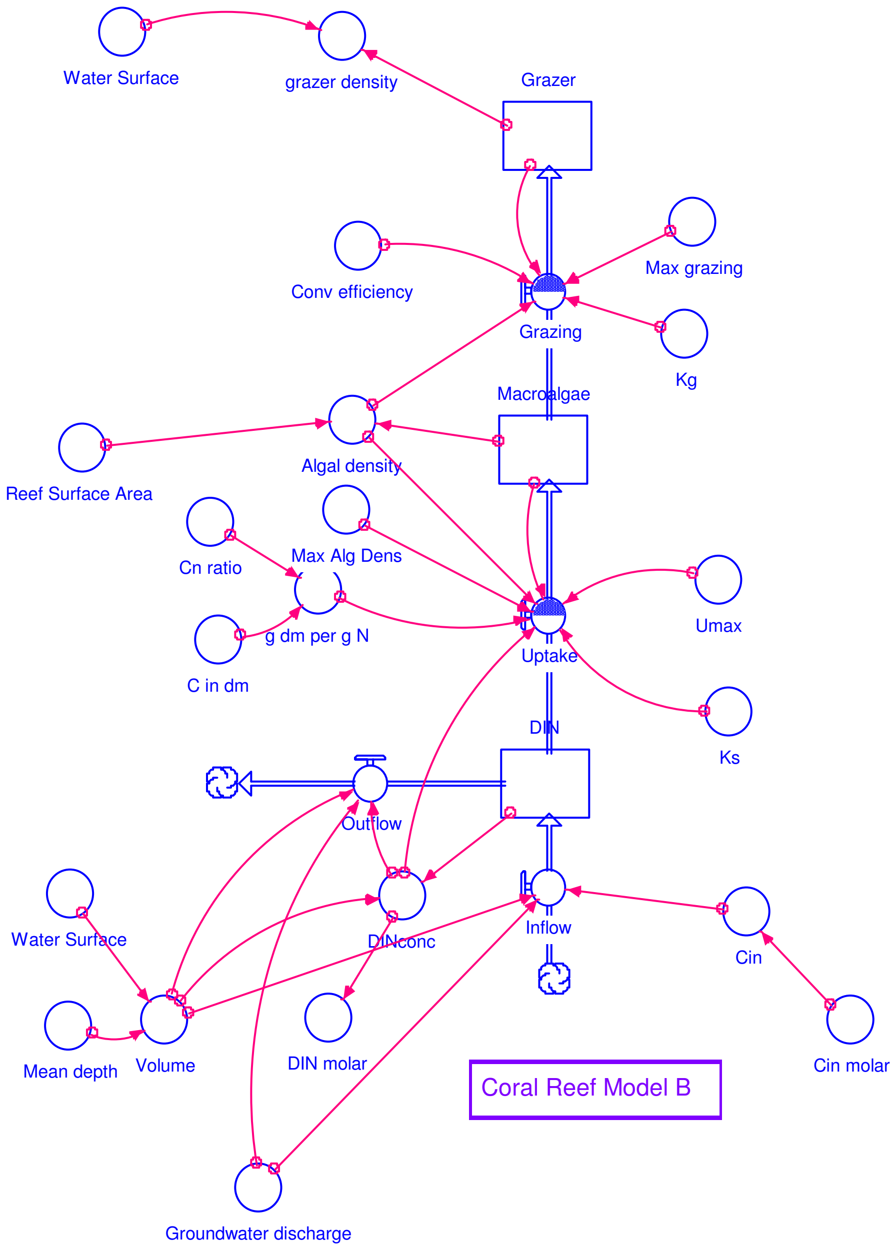
6. Set Max_grazing to 0 (zero). First, run the model for 300 days with a DT of 0.125 day at a DIN-concentration of the inflowing water of 0.5 micromolar. Describe what happens to the system (i.e., to the state variables in the system and their derivatives). Then repeat the simulation at higher inflow concentrations (up to e.g., 5 micromolar). Describe the changes in DIN level and macroalgae density. Finally, run the model for longer periods of time (up to 2500 days).

7. Evaluate the model. Indicate whether you think this is a good model of macroalgal growth. Are any important processes missing from the model? If so, what change to the model can you propose to improve the model?

