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WETLAND PLANTS FOR WASTE- AND STORM-WATER RUNOFF TREATMENT: MANAGEMENT CONSIDERATIONS

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Abstract

Prediction of growth and nutrient dynamics of P. australis is critical in sustainable management of aquatic habitats and management of wastewater treatment facilities using reeds. Therefore, a mathematical model (Reed model) was developed and validated recently to simulate the growth and internal nutrient dynamics of any well-established, mono-specific freshwater stand of P. australis. The field study undertaken to investigate the ecology and best timing strategies of shoot harvesting, identified the seasonal changes of the quality of the rhizome reserves as essential for proper vegetation management. The simulated results of the present study showed that at the time of peak standing stock of minerals, shoots contain 40% and 22.5% of whole plant N and P, respectively. Further this showed the use of Phragmites in waste-water treatment allows removal of N more easily than P, because higher percentage of N is bound with the easily removable shoot parts. Since the model simulates the seasonal variation of nutrient contents in different organs, it enables one to plan the harvesting season of P. australis to maximize the mineral-nutrient removal and also to estimate the nutrient amount that can be removed via harvesting at a specific time.

Key words: harvesting, mathematical model, nutrients, Phragmites

Introduction

Natural processes have always cleaned water as it flowed through rivers, lakes and streams and wetlands. The recognition of the crucial role of biological diversity and ecosystem complexity under natural conditions has led to the restoration of degraded stream, river and wetland ecosystems, thus taking advantage of their inherent water purification and hydrological buffering capacities. In the last several decades, various systems had been constructed to use some of these processes for water quality improvement. Constructed wetlands are now used to improve the quality of point and non-point sources of water pollution, including storm-water runoff, domestic and agricultural wastewater. For some wastewaters, constructed wetlands are the sole treatment; for others, they are one component in a sequence of treatment processes. One of the most common applications of constructed wetlands has been the treatment of primary or secondary domestic sewage effluent (Moshiri, 1993).

The treatment of wastewater or storm water by constructed wetlands can be a low-cost, low-energy process requiring minimal operational attention. Generally, the construction and working expenses should be only 10-50% of those required by conventional treatment technology. Most wetlands support a dense growth of vascular plants adapted to saturated conditions. Pollutants in such systems are removed through a combination of biological, physical and chemical processes including assimilation by the plant tissues, microbial transformations, sedimentation, precipitation and adsorption to soil particles (Brix and Schierup, 1989).

Constructed wetlands are usually planted with emergent vegetation (non-woody plants that grow with their roots in the substrate and their stems and leaves emerging from the water surface). Not all wetland species are suitable for wastewater treatment since plants for treatment wetlands must be able to tolerate the combination of continuous flooding and exposure to wastewater or stormwater containing relatively high and often variable concentrations of pollutants. Common emergents used include reeds (*Phragmites australis*), bulrushes (*Scirpus*), sedges (*Cyperus*), cattails (*Typha* species) and a number of broad-leaved species. However, *P. australis* remains as the most commonly used emergent plant species in constructed wetland systems used for waste-water treatment due its invasive growth and higher production capacity (Weisner et al., 1994).

However, given the extreme variability in the functional components of natural wetlands, predicting their response to wastewater application and translating such results from one geographic site to another is virtually impossible. While a significant improvement in quality is generally observed as a result of wastewater passage through wetland ecosystems, the extent of their treatment capacity is largely unknown beforehand. Therefore, the treatment capacity of natural wetlands is unpredictable, and design criteria for constructed wetlands cannot be directly inferred from results obtained with natural wetlands (Brix and Schierup, 1989). The significant time investment and costs associated with such extensive field studies hinders the advancement of knowledge in this field.

Ecosystem management models developed during the past few decades have proved to be increasingly useful tools in ecosystem investigations. Given the relative complexity of the natural interplay of mechanisms within aquatic macrophyte populations, models for these plant populations are far less common and necessarily of greater complexity (Asaeda et al., 2002). Therefore, a mathematical model (Reed model) was developed and validated recently to simulate the growth and internal nutrient dynamics of any well-established, mono-specific freshwater stand of *P. australis* (Asaeda and Karunaratne, 2000; Karunaratne and Asaeda, 2000). Also, large quantities of phosphorous and other nutrients which are taken up by the plants in such wetland systems could be conveniently removed from the system by harvesting of the plant shoots in a manner similar to cutting hay in agricultural practice. However, the time the reeds are harvested strongly influences the regrowth and consequently the effectiveness of harvesting or long term survival of *P. australis* populations. Therefore, a field study was also undertaken to investigate the ecology and best timing strategies of shoot harvesting of a *P. australis* stand in a swampy section of a wetland that is representative of many Japanese shallow water areas. Such investigations not only provide a basic understanding of the ecophysiological mechanisms linked to an ecosystem's primary production process but are also of importance when translating results from one geographic site to another to create effective methods for the management and conservation of reed stands. The site selected for this study extends the geographical coverage of such studies by adding new data.

