# Dynamic Modeling of growth of *Phragmites*, as a Functional Tool in Water Quality Management

水質制御機能に着目したアシの成長モデルについて

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**Abstract ;** Recently, much attention has been drawn on experimental analysis of production potential and nutrient composition of the emergent macrophyte, *Phragmites*. But very few has attempted to analysis the phenomena using numerical simulation models. A dynamic growth model has been developed with the objective to simulate the seasonal variation of above and below ground biomass of *Phragmites* and it has been extended to simulate the nutrient composition of above ground organs. Basically, this model comprised of two sub models, biomass sub and model nutrient sub model to simulate seasonal variation of biomass and nutrients. Given the initial rhizome biomass prier to growth commencement together with total global radiation ($\mu E/m^2/d$) and daily mean air temperature ($^0C$) for the intended simulation period, the model allows a reliable evaluation of production potential and mineral nutrient composition. This paper will discuss two applications made for seasonal variation of nutrient composition of *Phragmites*.

***Keywords*:** Emergent macrophytes, Harvesting, Numerical simulation, *Phragmites*

## 1. Introduction

Common reed *Phragmites* is a major component of freshwater bodies in temperate regions throughout the world . It abundantly grows along the margins of habitats such as swamps, littoral zones of lakes, ponds (Hocking et al 1983). Rooted macrophytes such as *Phragmites* absorb nutrients, both from sediments and overlying water and a larger fraction of accumulated nutrients such as nitrogen and phosphorous are associated with easily harvestable, above ground plant parts. This suggests, that by harvesting shoots at a desirable time alone, could remove a large quantity of nitrogen and phosphorous from

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a system. Therefore, biological methods, for removal of dissolved organic compounds from the domestic and agricultural waste using higher aquatic plants such as *Phragmites* are of increasing demand (Suzuki et al, 1985). *Phragmites*, which plays a dominant role in shallow aquatic ecosystems, can also be used to minimize eutrophication problems.

## 2. Model formulation

### *2.1. Biomass sub model*

#### *2.1.1. Governing equations for biomass*

Five state variables were selected depending on their importance and competence to illustrate the plant growth. Hence, plant biomass per square meter was divided into five major plant organs such as shoots including leaves and stems ($B_{sht}$) panicles ($B_p$) roots ($B_{rt}$) rhizomes ($B_{rhi}$) and new rhizomes ($B_n$) evaluated in grams per square meter by ash free dry weight. Net growth of a plant stand was described as the integral effect of photosynthesis ($Ph_{sht}$) respiration (R) mortality (D) reallocation of material from dead biomass, denoted by the fraction (C) of the mortality, and the assimilate translocation between shoots and below ground organs. Average height of a reed stand can vary from 0.5 m to as much as 8.0 m. Subscripts, rhi, rt, n, sht, and p were utilized to represent rhizomes, roots, newly formed rhizomes, shoots, and inflorescence respectively.

$$\frac{\partial B_{rhi}}{\partial t} = -R_{rhi} - D_{rhi} + C \cdot D_{rhi} - Rhif + y.\sum_{i=1}^{i=600} b_{sht-Trans}(i) + y.\sum_{i=1}^{i=600} Ph_{sht-Trans}(i)$$

$$\frac{\partial B_{rt}}{\partial t} = G_{rt}.f_{rt} - R_{rt} - D_{rt} + C \cdot D_{rt} - nRhif + x \cdot Rhif$$

$$\frac{\partial B_{n}}{\partial t} = -R_{n} - D_{n} + C \cdot D_{n} + nRhif + (1-y).\sum_{i=1}^{i=600} b_{sht-Trans}(i) + (1-y).\sum_{i=1}^{i=600} Ph_{sht-Trans}(i)$$

