Wetlands: Most relevant structural and functional aspects

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ABSTRACT

Although sometimes considered only as transition zones between aquatic and terrestrial environments, wetlands actually are true ecosystems, holding very peculiar attributes. The study of wetlands has become more pertinent as, all over the world, conflicting economic and scientific interests very often lead to wetland draining. Water, substrate, and the biota are the most important factors to consider for wetland characterization. Therefore, these determine the criteria for wetland identification. Emphasis is made on the ecological functions of wetlands. The validity of constructed wetlands is discussed.

Key words: wetlands, hydrology, wetland restoration

RESUMEN

Aunque a veces se los considera erroneamente zonas de transición entre los ecosistemas terrestres y los ecosistemas acuáticos, los humedales son en realidad verdaderos ecosistemas de características muy particulares. El estudio de los humedales se hace más pertinente al generalizarse los conflictos entre interéses económicos y científicos que conducen en muchos casos a su desecación. El agua, el substrato y la biota son los factores más importantes para la caracterización de los humedales, y, además, proporcionan los critérios para su caracterización como ecosistemas. En este trabajo se hace énfasis en las funciones ecológicas de los humedales, especialmente los asociados con la eutrofización. Finalmente, se discute la validez de la construcción y la recuperación de humedales.

Palabras clave: humedales, hidrología, restauración de humedales

INTRODUCTION

This paper is intended to bring attention to the paramount importance of wetlands and their ecological role. All over the world human populations have been "modernizing" their life styles at the expenses of sacrificing the environment. Wetlands were systematically destroyed for decades, when man faced these ecosystems only as generators of discomfort (humidity, mosquitoes) and as land unsuitable for agriculture. Therefore in most "civilized" countries wetlands were drained and transformed into terrestrial landscape, usually to increase the already large agricultural areas.

After the pioneer times, when wetland draining was the general practice, wetlands were viewed as habitat sites for wildlife: Especially those animals men liked to hunt or fish. The scientific community reflected this attitude to some degree, and relatively recent publications were still oriented towards the study of waterfowl (Lokemoen, 1973; Mack & Flake, 1980). Following this phase, scientists focused attention on the importance of wetlands as ecosystems and the need for wetland

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conservation to protect species and maintain biodiversity (*e.g.* Gibbs, 1993). Full ecological role of wetlands has become the objective of intensive research nowadays.

In Portugal there are no records of how much land was claimed to wetlands in the past to be transformed into agricultural fields. However, at present and according to the preliminary inventory of the Portuguese wetlands (Farinha & Trindade, 1994) a total of 130,943 ha, corresponding to 1.5 % of continental Portugal, is constituted of wetlands. This inventory is being reviewed and total wetland area has become smaller (author's personal observation).

DEFINITION, CARACTERIZATION AND IDENTIFICATION

In 1971 took place in Ramsar (Iran) *The Convention on Wetlands of International Importance especially as Waterfowl Habitat*. A document emerged, abbreviatedly known as the Ramsar Convention. This is an intergovernmental treaty calling for international cooperation for the conservation of wetlands. The Ramsar Convention defined wetlands as any areas of swamp, pond, peat, or water, natural or artificial, permanent or temporary, stagnant or flowing water, including estuaries and marine waters down to 6 meters below the low tide mark. The definition was sufficiently comprehensive to be accepted by a number of countries adhering later to the Convention. Portugal ratified the Ramsar Convention in 1980. The number of Contracting Parties (the countries that have signed it) amounts to about 100 worldwide. Signataries of the Convention meet every three years, so that definition and purposes are reviewed and updated to accommodate scientific progress.

Wetlands are ecosystems that depend on shallow inundation (or saturation at or near the surface) of the substrate. Inundation/saturation may be constant or recurrent. Minimum requisites for an ecosystem to be classified as a wetland are sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation (Committee on Characterization of Wetlands, 1995). Hydric soils and hydrophytic vegetation constitute the most frequently utilized characteristics for identification of wetlands.