PART B

8. Now open the Stella-file "Coral Reef Model B.STM". Note the differences between this model and the previous model (see Max_Alg_Dens). Run the model again with the same settings for Max_grazing (0) and Cin_molar. Describe the changes in DIN level and macroalgae density in relation to different DIN-input levels and simulation times.

9. Now give Max_grazing a value. In the literature, about coral reefs, grazing rates range from 2 to 100 mg dm per g fresh weight of grazer per day. Convert this to a value of Max_grazing and use it in the model. Again, look at the changes in DIN-level, macroalgae and grazer densities and explain what is happening.



PART C

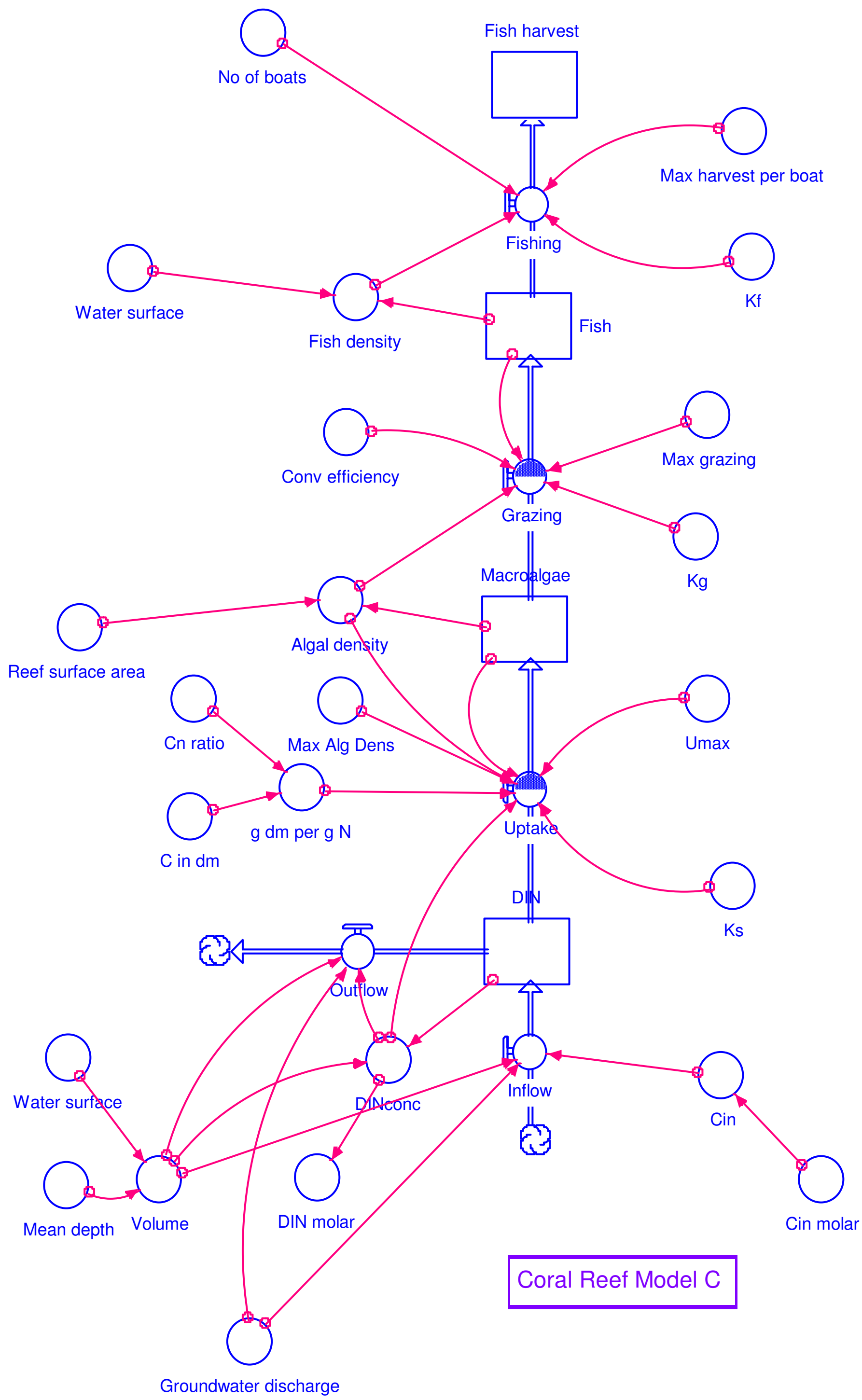
10. Open the Stella-file "Coral Reef Model C.STM". Grazers are now called "Fish" and a fishery has been added to the model. Observe the way the fishery is modeled. Make a list of the new variables and write down the units. Check that the dimensions and conversions are correct.

