Use of Aquatic Plants in Urban Drainage Wetlands

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ABSTRACT

Aquatic plants have high ability to purify water, and are often used in the waste water treatment system. However, the mechanism of water purification is different depending on the types of plants. Therefore it is important to understand the purification mechanism before one should apply it. Suspended organic matters are easily settled in the aquatic plant stands and are accumulated on the sediment surface. The settlement is more efficient with submerged plants than emergent species. Charophytes are calcified in the process of photosynthesis. Dissolved phosphorus and heavy metals are, then, co-precipitated, combined with calcium carbonate, and are stably removed from water. Emergent plants are often used in the treatment systems. The nutrient removal efficiency also depends on the morphology, phenology, cutting and other management regimes of the candidate plants. Harvesting the aboveground foliage enhances the nutrient removal rate. Numerical simulation models are useful tools to evaluate the efficiency of the treatment wetlands. The models consist of modules to simulate processes of growth, mortality and decomposition. The application of the model to wetland system successfully simulates the carbon and nutrient cycles and other parameters in the environment. Further modification of the model makes it capable of predicting the effect of the treatment quantitatively.

1. INTRODUCTION

Aquatic plants, which are often referred as macrophytes or hydrophytes, are plants that have adapted to living in aquatic environment. They are very efficient in water purification, and thus they are often used in the treatment wetlands as a low cost sustainable system [1,2]. They are classified into several types by their morphology. Emergent plants (Helophytes) are rooted in the bottom, but with leaves above the water surface, floating leaved plants (Nymphaeids) are also rooted in the bottom, while with leaves floating on the water surface, floating plants (Pleuston) float freely in the water, and submerged plants (Elodeids, Isoetids) complete their entire life cycle submerged. Different types of plants have different mechanisms to purify water. They are basically based on the life style of each plant in the aquatic environment [3,4].

The purpose of water treatment system is various. The application of emergent plants is most commonly considered practically, however, depending on the purpose, other types of plants are sometimes more suitable [5,6]. It is particularly important to understand the purification mechanisms to apply plants. In the designing of treatment system, the quantitative evaluation is desirable. A pilot plant is often used, however, it normally takes a long period to get sufficient results. Numerical models are developed and are practically used in the prediction of algal blooming in the reservoir. They are normally based on ecological/physiological characteristics of algae, which are empirically obtained. Similar model is available for the growth of aquatic plants [7-9]. This article discusses the use of aquatic macrophytes for plant purification, some mechanisms of purification, some management practices and models of aquatics plant growth.

2. VARIOUS FUNCTIONS OF AQUATIC PLANTS FOR WATER PURIFICATION

There are several processes for the removal of nutrients in the treatment wetlands. The first process is the uptake of nutrients from the overlying or underground interstitial water. Figure 1 illustrates the carbon and nutrient cycling through various types of aquatic plants.

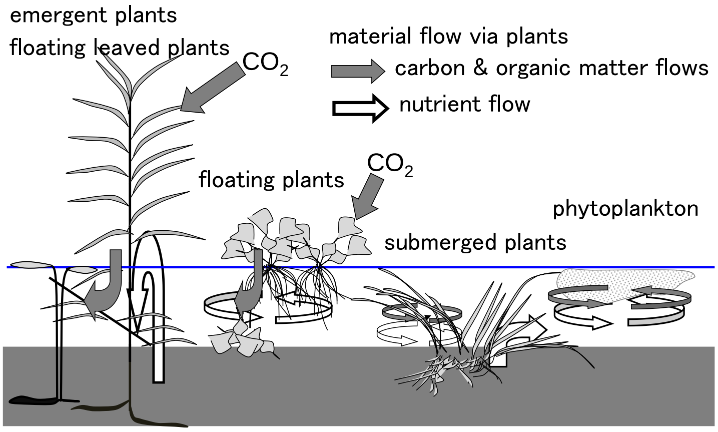


Figure 1: Carbon and nutrient flow patterns of various types of aquatic plants [10].

In case of emergent and floating leaved plants, carbon sources are carbon dioxide in the atmosphere. Up-taken carbon is used to produce their body and then is released into the surrounding water in the decomposition process after the mortality of the aboveground biomass. At the same time, some fraction of carbon is stocked in the rhizomes for several years until rhizomes die. In the decomposition process of the aboveground biomass, oxygen in the water is consumed. Therefore, in the community of these plants, oxygen of the overlying water is reduced. Nutrients are taken from the underground interstitial water through roots, and is finally released into the overlying water. As rhizomes increase year by year, thus nutrients are taken up as a net. The emergent or floating-leaved plants, however, essentially pump up nutrients from the ground to overlying water, although some fraction is stocked in rhizomes, too.