The states of the factors water, substrate, and biota determine the criteria for identification of wetlands. Hence, (1) the hydrologic criterion, referring to a sustainable inundation or saturation, (2) the substrate criterion, *i.e.* the physical and chemical conditions of the substrate reflecting sustained saturation, and (3) the biologic criterion, referring to the presence of species particularly adapted to the sustained flooding or saturation condition of the substrate, will be summarily described below.

Water constitutes a special attribute, because both the substrate typical of wetlands and the biota characteristic of these ecosystems can be present only if the hydrologic conditions are met, *i.e.* when there is sustained inundation or saturation of the substrate. Inundation or saturation will have to persist over time.

Disturbances affecting the biota or the soil of a wetland may have as a result the temporary absence of the organisms or even the substrate characteristic of wetlands. On the contrary, when hydrologic properties are discontinued the wetland will disappear, even when the substrate characteristics and the typical species persist for some time. Thus, when hydrologic conditions change, the presence of typical biota and substrate in itself does not constitute a safe indication that the system is a wetland.

Water

There are specific hydrologic conditions which constitute *sine qua non* conditions for the development and sustainability of wetland ecosystems. To study the hydrology it is necessary to gather information on at least three elements: The duration of the inundation or saturation with respect to the growing season; the critical depth for saturation; and the frequency of that inundation or saturation. Saturation must last at least 15 days during the growing season in most years. Minimum saturation depth corresponds to the upper layer of the majority of plant roots, which is roughly 30 cm. The depth of the phreatic table is a direct indicator of the saturation depth (Committee on Characterization of Wetlands, 1995).

Substrate

Most wetlands are characterized by the existence of the so called hydric soils. These are associated to physical and chemical indicators of long standing, recurrent saturation. One of those indicators is cessation of oxygen transportation by interstitial water in the substrate. Permanent lack of oxygen in those saturated soils is caused by roots and associated microbia and other soil organisms. All of them take up oxygen and the diffusion of this gas in water is extremely slow as well. Therefore in most cases there is no oxygen replacement, the loss will be permanent. As a consequence, reduced compounds will accumulate to large quantities. Hydric soils are therefore characterized by lack of oxygen and very low redox potentials during saturation, which in turn leads to alteration of color of the soil. Many terrestrial plants can not tolerate conditions such as these, and will not survive the environmental conditions associated to the lack of oxygen (Committee on Characterization of Wetlands, 1995).

Vegetation

All countries should have a plant list designated "National List of the Plant Species that Occur in Wetlands", known by the abbreviation "Hydrophytes List". This document would allow decision on whether one is in presence of vegetation typical of wetlands. As a practical rule there is a frequently utilized criterion – the dominance measure, or 50 % rule: A given plant community is typical of wetlands when more than 50 % of the dominant taxa are hydrophytic (Committee on Characterization of Wetlands, 1995).

Wetland delineation

Recently, the primary indicators method (PRIMET) was devised with the purpose of helping to accurately define the limits of wetlands throughout the United States territory (Tiner, 1993). This method is based on the premise that every wetland in its natural undrained condition possesses at least one unique and distinctive feature that distinguishes it from the adjacent upland. The unique characteristics of vegetation and soil are used for wetland identification and delineation. In the words of the author, "PRIMET is not intended to diminish the need for phytosociological studies of wetlands or detailed descriptions of hydric soils, but simply seeks to produce accurate, consistent, and reproducible wetland delineations with minimal effort". Tiner believes that the concept should be adaptable worldwide.

Most often wetlands are at boundaries between terrestrial and aquatic ecosystems. This is true for all coastal wetlands as well as for many freshwater wetlands, which constitute transition zones between the terrestrial environment and streams or lakes. Emphasis should be given to the fact that, although so located, these wetlands are ecosystems in themselves.

Other transition zones, also adjacent to streams, although having certain attributes of wetlands *e.g.* flooding and some phytosociological properties, can not be classified as wetlands. Because these do not fulfill all the conditions required to be a wetland: The fundamental criterion for identification of a wetland is its hydrology, the area must be recurrently flooded for at least as many as 15 days during the growing season on repeated years.