11. Look at the effect of fishing on the densities of fish and algae. Increase the fishing intensity (how?) and see what happens to the system. Also run the simulation for a longer period of time (e.g., 7,000 days).

PART D

12. Point out the feedback mechanisms that exist in this model.

13. What do you conclude in relation to the model objective? Which factor is most important in regulating macroalgal density?



GROUP WORK MODELLING CASE STUDY

1. PROCEDURE

1.1. Introduction

During weeks 2 and 3 of the ESA module, participants will work on a case study of an environmental systems analysis problem. Some proposed topics for case studies are given below, but students are also allowed to propose their own topics (on the condition that they can show that there is enough information and data to support the construction of a simple model). The procedure for working on the case studies is given here.

1.2. Procedure

General: Participants will work in groups of three or four (4) participants. After selecting the topic for the case study, the participants will collect the information and data needed for the construction of the model using the IHE library facilities (appr. 1 day). Then, they will make a conceptual model and define the model objectives (1 day). The next step is the formulation of the mathematical model and implementation of this model in Stella (2 days). After completion of this phase, the models will be discussed in the group. Then, the models are finalised and used for evaluation of scenarios and/or management options (1.5 day). The results should be prepared in the form of a Powerpoint presentation and a report (1 day) and presented to the other participants and the examiners (0.5 day).

1.3. Steps in the modelling process after selection of topic

1. Collect information. Use the library facilities and the Internet if necessary. Don't forget to document the sources of information, especially when quantitative information for parameters is used.

2. Describe the system and describe the problem (word model). Focus on management aspects of the system.

3. Draw a conceptual diagram and identify the state and rate variables of the model.

4. Translate the conceptual model into mathematical equations and identify the parameters you need to quantify. Document the sources for these values.

5. Construct the model in Stella. Incorporate graphs and tables for presentation of model output. Use the Document feature of Stella to enter information about the parameters and about the units of all variables.

6. Parameterize and calibrate the model.

7. Simulate scenarios or evaluate different management options with the model. Discuss the simulation results in the light of model assumptions and the quality of the data used.

8. Write a report and make a presentation about this modelling exercise.

2. TOPICS

2.1. Periphyton-based fish production

Description:
Fish culture in ponds is traditionally based on the production of phytoplankton. Phytoplankton blooms are created by fertilizing and/or manuring the pond. However, many herbivorous fish species are not efficient at utilizing phytoplankton. Moreover, phytoplankton blooms are not always stable. Collapse of an algal bloom may lead to massive mortality of the algae and subsequent depletion of oxygen in the pond. Recently, research has shown that equipping ponds with substrates for periphyton (composed of bacteria, algae and other organisms attached to the substrate) may provide an alternative source of food for fish. Periphyton is more stable and may be more efficient in utilizing lower concentrations of nutrients in the pond water. More fish may be able to utilize periphyton than phytoplankton. To optimize a periphyton-based fish culture system, the combined effects of periphyton productivity, the ability of fish to utilize the periphyton, and the available substrate for periphyton need to be evaluated. this can be done with a simulation model. Such a model may be used to recommend optimum combinations of substrate density and fish stocking density.

Some references:
Azim, M.E., M.A. Wahab, A.A. van Dam, M.C.M. Beveridge and M.C.J. Verdegem (2001) The potential of periphyton-based culture of two Indian major carps, rohu Labeo rohita (Hamilton) and gonia Labeo gonius (Linnaeus). Aquaculture Research 32, 209-216.

Azim, M.E., M.A. Wahab, A.A. van Dam, M.C.M. Beveridge, A. Milstein and M.C.J. Verdegem (2001) Optimization of fertilization rate for maximizing periphyton production on artificial substrates and the implications for periphyton-based aquaculture. Aquaculture Research 32, 749-760.

Azim, M.E., M.C.J. Verdegem, M.M. Rahman, M.A. Wahab, A.A. van Dam and M.C.M. Beveridge (2002) Evaluation of polyculture of Indian major carps in periphyton-based ponds. Aquaculture 213, 131-149.