Floating plants take up nutrients from the overlying water and release them into the same media. Thus, they behave as nutrient sink. However, oxygen in water declines as a net. In case of submerged plants, carbon dioxide is taken up from the overlying water in a process of photosynthesis. At the time, oxygen released into the water. While, when their dead body is decomposed, oxygen is consumed. Therefore, the oxygen budget is theoretically zero. Submerged plants take up nutrients both from the overlying and underground water. Thus, they become nutrient sources, too. As such, if we consider nutrient removal of the overlying water, most of aquatic plants work as nutrient source in the lifecycle. Also, the budget of oxygen in the water is negative, and they contribute to produce anoxic condition except for submerged plants.

The second process is the acceleration of settling of suspended organic particles in the overlying water. Accumulated fine sediment in aquatic plant stands is often observed (see Figure 2). The settling of suspended sediment is enhanced by the attenuation of the flow velocity or turbulence. Floating leaved or floating plants substantially decrease turbulence in the water column. In the flowing water, water velocity is decreased due to the obstruction by the plant body. Organic particles contain nutrients, thus the settling of suspended sediment contributes to reduce the nutrient concentration in water. Figure 3 indicates the accumulation/release of nutrients inside *Sparganium erectum* stands at a lowland stream. *S. erectum*, forming as submerged in winter, emerges in spring and collapses in the middle of the growing season. Suspended sediments settle or become suspended depending on their growth stages [1,11]. If suspended organic sediments settle, contained nutrients accumulate in the bottom sediment surface. It is found that nutrients are accumulated more efficiently at the stages of submerged shoots and collapsed shoots rather than emergent shoots. Suspended sediments settle intensively in the low velocity zone near the bottom created by submerged or collapsed shoots.

Figure 2: Accumulation of fine sediment in the emergent plant (*Zizania latifolia*) stands. Rokkaku River at western Japan.

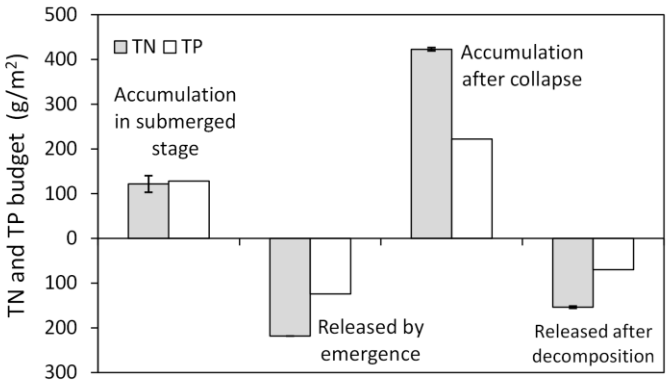
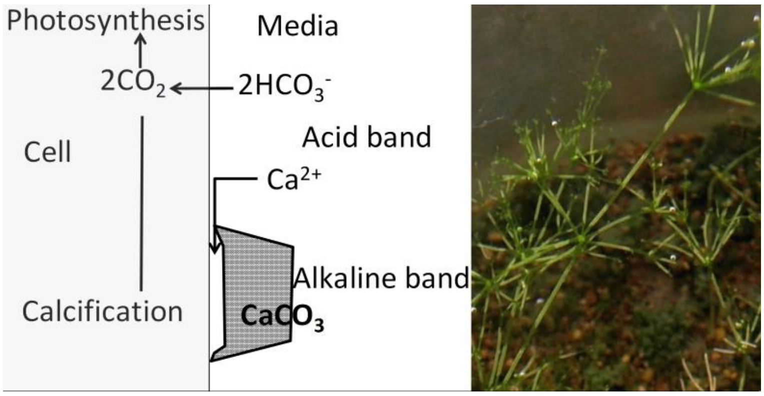


Figure 3: The amount of accumulation /release of total nitrogen and total phosphorus in the sediment at different growth stages of *Sparganium erectum* [1].

Aquatic plants aerate the rhizospheric zone by transporting oxygen to roots. The bottom sediment is normally anoxic, and unfavourable substances, such as hydrogen sulphide, or methane, are produced there [12]. In the stagnant water, the release of phosphate or ammonium from the sediment into the overlying water is enhanced under the anoxic condition. There are an amount of studies conducted on the aeration rate by various aquatic plants [13-15].