$$\frac{\partial b_{sht}(i)}{\partial t} = Ph_{sht}(i). - R_{sht}(i) - D_{sht}(i) + C.D_{sht}(i) + (1\text{-}x).Rhif.(b_{sht}(i)/B_{sht})$$
$$- b_{sht-Trans}(i) - Ph_{sht-Trans}(i) - b_{sht-pTrans}(i) - Ph_{sht-pTrans}(i) - G_{rt}$$

$$\frac{\partial B_{p}}{\partial t} = \sum_{i=1}^{i=60} Ph_{sht-pTrans}(i) + \sum_{i=1}^{i=600} b_{sht-pTrans}(i)$$

where;

$$Ph_{sht}(i) = P_m.\theta^{(T-a)}.\frac{I_{PAR}(i)}{K_{PAR} + I_{PAR}(i)}.\frac{N}{K_N + N}.\frac{P}{K_P + P}.\frac{K_{age}}{K_{age} + Age_{sht}}.b_{sht}(i)$$

$$G_{rt} = g_m.\frac{K_{rt}}{K_{rt} + Age_{rt}}.B_{rt}\text{; } nRhif = \phi_n.B_{rt}\text{ ; } B_{sht} = \sum_{i=1}^{i=600} b_{sht}(i)\text{; } Rhif = \alpha_{rhi}.B_{rhi}$$

$$R = \gamma_m.\theta^{(T-a)}B\text{; } D = \beta_m.\theta^{(T-a)}B$$

Total height (6.0 m in the model) of the plant stand was stratified into 1cm-thick horizontal layers in which dry matter budget and elongation were calculated separately. Then the above-mentioned quantities were integrated over the plant height to get the biomass per square meter after every one-day time step.

*2.1.2. Photosynthetically Active Radiation (PAR) regime in the plant stand*

Many researches have proposed that photosynthetically active radiation (PAR) is about 40%~45% of daily total global radiation (Dykyjová, 1971). [i.e. $I_{PAR} = 0.45$ . (Global radiation)]

Following the Lambert-Beer law, PAR in i-th layer is given by;

$$I_{iPAR} = I_{PAR} . e^{-k.F_i}$$

where $I_{PAR}$ is the PAR intensity in the open and $I_{iPAR}$ that in the stand at a level above which there is a cumulative leaf area index, $F_i$ [$F_i = \sum_{i=1}^{i=i} LAI(i)$].

*2.2 Nutrient sub model*

Eight nutrient functions were defined by using four sets of observed data (from Southern Moravia, New South Wales, Australia, Japan and Scotland) to estimate the seasonal variation of mineral nutrient composition of shoots, stems, leaves and panicles. All observed data of nitrogen and phosphorous contents of various plant organs were plotted against time and a curve was fitted in the form of a power function for each plant organ, which was referred as nutrient function.

| Plant Organ | nitrogen | phosphorous |
|---|---|---|
| Shoots | $0.0908*jday^{-0.3276}$ | $3.8488*jday^{-1.5311}$ |
| Stems | $0.3791*jday^{-0.6449}$ | $144.95*jday^{-2.2553}$ |
| leaves | $0.6839*jday^{-0.565}$ | $0.1373*jday^{-0.771}$ |
| Panicles | $0.0003*jday^{-0.0474}$ | $0.00001*jday^{-0.0015}$ |

Table 1. Nutrient functions for various plant organs.

All functions are given in table 1. Analysis of observed data from varying tropic conditions has shown that mineral contents per gram dry weight of plant organ biomass