Dempster P.W., Beveridge M.C.M. and Baird D.J. (1993) Herbivory in the tilapia Oreochromis niloticus: a comparison of feeding rates on phytoplankton and periphyton. J. Fish Biol. 43, 385-392.

Ekpo, I. and Bender, J. (1989) Digestibility of a commercial fish feed, wet algae and dried algae by Tilapia nilotica and silver carp. Progr. Fish Cult. 51, 83-86.

Getachew, T. (1988) Digestive efficiency and nutrient composition gradient in the gut of Oreochromis niloticus L. in Lake Awasa, Ethiopia. J. Fish Biol. 33, 501-509.

Huchette, S.M.H., Beveridge, M.C.M., Baird, D.J. and Ireland, M. (2000) The impacts of grazing by tilapias (Oreochromis niloticus L.) on periphyton communities growing on artificial substrate in cages. Aquaculture 186, 45-60.

Jiménez-Montealegre, R. (2001) Nitrogen transformation and fluxes in fish ponds: a modelling approach. PhD-thesis, Wageningen University, The Netherlands, 185 pp.

Keshavanath, P., B. Gangadhar, T.J. Ramesh, J.M. van Rooij, M.C.M. Beveridge, D. Baird, M.C.J. Verdegem and A.A. van Dam (2001) Use of artificial substrates to enhance production of freshwater herbivorous fish in pond culture. Aquaculture Research 32, 189-197.

Keshavanath, P., B. Gangadhar, T.J. Ramesh, M.C.M. Beveridge, A.A. van Dam and M.C.J. Verdegem (2001). On-farm evaluation of Indian major carp production with sugarcane bagasse as substrate for periphyton. Asian Fisheries Science 14, 367-376.

Keshavanath, P., B. Gangadhar,T.J. Ramesh, A.A. van Dam, M.C.M. Beveridge and M.C.J. Verdegem (2002) The effect of periphyton and supplemental feeding on the production of the indigenous carps Tor khudree and Labeo fimbriatus. Aquaculture 213, 207-218.

Westlake, D.F., Adams M.S., Bindloss, M.E., Ganf, G.G., Gerloff, G.C., Hammer, U.T., Javornicky, P., Koonce, J.F., Marker, A.F.H., McCracken, M.D., Moss, B., Nauwerck, A., Pyrina, I.L., Steel, J.A.P., Tilzer, M. and Walters, C.J. (1980) Primary production. In: E.D. LeCren and R.H. Lowe-McConnell (eds.) The Functioning of Freshwater Ecosystems (International Biological Programme 22). Cambridge University Press, Cambridge, 588 pp.

2.2. Water hyacinth in Lake Victoria

Description:

Water hyacinth (*Eichhornia crassipes*) originates from South America and is exotic to Africa. It was imported as an ornamental plant but has been very successful in open water bodies. Due to its rapid spread, it has caused problems for sectors like drinking water production and fisheries. In Lake Victoria, it was first reported in 1989. Several techniques for controlling water hyacinth have been tried, including biological control with weevils. The interactions between nutrient levels, hyacinth production and control by weevils in Lake Victoria may be studied using a model. Such a model can be used for recommending the best strategy for reducing the water hyacinth infestation in the lake.

Some references:

Bales, J.L.; Curtin, G.K.; Campbell, I.C.; Hart, B.T. Victoria State Rivers and Water Supply Commission Eutrophication Study of Lake Daylesford, Victoria Australian Journal of Marine and Freshwater Research, Vol 31, No 5, p 573-587, October, 1980.

Blinn, D.W.; Bailey, P.C. Land-use influence on stream water quality and diatom communities in Victoria, Australia: a response to secondary salinization. Hydrobiologia, vol. 466, no. 1-3, pp. 231-244; 2001.

Bootsma, H.A.; Hecky, R.E. Conservation of the African Great Lakes: A limnological perspective. Conservation Biology, vol. 7, no. 3, pp. 644-656; 1993.

Burton, H.R. Chemistry, Physics and Evolution of Antarctic Saline Lakes Hydrobiologia, Vol 82, p 339-362, 1981.

Dauffenbach, J. Managing Aquatic Plants on a Massive Scale. Lake Line, vol. 20, no. 3, pp. 25-27; 2000.