Materials and Methods

Reed model to simulate the growth and nutrient dynamics

The reed model simulates the growth pattern and nutrient dynamics of a well-established, monospecific, freshwater stand of *P. australis* (Karunaratne and Asaeda, 2002; Asaeda and Karunaratne, 2000; Karunaratne and Asaeda, 2000). The model predicts reed growth and nutrient dynamics based on the flow diagram presented in Figure 1. Required inputs include (i) meteorological data (daily total global irradiance (μmol m^{-2} d^{-1}), (ii) daily mean air temperature (°C), and (iii) below-ground biomass (rhizome and root separately, g m^{-2}) in the spring. The model is capable of simulating the seasonal variation of

(i) Total above-ground biomass and components thereof (total shoot, stem, leaf and panicle),

(ii) Below ground-biomass (rhizome, new rhizome and root)

(iii) Leaf area index (LAI) and shoot height.

(iv) Nitrogen and phosphorous contents of above- and below-ground biomass and components thereof (total shoot, stem, leaf, panicle, rhizome and root)

(v) Internal mineral-nutrient budget for *P. australis* and estimation of mineral-nutrient uptake from the sediment by the plant.

Field study to investigate the best timing strategies of shoot harvesting

The study was conducted from April through October 2000 in a wetland portion of Akigase Park located on the flood plain of Arakawa River in central part of Japan (35^0 51′ N, 139^0 39′ E). The park, located on the flood plain of the Arakawa River, is a nature reserve covering some 500 ha adjacent to the river and is comprised of many such wetland areas. The study site was dominated by a monospecific and more or less homogeneous (shoot height and stem distribution) stand of *P. australis*. Methods follow same protocols as given in Karunaratne et al. (2003a,b,c,d).

Effects of shoot harvesting during two summer months in June (June-cut stand) and July (July-cut stand), on the stand morphology, above- and below-ground biomass and rhizome storage level (in terms of age specific rhizome bulk density, ρ_{rhiz}) were investigated between themselves and to an uncut control stand.