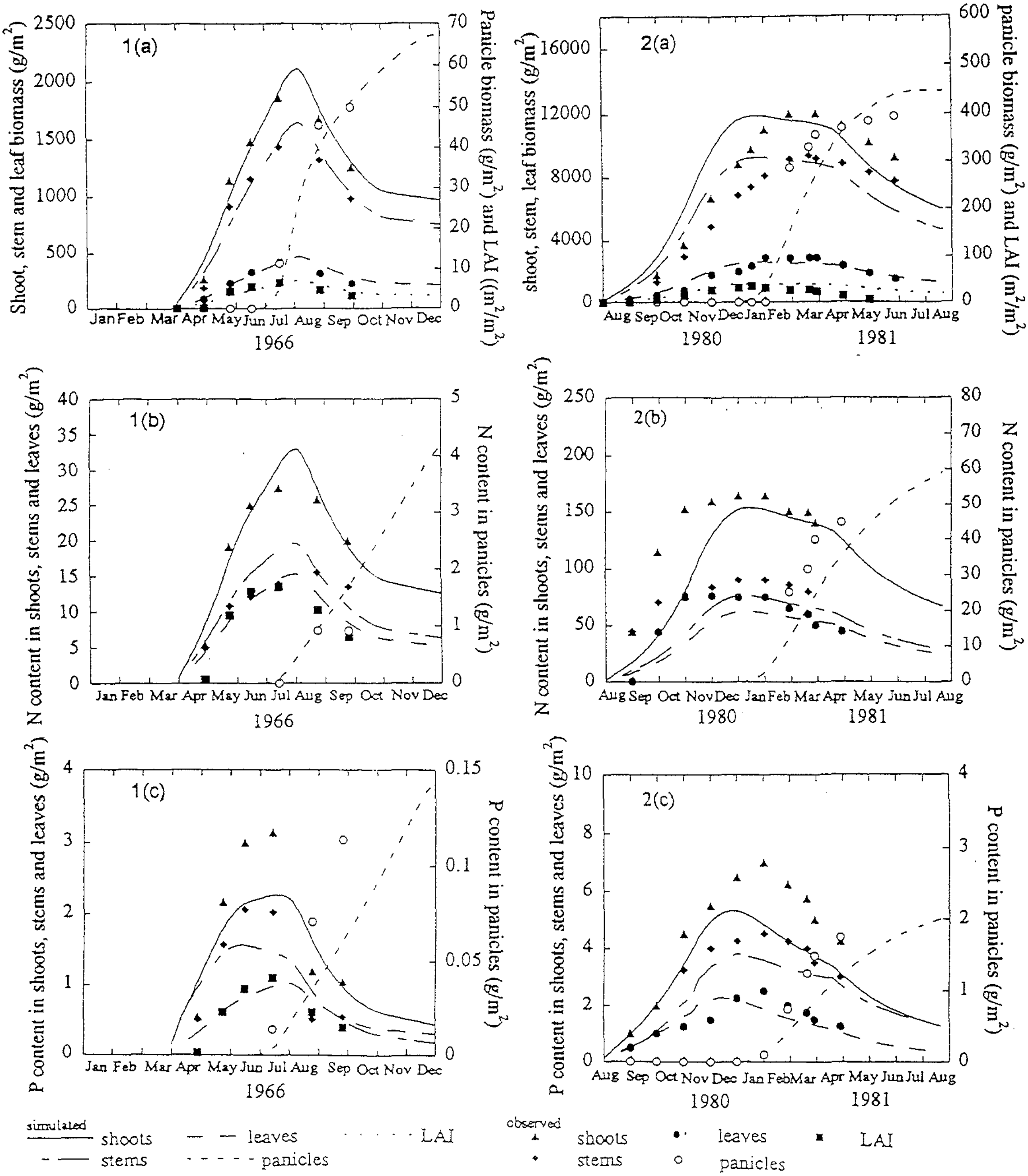


Fig. 1(a)-(c) Seasonal variation of above ground biomass, nitrogen and phosphorous contents of Phragmites (Nesyt fishpond, Southern Moravia)

Fig. 2(a)-(c) Seasonal variation of above ground biomass, nitrogen and phosphorous contents of Phragmites (New South Wales, Australia) does not differ significantly, indifferent to the tropic level of the site. Hence, nutrient content of each plant organ was defined as shown below.

