

# 1 Wetland Functioning in Relation to Biodiversity Conservation and Restoration

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## 1.1 Introduction

Wetland ecosystems are a natural resource of global significance. Historically, their high level of plant and animal (especially bird) diversity is perhaps the major reason why wetland protection has become a high priority worldwide, supported by international agreements such as the Ramsar Convention and the International Convention of Biological Diversity. More recently, a number of goods and services provided specifically by wetland ecosystems have been identified that may even outweigh biodiversity in terms of their importance for human welfare and sustainable natural resource management worldwide. Wetlands, as transitional zones between land and water, provide a natural protection against extreme floods and storm surges. They may also store freshwater to be used for drinking water preparation or for irrigation. Wetlands bordering streams, rivers and lakes have a water quality enhancement function that is increasingly recognized. Because riverine and lacustrine wetlands often provide a spawning habitat, their importance as a source of juvenile fish for adjacent aquatic ecosystems should not be underestimated. In addition to these local and regional benefits, wetlands as a global resource provide a net sink of carbon dioxide. The world's peatlands are the only type of terrestrial ecosystem with a long-term net carbon storage function. However, the large amounts of carbon that have accumulated historically in peatlands may be released as a result of degradation, such as drainage, excavation, or fertilization.

Wetlands do produce a striking variety of goods and services and it is no wonder that, more often than any other terrestrial ecosystem, they are used by environmental economists to illustrate ecosystem functions and their values to mankind. However, in spite of the high biodiversity and the high impor-

tance of the goods and services of wetland ecosystems, their global status is poor and, in many situations, they are degrading at ever faster rates as a result of a wide variety of human impacts. Many wetlands, particularly river floodplains, deltas and estuaries, are especially impacted by human activities. Early civilizations have been successful particularly because of their utilization of wetland resources. Where agriculture has thrived, the natural fertility of the soils and transport has been favored by river channels and associated wetlands. In the industrial era, human impacts have become dramatically negative as a result of floodplain reclamation, poldering, construction of flood control structures, drainage for agriculture, excavation of peat for fuel and the modification and straightening of river channels in favor of navigation. Worldwide, more than 50 % of the wetland resource has been lost because of these reasons. In some densely populated regions in Europe, North America and East Asia, more than 80 % of the wetlands have been lost or severely degraded. This clearly stresses the urgent need to restore or (re)create wetlands ecosystems.

This volume presents an integrated account from several of the major symposia presented at the 7th INTECOL International Wetlands Conference (Utrecht, The Netherlands). In this introductory chapter, we will give an overview of recent advances in the comprehension of how plants and animal function in wetlands, the biodiversity conservation of wetland ecosystems and their ecological restoration. We will also identify remaining gaps in scientific knowledge and understanding that need to be addressed to optimize biodiversity conservation and restoration of wetlands across the globe.

## 1.2 Functioning of Plants and Animals in Wetlands

Plant species inhabiting wetlands possess physiological and morphological adaptations that support long-term survival of flooding, even sometimes with remarkably high plant productivity (e.g. Mitsch and Gosselink 2000; Larcher 2003). The most widespread physiological adaptation to tolerate short-term anoxia is the ability to switch to fermentation as the main pathway for extracting energy. This takes place in combination with energy conservation measures derived from a complex down-regulation of non-essential energy-consuming processes. Furthermore, wetland species may have developed mechanisms to tolerate the toxic end-products of fermentation, especially by diversification of end-products or production of less toxic compounds (malate). The most important strategy of wetland plants against anoxic conditions is, however, the presence of air spaces (aerenchyma) in roots and stems, allowing oxygen diffusion from the aerial plant parts to the roots. In non-wetland species root porosity is rather low (2–7 %), whereas wetland species have much higher root porosities (on average 20–50 %). This internal

pathway may sustain internal aerobic conditions across the root, even reaching the root tips. Well aerated roots of many wetland species may even release oxygen to the surrounding soil, forming an oxidized rhizosphere. This is an important mechanism to detoxify harmful soluble reduced ions such as manganese and sulfide. Red-brown deposits ( $\text{Fe}^{3+}$  oxides) around roots of wetland species are a clear indication of this phenomenon. Another morphological adaptation to waterlogged conditions is the formation of adventitious roots just above the anoxic zone of the soil, thus functioning in a more or less aerobic situation. This is especially triggered by increased ethylene concentrations after inundation in both wetland and terrestrial species.

Escape-mediated plant survival in wet environments is described by Jackson (Chapter 2). It is shown that the shoots of several plant species possess a means of escaping submergence through prompt, gravity-directed upward extension growth. The growth is usually  $\text{O}_2$ -dependent and mostly entrapped ethylene is the triggering signal. This gas initiates and sustains an abnormally fast rate of shoot elongation underwater. A rapid decrease in the growth-inhibiting hormone abscisic acid, mediated by ethylene, is often a pre-requisite for the escape to start. Thus, there is an increased probability of shoots regaining contact with the atmosphere before reserves become exhausted. This mechanism may especially be of importance for survival in ecosystems with unpredictable periods of complete submergence of the vegetation. In this situation, the ability to have some underwater photosynthesis may be of importance for the survival of normally non-aquatic plant species. In addition, it has been found that the shoots of certain species that over-winter as dormant tubers, rhizomes or turions are stimulated to elongate very rapidly, even under the complete absence of  $\text{O}_2$ . In contrast, some species have evolved suppression of this fast shoot extension, resulting in an underwater quiescence that may confer an advantage for survival where the prevailing water depth is too great for escape.