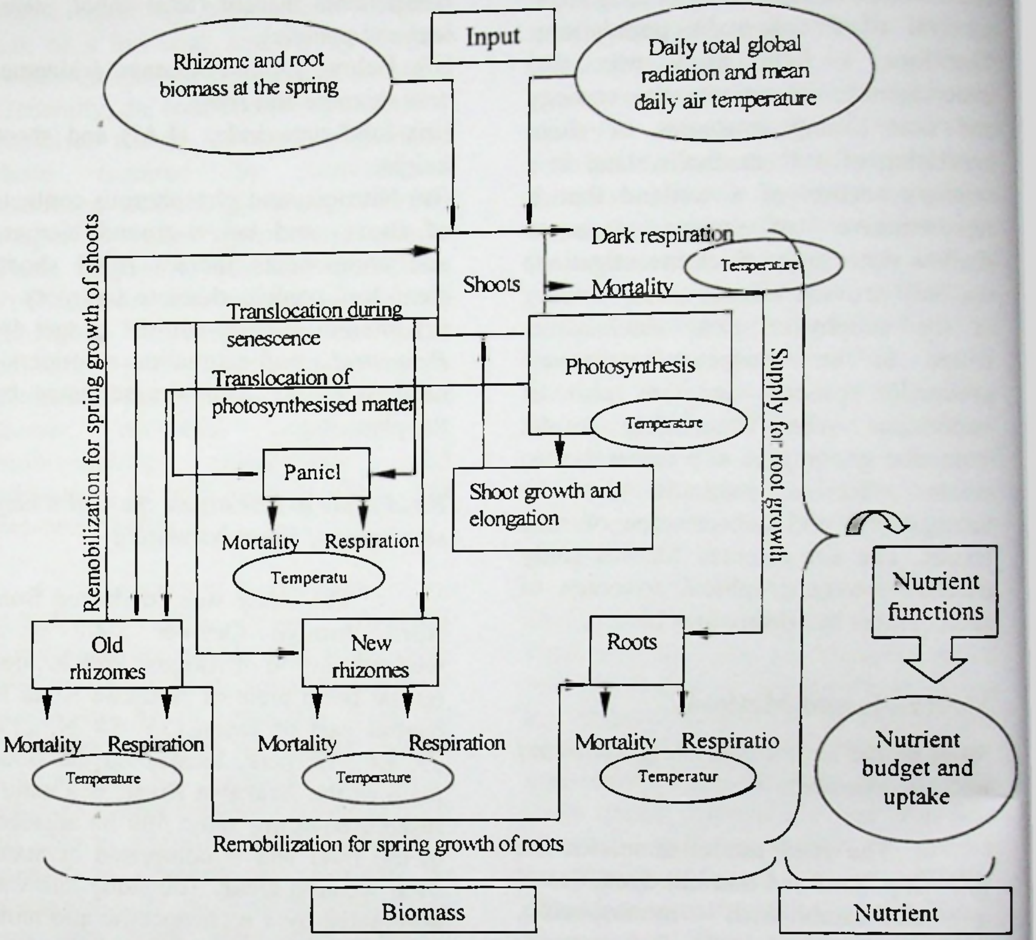

Fig. 1: The schematic representation of the procedure adopted in Reed model to predict the plant growth pattern and nutrient dynamics of P. australis

Results

Reed model

The capacity of the reed model to predict seasonal variations of biomass parameters (shoot, stem, leaf, panicle, rhizome and root), LAI and shoot height and nutrient contents and uptake of *P. australis* was illustrated by comparing the simulated results with the published field data from Australia, Czech Republic, Japan, Scotland and Denmark. In this paper the only model simulations compared with the observed data from Denmark (Vejlerne Nature Reserve, a fresh water wetland area in the province of Thy in North Jutland), is presented.

The model simulated the seasonal pattern of biomass components and shoot height of *P. australis* with concordance correlation coefficients The close to 1.0 (not shown). Figures 2 (a) to (c) show the seasonal courses of nutrient contents in shoots, rhizomes and roots of *P. australis* as simulated by the model. The major advantage of this type of computation is that it enables an estimation of nutrient absorption patterns of *P. australis*.

Nutrient analysis revealed that the annual uptake of nitrogen (N) and phosphorous (P) from sediment by *P. australis* in the Denmark Vejlerne Nature Reserve was 14.39 and 1.61gm^{-2} respectively. Harvesting of *P. australis* shoots at their peak nutrient content would remove 22.3 and 1.93 g m^{-2} of N and P, respectively, from the system. The current analysis of nutrient budget of *P. australis* and annual sediment nutrient uptake (by *P. australis*) need not necessarily be restricted to the Vejlerne Nature Reserve in Denmark. The model makes it possible to analyze the nutrient budgets of reed-dominated aquatic habitats, since the reed growth (biomass) model can be applied to different location. Even though the plant tissue bound nutrients remain more or less same in wider range of habitats, the sediment uptake of nutrients is directly proportional to the plant vigor. Also, the spring rhizome biomass more or less determines the maximum shoot biomass attained by an established reed stand. Karunaratne and Asaeda (2000) proposed a method to estimate the rhizome biomass of *P. australis* at the beginning of spring growth of shoots in terms of the maximum shoot biomass of the same growing season, provided that the stand is well established and do not undergo sudden environmental stresses. Based on this method and the present, sediment nutrient uptake estimations, the ability of a *P. australis* stand to remove sediment bound nutrients can roughly be estimated. Therefore, 1 kg m^{-2} of spring rhizome biomass would yield to an annual uptake of 7.20 and 0.81 g m^{-2} of N and P from sediment.