Mineral content = Nutrient Function * biomass

### 3. *Application to field data*

The model was first applied to experiments done at Nesyt fishpond in Southern Moravia in Czech Republic (Kvêt et al., 1969). The fishpond has an area of about 300ha and water volume of about 4,500,000m$^3$. 10% of the fish pond area is covered with reed stands, out of which 50% were pure stands of *Phragmites*, 20% were pure *Typha* stands, and 30% were mixed stands (Ûlehlová et al., 1973). Since meteorological data for the year 1966 were not available, ten years data, from 1984 to 1994, for daily global radiation and daily mean temperature were averaged to estimate the appropriate values for 1966.

Seasonal variations were computed for the above ground biomass and nutrient contents. Figure 1(a) shows the simulated results of shoots, stems, leaves, panicle biomass and leaf area index compared with observed data. All apparent trends, such as the high initial growth rate followed by a slow growth rate, time of peak biomass attained, ceasing of growth and decline of biomass due to senescence were successfully reproduced. Figure 1(b) provides the comparison of simulated and observed results of nitrogen content during the growing season while figure 1(c) shows seasonal variation of phosphorous content in above ground plant organs.

Next application was made for a set of data (1980/81 growing season) of a swampy section of Mirool Creek, New South Wales in Australia (Hocking, 1989). The climate of the region was warm and dry, with a mean daily average temperature of 32 $^0$C for January and 15 $^0$C for July, where the temperature of the warmest month being 6.4 $^0$C higher than Nesyt fishpond. The site was a flat field, 500m long and 75m wide adjacent to Mirool Creek. Since the growing season starts in the middle of the year, the length of the growing season always drags to the next year. Thus, Julian day count started in the beginning of July 1980 for 1980/81 growing season.

Simulated results of shoot, stem, leaf, panicle biomass and LAI are shown in Figure 2(a). Nitrogen and phosphorous contents are shown in figures 2(b) and 2(c), compared with the observed results. Here also, simulated results maintain all the features typical to *Phragmites*.

## 4. Discussion

The concept behind waste-water treatment plants using *Phragmites*, is to remove mainly, nitrogen and phosphorous through harvesting the *Phragmites* shoots at appropriate time such that, at the time of harvesting shoots contain their maximum amounts of nutrients. It was evident that both seasonal patterns of biomass and nutrient composition follow a similar trend. It could be seen that simulated nitrogen composition well follows observed data while simulated phosphorous composition somewhat deviates from the observed data. However, simulated results maintain all the features typical to *Phragmites*. The model in discussion, can be utilized to predict the time period in which the shoots contain maximum amount of nutrients thus enabling to use it as a management tool for planning the harvesting season.

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**Notations used in the equations**

$x$- fraction of rhizome biomass for root formation; $y$- fraction of shoot biomass for remobilization of rhizomes; $b_{sht}(i)$- Shoot biomass in i[th] layer; $b_{sht\text{-}Trans}(i)$, $b_{sht\text{-}pTrans}(i)$-translocated shoot biomass for rhizomes and panicles respectively; $Ph_{sht\text{-}Trans}(i)$, $Ph_{sht\text{-}Trans}(i)$-translocated photosynthesized material for rhizomes and panicles respectively; *Rhif*-rhizome flow for formation of shoots; $P_m$-maximum photosynthesis rate; $I_{PAR}$-photosynthetically active radiation; $K_{PAR}$, $K_{age}$, $K_p$, $K_N$-half saturation constant of PAR, age of shoots, phosphorous and nitrogen; $K_{rt}$-half saturation cons. Of roots; $C$-fraction of dead biomass used for growth; $G_{rt}$-Growth of roots; $g_m$-maximum growth rate of roots; $\gamma_m$, $\beta_m$-maximum respiration and mortality rates of relevant organ; $\theta$-Arrhenius constant; $T$-temperature; $a$-constant; $\phi_n$-fraction of root for rhizome formation; *Rhif*- rhizome flow for shoot formation; *nRhif*- root flow for new rhizome.