The crucial role of macrophytes in regulating trophic interactions in shallow lakes is clearly demonstrated by Burks et al. (Chapter 3). They define shallow lakes as permanently flooded wetlands that may be surrounded by emergent vegetation (i.e. marshy habitat). Water depth is typically less than 3 m. Studies on the role of trophic interactions with submerged plants in shallow lakes are not novel, but the study of other growth forms of macrophytes (i.e. floating-leaved, emergent, freely-floating) is an expanding field of research. Four key issues can be identified in this context. Firstly, zooplankton (and planktivorous fish) depend on macrophytes as habitat refuge, although the role of emergent vegetation is still unclear. Second, biochemical interactions ("allelopathy") between macrophytes and competing primary producers can be of major importance for the structure of the plant community; and the deterrent chemical nature of some aquatic plants may even strongly influence the biological community. Furthermore, macrophytes form a substrate for epiphyton. In eutrophic to hypertrophic lakes, a negative relationship exists

between macrophyte biomass and epiphyton growth. However, the density of epiphyton, in turn, depends on the amount of grazing macroinvertebrates (e.g. snails), but not on nutrients. These grazers may help maintain littoral communities by continuously removing unwanted algae or sediments. Finally, the interaction between macrophytes and fish can be of major importance for the functioning of shallow lakes, but the complexity of these interactions is large and, in many situations, not known. It is suggested that the presence of aquatic macrophytes is a driving force for interactions within the rest of the food web, and thus determines which trophic interactions play a role in shifts between alternative shallow lake states.

The structure and functioning of wetlands can be (strongly) influenced by vertebrate herbivory, as recently reviewed by Van den Wyngaert and Bobbink (2006). The most important large herbivores of wetland ecosystems are several species of rodents and waterfowl, though the latter are mostly restricted to wetlands where open water is also present. The effects of wetland herbivores, which use above-ground plant parts, are in general more or less comparable with those found in terrestrial ecosystems. Two typical differences are distinguished between the effects of vertebrate herbivory in wetlands compared with those in terrestrial systems.

First, herbivory of leaves and shoots does not severely restrict annual above-ground plant production in wetland ecosystems, as long as there is oxygen transport to the below-ground storage organs. Damage to the shoots of emergent macrophytes below water level by foraging herbivores is in most cases lethal and strongly reduces above-ground plant production. In this way, the structure of the plant community can be strongly affected despite the removal of only a small part of the biomass.

Second, the consequences of grubbing and consumption of below-ground storage organs by natural herbivores in wetlands with their wet and soft soils can be obvious. Grubbing for below-ground storage organs can severely disturb the vegetation; and, when the regeneration time is long, grubbed vegetation is much more sensitive to increasing grazing pressure. Increased grubbing may lead to denudation rather than replacement of the plant species by a less palatable one (Fig. 1.1). The affected wetland ecosystems may evolve to a "low steady state" or, if grazing pressure is above carrying capacity, can become completely deteriorated.

It is clear that the effects of herbivores can be of major importance to the structure and dynamics of various wetlands, although their nutrient cycling is considered to be detritus-based. In contrast, herbivory of aquatic macrophytes is, in general, of minor importance in shallow lake ecosystems, although large invertebrate grazers (especially crayfish) affect the macrophyte cover in a few cases (Chapter 3).

Interest in biological invasions has rapidly increased in recent decades and today they are a major concern in ecology and conservation. Particularly dramatic consequences of invasions have been observed on island ecosystems



**Fig. 1.1** Grubbing of Canadian subarctic salt marsh by lesser snow geese (*Anser caerulescens caerulescens*) has created bare soil, where an increase in salinity inhibits revegetation (photo kindly made available by Peter Kotanen)

where endemic species suffered severely, but wetlands (marshes, lakes, rivers) and estuaries are also among the most affected systems. The nature and impacts of invasions in these ecosystems are described in detail by Van der Velde et al. in Chapter 4. Human-mediated dispersal of transport of species is nowadays clearly much higher than natural dispersal in historical periods. The number of introduced species is related to the number of introduction events and to the number of individuals per event. Freshwater, estuarine and coastal wetlands are amongst the most invaded systems worldwide, because of the numerous introduction vectors and activities that facilitate invasions in these environments. Impacts of invasions may occur at all levels of ecological organization and are especially severe when the introduced species function as an ecosystem engineer (e.g. Crooks 2002). In addition, Van der Velde et al. give an overview of approaches that are used to understand and predict biological invasions. They clearly show that the relational key-lock approach is most promising, because it integrates the importance of ecosystem characteristics for the success of the invader, who in turn must possess the “right” characteristics to invade a particular ecosystem. Recent studies on propagule pressure generally met with success in explaining vulnerability of ecosystems to

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