De Deckker, P.; Williams, W.D. Adelaide Univ. (Australia). Dept. of Zoology. Physico-Chemical Limnology of Eleven, Mostly Saline Permanent Lakes in Western Victoria, Australia Hydrobiologia HYDRB8, Vol. 162, No. 3, p 275-286, May 24, 1988.

Gichuki, J.; Guebas, F.D.; Mugo, J.; Rabuor, C.; Triest, L.; Dehairs, F. Species inventory and the local uses of the plants and fishes of the Lower Sondu Miriu wetland of Lake Victoria, Kenya. Hydrobiologia, vol. 458, no. 1-3, pp.

Gophen, M.; Ochumba, P.B.O.; Kaufman, L.S. Some aspects of perturbation in the structure and biodiversity of the ecosystem of Lake Victoria (East Africa) Aquatic Living Resources, vol. 8, no. 1, pp. 27-41; 1995.

Guildford, S.J.; Hecky, R.E. Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? Limnology and Oceanography [Limnol. Oceanogr.], vol. 45, no. 6, pp. 1213-1223; 2000.

Haynes, D.; Rayment, P.; Raynes, K.; Mosse, P.R.L. Laboratory-based investigation into the potential for algal proliferation in Lake Coleman, Victoria. Australian Journal of Marine and Freshwater Research, vol. 45, no. 4, pp. 625-634; 1994.

Hecky, R.E.; Bugenyi, F.W.B.; Ochumba, P.; Talling, J.F.; Mugidde, R.; Gophen, M.; Kaufman, L. Deoxygenation of the deep water of Lake Victoria, East Africa. Limnology and Oceanography, vol. 39, no. 6, pp. 1476-1481; 1994.

Kalff, J. McGill Univ. Phosphorus Limitation in Some Tropical African Lakes Hydrobiologia, Vol 100, p 101-112, April, 1983.

Kansiime, F.; Nalubega, M. Natural treatment by Uganda's Nakivubo swamp. Water Quality International [Water Qual. Int.], p. 29; 1999.

Kilham, S.S.; Kilham, P. Michigan Univ. Tropical Limnology: Do African Lakes Violate the 'First Law' of Limnology Internationale Vereinigung fuer Theoretische und Angewandte Limnologie. Verhandlungen IVTLAP, Vol. 24, No. 1, p 68-72, September 1990.

Kipkemboi, J.; Kansiime, F.; Denny, P.* The response of Cyperus papyrus (L.) and Miscanthidium violaceum (K. Schum.) Robyns to eutrophication in natural wetlands of Lake Victoria, Uganda. African Journal of Aquatic Science; Afr. J. Aquat. Sci., vol. 27, no. 1, pp. 11-20; 2002.

Lehman, J.T. Comparison of phosphorus concentration and turnover rates in lakes Erie, Huron, and Michigan with those of the East African Great Lake Victoria. PROCEEDINGS OF THE 38TH CONFERENCE OF THE INTERNATIONAL ASSOCIATION OF GREAT LAKES RESEARCH.; INTERNATIONAL ASSOCIATION FOR GREAT LAKES RESEARCH; 2200 BONISTEEL BOULEVARD, ANN ARBOR, MI 48109-2099 (USA); p. 54; 1995.

Lehman, J.T.; Branstrator, D.K. Nutrient dynamics and turnover rates of phosphate and sulfate in Lake Victoria, East Africa. Limnology and Oceanography, vol. 39, no. 2, pp. 227-233; 1994.

Lindenschmidt, K.-E.; Suhr, M.; Magumba, M.K.; Hecky, R.E.; Bugenyi, F.W.B. Loading of solute and suspended solids from rural catchment areas flowing into Lake Victoria in Uganda. Water Research [Water Res.], vol. 32, no. 9, pp. 2776-2786; 1998.