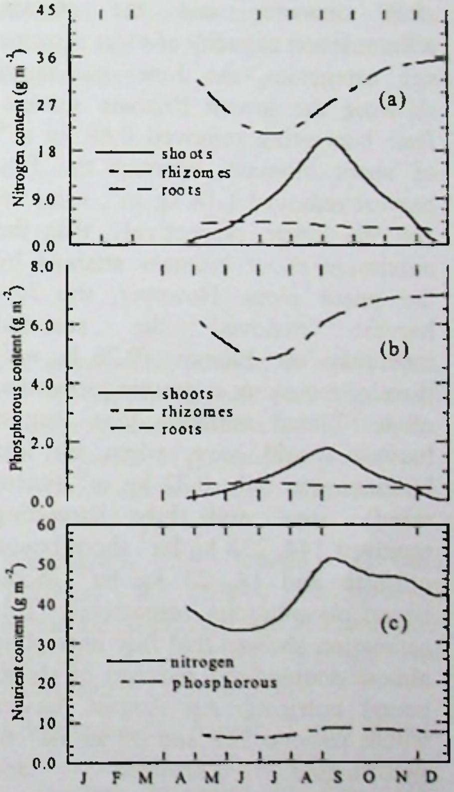

Fig. 2. Seasonal courses of nutrient contents of (a) nitrogen, (b) phosphorus, in shoots, rhizomes and roots separately and (c) nitrogen and phosphorus retained by the whole plant system of P. australis as simulated by the model

Field Study

The best time of shoot harvesting to maximize the mineral nutrient removal and the long term survival of a P. australis plant stand was investigated. The study identified the seasonal changes of the quality of the rhizome reserves as essential for proper vegetation management. Both harvesting treatments increased leaf production and decreased shoot height, stem diameter and the storage accumulation capacity of older rhizome age categories, the June- cut stand showing the lowest rhizome storage. June harvesting removed 0.69 kg m^{-2} of shoot biomass, whereas the July harvest removed 1.18 kg m^{-2}, some 46 and 9% lower, respectively, than the maximum shoot biomass attained by the uncut plots. However, the July harvest removed the seasonal maximum leaf biomass (0.26 kg m^{-2}) thereby removing a greater proportion of leaf-bound nutrients than August harvest would have, when the leaf biomass was only 0.22 kg m^{-2} (uncut stand). June and July harvesting removed 144, 228 kg ha^{-1} shoot-bound nitrogen and 14, 23 kg ha^{-1} shoot-bound phosphorous, respectively. This estimation showed that July harvesting almost doubled the removal of shoot-bound nutrients. An August harvest would remove 219 and 20 kg ha^{-1} of shoot-bound nitrogen and phosphorous, respectively. Considered the fact that the leaf tissues have a higher nutrient content than stem tissues, the above estimate is a lower limit for the shoot bound nutrients. Therefore, July harvesting, which removes the maximum leaf biomass may remove a greater quantity of nutrients than would an August harvest, even if the total shoot biomass removed is slightly lower.

Discussion

Prediction of growth and nutrient dynamics of *P. australis* is critical in sustainable management of aquatic habitats and management of wastewater treatment facilities using reeds. During the growing season the plants absorb and incorporate the nutrients into their own structures (Brix and Schierup, 1989). The simulated results of the present study showed that at the time of peak standing stock of minerals, shoots contain 40% and 22.5% of whole plant N and P, respectively. Further this showed the use of *Phragmites* in waste-water treatment allows removal of N more easily than P, because higher percentage of N is bound with the easily removable shoot parts. Since the model simulates the seasonal variation of nutrient contents in different organs, it enables one to plan the harvesting season of *P. australis* to maximize the mineral-nutrient removal and also to estimate the nutrient amount that can be removed via harvesting at a specific time. Assuming long-term average meteorological conditions and continued favorable environmental conditions, the model can then also serve to project future variations in above- and below-ground biomass and also reed nutrient contents, provided the specific rates of winter respiration and mortality of below-ground parts are known. Other minor nutrients such as potassium, calcium, magnesium etc. can also be simulated using the same procedure adopted to simulate N and P in plant organs. Therefore, the present reed model (biomass/nutrient) when combined with models describing the other important wetland processes such as denitrification, fixation and diffusion, coupled with nutrient loading pattern of such systems, can be used to propose management strategies to optimize the nutrient removal efficiency in a constructed wetland.

The field study reiterated the importance of ecophysiological mechanisms regulating *P. australis* plant communities and identified the seasonal changes of the quality of the rhizome reserves as essential for proper vegetation management. Therefore, a harvest of above-ground biomass in May to June would be more effective in reducing the growth than a harvest in July to August or later, when rhizome reserves have already been replenished. Therefore, July or later is the appropriate harvesting time for plant stands used in pytoremediation and wastewater treatment where a larger shoot bound nutrient stock is removed, while preserving a healthy stand for the subsequent years. A harvest in May to June would be more effective in reducing the growth and repeated June-cutting may likely weaken the stand beyond repair after several years.

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