The above mentioned transition zones are designated riparian zones (Committee on Characterization of Wetlands, 1995). Their importance is extraordinary: Despite their different hydrologic regime, riparian zones perform many ecological functions of wetlands. Examples are conservation of biodiversity, prevention of flood damage to river ecosystem communities, habitat for waterfowl, among others.

ECOLOGICAL FUNCTIONS OF WETLANDS

In wetlands certain ecological functions are naturally intensified which contribute in large scale to improvement of the (ecological) quality of adjacent ecosystems, in particular the aquatic ones. In the following paragraphs attention will be driven to the most important of those functional aspects, yet with no particular presumption for establishing an order of importance.

Among the most conspicuous functions of wetlands is protection of adjacent land/water ecosystems during storm flooding events. The wetland helps smoothing of the flooding hazardous effects and permits avoidance of undesirable consequences such as human injury (at times catastrophic) and material damage. This is sometimes called flood abatement.

Another aspect related to flooding is the prevalent gradient in the frequency of inundation occurring within a wetland or a group of similar wetland types. This, synergistically with the frequently observed continuum of flooding depth, generates landscape- and resource-based transitions which will affect the whole functioning of the wetland along environmental gradients (Brinson, 1993).

A usually intense process occurring in wetlands is denitrification (NO_3, NO_2, N_2). The product, molecular nitrogen, is rapidly volatilized to the atmosphere, therefore denitrification is a process of nitrogen removal from the ecosystem. While still in the water, molecular nitrogen may be taken up by cyanobacteria, thus making the link inorganic–organic. However, this uptake by producers is much less important, quantitatively, than volatilization into de air.

Retention of nutrients in the sediments constitutes a very important ecological function of wetlands. The first stages of sediment deposition are not important, since surficial sediments are subjected to disturbances, bringing previously settled materials back to the water. Just like in lakes, materials concealed in the deep sediments (say, below 20 cm into the substrate) are those considered out of circulation in the biota for a long time.

Walbridge and Lockaby (1994) measured significant annual carbon exports from forested wetlands, accomplished through biological processes such as microbial immobilization. The same authors in the same paper mention transformation of appreciable quantities of inorganic nitrogen and phosphorus to organic forms subsequently exported downstream.

Wetlands are extremely important in the processing of organic matter (Wetzel, 1992). Although being depositional zones by excellence, wetlands functioning as organic matter deposit and further processor will ultimately depend on hydrology. This dependence will in turn influence the rates of decomposition. However, in most wetlands of the world the slope gradients are very modest, rendering surface hydrological flows very diffuse – hence water from precipitation events tends to migrate slowly over and through decaying organic matter rather than physically transporting the particles (Wetzel, 1992). Therefore, exportation of organic matter from the wetland is largely as dissolved organic matter.

Among organisms inhabiting wetlands, aquatic macrophytes, and specially their associated microbial communities, exert a particularly relevant role in organic matter decomposition and nutrients cycling. According to Wetzel and SØndergaard (1998) submerged macrophyte communities, and the attached microflora, are fundamental in structuring microbial metabolism and biogeochemical cycling at the ecosystem level of organization.

With no doubt the long appreciated function of wetlands as place for nesting and preferential habitat for waterfowl is one of the most important ecological functions of these ecosystems. Although relevant for sedentary waterfowl, wetlands are absolutely essential for migratory aquatic birds.

The peculiar conditions of the substrate, with permanent or almost permanent anoxia, allow for the development of plant species unique of wetland environments. This generates very typical phytosociological associations, distinctive of wetlands as well. Preservation of this type of plants and plant associations in wetlands will contribute to the maintenance of biodiversity.

THE VALUE OF WETLANDS

Unlike in past decades, at the present time there is a general acceptance by the society of the usefulness of wetlands. People are starting to understand the ecological role of wetlands as a unique type of ecosystem. Perhaps the most striking feature for the public in general is how the processes occurring in wetlands contribute to improve water quality of adjacent rivers and lakes. Society recognizes the value of wetlands as people understand the utility of these ecosystems in improving their own quality of life.