Liti, D.; Kallqvist, T.; Lien, L. Norsk Inst. for Vannforskning Limnological Aspects of Lake Turkana, Kenya Internationale Vereinigung fuer Theoretische und Angewandte Limnologie. Verhandlungen IVTLAP, Vol. 24, No. 2, p 1108-1111, March 1991.
Lung'ayia, H.; Sitoki, L.; Kenyanya, M. The nutrient enrichment of Lake Victoria (Kenyan waters) Hydrobiologia, vol. 458, no. 1-3, pp. 75-82; 2001
Lung'ayia, H.; Sitoki, L.; Kenyanya, M. The nutrient enrichment of Lake Victoria (Kenyan waters) Hydrobiologia, vol. 458, no. 1-3, pp. 75-82; 2001.
Masifwa, W.F.; Twongo, T.; Denny, P.* The impact of water hyacinth, Eichhornia crassipes (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. Hydrobiologia, vol. 452, no. 1-3, pp. 79-88; 2001.
Muli, J.R. Environmental problems of Lake Victoria (East Africa): What the international community can do. Lakes and Reservoirs: Research and Management, vol. 2, no. 1-2, pp. 47-53; 1996.
Ntiba, M.J.; Kudoja, W.M.; Mukasa, C.T. Management issues in the Lake Victoria watershed. Lakes and Reservoirs: Research and Management, vol. 6, no. 3, pp. 211-216; 2001
Nyirabu, C.M. Lake Victoria in East Africa. Stockholm International Water Institute. Report, no. 2; With Rivers to the Sea: Interaction of Land Activities, Fresh Water and Enclosed Coastal Seas; SIWI; 1998.
Ochumba, P.B.O. Kenya Marine and Fisheries Research Inst. Massive Fish Kills Within the Nyanza Gulf of Lake Victoria, Kenya Hydrobiologia HYDRB8, Vol. 208, No. 1/2, p 93-99, December 1990.
Ochumba, P.B.O.; Kibaara, D.I. Kenya Marine and Fisheries Research Inst. Observations on Blue-green Algal Blooms in the Open Waters of Lake Victoria, Kenya African Journal of Ecology AFOEDE, Vol. 27, No. 1, p 23-34, 1989.
Ogutu-Ohwayo, R.; Balirwa, J.S.; Hecky, R.E.; Mugidde, R. Evolution of fish populations in Lake Victoria (East Africa) in relation to environmental pressures. Abstracts from the 44th Conference on Great Lakes Research, June 10-14, 2001. Great Lakes Science: Making it Relevant; International Association for Great Lakes Research; 2205 Commonwealth Boulevard Ann Arbor MI 48105 USA; pp. 101-102; 2001.
Scheren, P.; Zanting, H.; Lemmens, A.* Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. Journal of Environmental Management [J. Environ. Manage.], vol. 58, no. 4, pp. 235-248; 2000.
Seehausen, O.; Witte, F.; Katunzi, E.F.; Smits, J.; Bouton, N. Patterns of the remnant cichlid fauna in southern Lake Victoria. Conservation Biology, vol. 11, no. 4, pp. 890-904; 1997.
Talbot, M.R.; Laerdal, T. The Late Pleistocene - Holocene palaeolimnology of Lake Victoria, East Africa, based upon elemental and isotopic analyses of sedimentary organic matter. Journal of Paleolimnology [J. Paleolimnol.], vol. 23, no. 2, pp. 141-164; 2000.
Verschuren, D.; Edgington, D.N.; Kling, H.J.; Johnson, T.C. Silica depletion in Lake Victoria: Sedimentary signals at offshore stations. Journal of Great Lakes Research, vol. 24, no. 1, pp. 118-130; 1998.

2.3. Cockle fisheries in the Waddensea

Description:

Cockle fishing in the Dutch Waddensea has been practised since 1960. The technique used nowadays for fishing is called suction dredging. This technique lifts cockles and sediments up, after which the cockles are separated from the sediment and the sediment is returned to the sea. This leads to a loss of silt from the sediment, leaving behing only the coarse sediment particles. During recent years, the number of cockles has decreased strongly, leading to questions about the damage that cockle fishing does to the sea bottom and the sustainability of this fishing method. Make a model that investigates the interaction between fishing, sediment and cockles and formulate an advice on the management of the Waddensea fisheries.