It is difficult, however, to establish an actual price for wetlands. Ecological value is not susceptible to pricing. When economic (or industrial) interests confront scientific interest, the match is never fair. On one side economists place a monetary value per square meter of wetland, on the other side scientists can not determine a price for the (actually beyond estimation) ecological functions of wetlands.

This is the reason why there are problems to implement conservation of wetlands. The *value* of the object of negotiation is different for each group, industrialists and scientists. While the former would like to eradicate wetlands to plant *e.g.* monocultures of trees for the wood industry because they want the sales profit, the latter see in the wetland, and above all, its ecological functions – regulation of the hydrologic cycle, the role in the biogeochemical cycling of nutrients, habitat for waterfowl and other animals. Obviously scientists are in a disadvantageous position when it comes to those polemics. In a market where one side is able to establish a monetary value and the other side is not, there is no sense in negotiating.

Ecological functions of wetlands ought to be considered as a peoples' right. Such as it is progressively being accepted by society that the peoples are entitled to their own sources of good quality water, those same peoples will soon start claiming the conservation of wetlands. The Portuguese government, as well as the governments of all other countries subscribing the Ramsar Convention, publicly committed to preserving the wetlands located in the respective territories.

CONSTRUCTED WETLANDS

One of the first concerns respecting wetland creation is their future location on the landscape. This location will have to be determined according to the purpose for which the wetland is constructed. One of the basic concepts of landscape ecology is that the relative location of ecosystem components will influence the functioning of the ecosystem (Greiner & Hershner, 1998). Likewise, if this notion is transposed to a level of organization higher than the ecosystem, it will still be applicable: The manner in which ecosystems are distributed in space will affect the mode of functioning of those ecosystems.

Usually, the objective to reach with the construction of a wetland is improvement of water quality of an aquatic system, a river or a lake. When the goal is to improve water quality of a river the wetland should, for a better achievement, be constructed at a high altitude in the watershed, while the best results with lake water quality improvement are reached when the wetland is constructed at a low altitude in the watershed (Greiner & Hershner, 1998). Often water quality is improved in freshwater systems through reduction of nitrogen and phosphorus inputs. These and other nutrients will have to be retained in the wetland before reaching the river or lake which water quality is to be improved. In this context, it is important to know the nutrients load, and that this will be dependent on land-use in the watershed: For the same surface area, a much larger load will be expected from agricultural fields than from forested land. Retention in wetlands is the main process. Therefore, retention will apply not only to nutrients but also to pollutants originated in industry, which will be prevented from reaching river or lake waters through retention in the wetland as well.

Another priority to consider is the area of the constructed wetland. Hydrogeomorphic assessment can be used to determine the minimum area the wetland should cover to achieve an objective of no net loss in any wetland function (Rheinhardt *et al.*, 1997). This method was devised for situations of restoration of wetland areas altered by (industrial or other) project impacts.

Vegetation to plant in the constructed wetland is extremely important. Also in this aspect constructed wetlands will have to "mimic" natural ecosystems. The principal resemblance will be that in the wetland there must be a variety of macrophytes, not monocultures. Furthermore, it has been found (Templer *et al.*, 1998) that native plant species, when it comes to reconstruction of a wetland, will have ecologically significant better effects on nutrient cycling as compared to non-native vegetation.

Vegetation can be so well adapted to wetland environments that will perform better in anoxic conditions than in situations where oxygen is available: Spencer and Ksander (1997) found that vegetative propagules of submersed aquatic macrophytes sprouted sooner in anoxia than those exposed to an aerobic atmosphere; in the experiment, *Potamogeton* propagules buried deep in the sediments, where redox potential was low and conditions of anoxia prevailed, sprouted more rapidly than those propagules buried closer to the surface, where environmental conditions were supposedly better.

Because ecosystems are similar only in general terms, and because individual peculiarities may affect their overall functioning, construction of wetlands must not follow the same pattern for different locations. Each case will have to be studied independently. In spite of that, and because results in the future will depend on past success and failure, it is recommended (McKinstry & Anderson, 1994) that accurate records be kept of wetlands creation and restoration projects.

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