Some references:

Coosen, J.; Twisk, F.; van der Tol, M.W.M.; Lambeck, R.H.D.; van Stralen, M.R.; Meire, P.M.; Nienhuis, P.H.; Smaal, A.C. (eds.) Variability in stock assessment of cockles (Cerastoderma edule L.) in the Oosterschelde (in 1980-1990), in relation to environmental factors. Hydrobiologia, vol. 282-283; THE OOSTERSCHELDE ESTUARY (THE NETHERLANDS): A CASE-STUDY OF A CHANGING ECOSYSTEM.; pp. 381-395; 1994.
de Jonge, V.N.; de Jonge, D.J. Rijkswaterstaat Role of Tide, Light and Fisheries in the Decline of Zostera marina L. in the Dutch Wadden Sea Netherlands Journal of Sea Research NJSRBA, Vol. S20, p 161-176, 1992.
De Jonge, V.N.; McComb, A.J. (ed.) The Ems Estuary, The Netherlands. EUTROPHIC SHALLOW ESTUARIES AND LAGOONS.; CRC PRESS; BOCA RATON, FL (USA); pp. 81-107; 1995.

De Jonge, V.N.; Van Raaphorst, W.; McComb, A.J. (ed.) Eutrophication of the Dutch Wadden Sea (western Europe), an estuarine area controlled by the River Rhine. EUTROPHIC SHALLOW ESTUARIES AND LAGOONS.; CRC PRESS; BOCA RATON, FL (USA); pp. 129-149; 1995.

Herman, P.M.J.; Nienhuis, P.H.; Smaal, A.C. (eds.) Theme 6: The analysis of a dynamic simulation model for the Oosterschelde ecosystem -- a summary. Hydrobiologia, vol. 282-283; THE OOSTERSCHELDE ESTUARY (THE NETHERLANDS): A CASE-STUDY OF A CHANGING ECOSYSTEM.; pp. 431-436; 1994.

Nienhuis, P.H.; Smaal, A.C.; Knoester, M.; Nienhuis, P.H.; Smaal, A.C. (eds.) The Oosterschelde Estuary: An evaluation of changes at the ecosystem level induced by civil-engineering works. Hydrobiologia, vol. 282-283; THE OOSTERSCHELDE ESTUARY (THE NETHERLANDS): A CASE-STUDY OF A CHANGING ECOSYSTEM.; pp. 575-592; 1994.

Piersma, T.; Koolhaas, A.; Dekinga, A.; Beukema, J.J.; Dekker, R.; Essink, K. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. Journal of Applied Ecology; J. Appl. Ecol., vol. 38, no. 5, pp. 976-990; 2001.

Van Dijk, H.W.J.; Elliott, M.; Ducrotoy, J.-P. (eds.) Integrated management and conservation of Dutch coastal areas: Premises, practice and solutions. Marine Pollution Bulletin, vol. 29, no. 6-12; PROCEEDINGS OF ENS (ENVIRONMENT NORTH SEAS)'93 CONFERENCE HELD IN STAVANGER, 24-27 AUGUST 1993.; pp. 609-616.

2.4. The Jinja constructed wetlands

Description:

Constructed wetlands can be used for the treatment of wastewater. This may be an attractive alternative to other, more expensive technologies for wastewater treatment. In constructed wetlands, aquatic plants like Phragmites sp. or Cyperus sp. absorb nutrients. The nutrients are removed from the system by harvesting the plants. For designing such a system, the size of the wetland in relation to the hydraulic loading rates, the concentration of pollutants and the harvesting rate have to be taken into account. The general objective of a model of the constructed wetland plant is to optimise nutrient removal.

Some references:

Ayaz, S.C.; Akca, I.; Wilderer, P.A.; Deininger, A. (eds.) Treatment of wastewater by constructed wetland in small settlements. Water Science and Technology, vol. 41, no. 1; Elsevier Science Ltd., Pergamon; P.O. Box 800 Kidlington Oxford OX5 1DX UK; pp. 69-72; 2000.

Ayaz, S.C.; Akca, L. Treatment of wastewater by natural systems. Environment International; Environ. Int., vol. 26, no. 3, pp. 189-195; 2001.

Greenway, M.; Haberl, R.; Perfler, R.; Laber, J.; Cooper, P. (eds.) Nutrient content of wetland plants in constructed wetlands receiving municipal effluent in tropical Australia. Water Science and Technology, vol. 35, no. 5; WETLAND SYSTEMS FOR WATER POLLUTION CONTROL 1996.; pp. 135-142.

Greenway, M.; Woolley, A.; Tanner, C.D.; Raisin, G.; Ho, G.; Mitsch, W.J. (eds.) Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation. Ecological Engineering, vol. 12, no. 1-2; Elsevier Science B.V.; P.O. Box 211; pp. 39-55; 1999.

Kantawanichkul, S.; Neamkam, P.; Shutes, R.B.E.; Kadlec, R.H.; Reddy, K.R. Nitrogen removal in a combined system: vertical vegetated bed over horizontal flow sand bed. Water Science and Technology, vol. 44, no. 11-12; Wetland Systems for Water Pollution Control 2000; Elsevier Science Ltd., Pergamon; P.O. Box 800 Kidlington Oxford OX5 1DX UK; pp. 137-142; 2001.

Kantawanichkul, S.; Pilaila, S.; Tanapiyawanich, W.; Tikampornpittaya, W.; Kamkrua, S.; Cooper, P. (ed.) Wastewater treatment by tropical plants in vertical-flow constructed wetlands. Water Science and Technology, vol. 40, no. 3; Elsevier Science Ltd., Pergamon; P.O. Box 800; pp. 173-178; 1999

Nyakang'o, J.B.; Van Bruggen, J.J.A.; Cooper, P. (ed.) Combination of a well functioning constructed wetland with a pleasing landscape design in Nairobi, Kenya. Water Science and Technology, vol. 40, no. 3; Elsevier Science Ltd., Pergamon; P.O. Box 800; pp. 249-256; 1999.

Okurut, (proefschrift)

Tanner, C.C. Plants for constructed wetland treatment systems -- a comparison of the growth and nutrient uptake of eight emergent species. Ecological Engineering, vol. 7, no. 1, pp. 59-83; 1996.

2.5. The Zeeland seagrass fields

Description:

Traditionally, seagrass fields were a chracteristic component of Dutch nearshore ecosystems. However, during the past years the seagrass beds have been declining dramatically. The production of seagrass depends, among other things, on light for photosynthesis, on nutrients and on grazing, e.g. by geese. To prevent further deterioration, the question is what is the most important cause of the seagrass decline and which measures may be taken to effectively counter the process. This can be done with a model that includes the balance of growth and mortality of seagrasses, and the effects of losses due to grazing.

Some references:

Cambridge, M.L.; Chiffings, A.W.; Brittan, C.; Moore, L.; McComb, A.J. Western Australia Univ. Loss of Seagrass in Cockburn Sound, Western Australia: II. Possible Causes of Seagrass Decline Aquatic Botany AQBODS, Vol. 24, No. 3, p 269-285, June 1986.

Carter, V.; Paschal, J.E.; Bartow, N. Geological Survey Distribution and Abundance of Submersed Aquatic Vegetation in the Tidal Potomac River and Estuary, Maryland and Virginia Available from Dist Branch; USGS 604 S. Pickett St. Alexandria, VA 22034. USGS Water-Supply Paper 2234-A, 1985.

Hootsmans, M.J.M.; Vermaat, J.E.; Beijer, J.A.J. Agricultural Univ. Periphyton Density and Shading in Relation to Tidal Depth and Fiddler Crab Activity in Intertidal Seagrass Beds of the Banc d'Arguin (Mauritania) Hydrobiologia HYDRB8, Vol. 258, p 73-80, May 14, 1993.

Ruiz, J.M.; Perez, M.; Romero, J. Effects of Fish Farm Loadings on Seagrass (Posidonia oceanica) Distribution, Growth and Photosynthesis. Marine Pollution Bulletin; Mar. Pollut. Bull., vol. 42, no. 9, pp. 749-760; 2001.

Sfriso, A.; Marcomini, A. Macrophyte production in a shallow coastal lagoon. Part I: Coupling with chemico-physical parameters and nutrient concentrations in waters. Marine Environmental Research, vol. 44, no. 4, pp. 351-375; 1997.

Vermaat, J.E.; Verhagen, F.C.A. Seasonal variation in the intertidal seagrass Zostera noltii Hornem: Coupling demographic and physiological patterns. Aquatic Botany, vol. 52, no. 4, pp. 259-281; 1996.

Wetzel, R.L.; Neckles, H.A. Virginia Inst. of Marine Science Model of Zostera marina L. Photosynthesis and Growth: Simulated Effects of Selected Physical-Chemical Variables and Biological Interactions Aquatic Botany AQBODS, Vol. 26, No. 3/4, p 307-323, December 1986.