Some submerged species have an important process to remove phosphate and heavy metals from water. Charophytes use hydrogen carbonate in the process of photosynthesis, and at the same time produces calcite encrustation on the surface of stems, branchlets and oogonia, using calcium ion in water [16] (see Figure 4a). Figure 4b shows the calcified *Chara fibrosa*.

Phosphorus and heavy metals are co-precipitated with the calcite [17] through adsorption process. Charophytes contain a large amount of sulphur related amino acid such as cysteine, which is known as building block of Metallothionein (MT). Binding heavy metal and MT is considered as detoxification process by organisms exposed to heavy metal [18,19]. Thus in a relatively high concentration of heavy metal, charophytes are still vital [20]. Figure 5 illustrates the fraction of different types of Cd of charophytes [18]. A large fraction is combined with calcium carbonate. Therefore, differently from other aquatic plants, calcite combined heavy metals are not released easily and are socked in the bottom sediment permanently. The system is applicable various types of heavy metals, such as cadmium [18], chromium [21], zinc [20,22], as long as suitable calcium concentration is maintained.



(a) (b)

Figure 4: Mechanism of calcification [16]

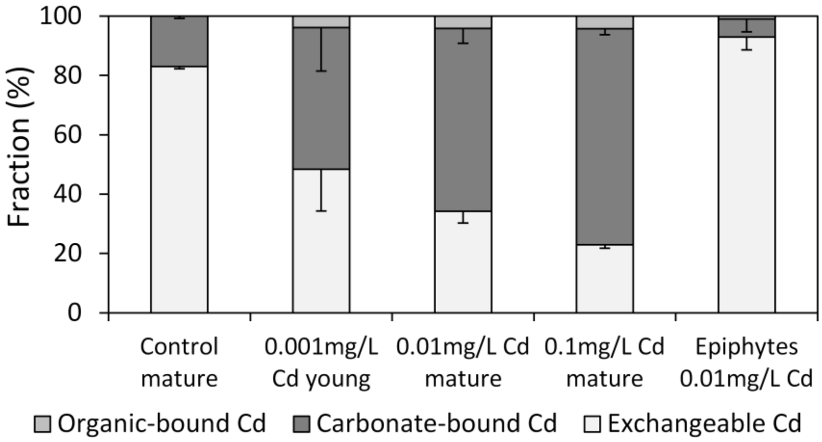


Figure 5: fraction of different type Cd of charophytes [17]

3. EMERGENT PLANTS

Emergent plants are most often used in the treatment wetland [6]. Perennial plants survive the winter as rhizomes and then new shoots emerge in spring and using the storages in the rhizomes. After the shoots are grown sufficiently, the rhizomes are replenished with photosynthesized materials in the shoots. In the middle of summer, the shoot growth terminates, forming flowers. In the late summer, aboveground organs die, and a part of contained materials is translocated to rhizomes for the next year growth. The dead materials of aboveground biomass are gradually decomposed and contained nutrients are released into the surrounding water [23].

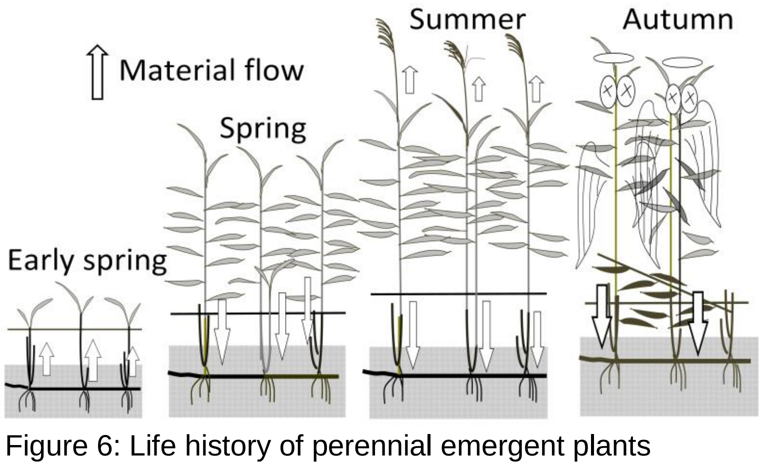


Figure 6: Life history of perennial emergent plants

Rhizomes are gradually replaced by new segments and increase their biomass [24].

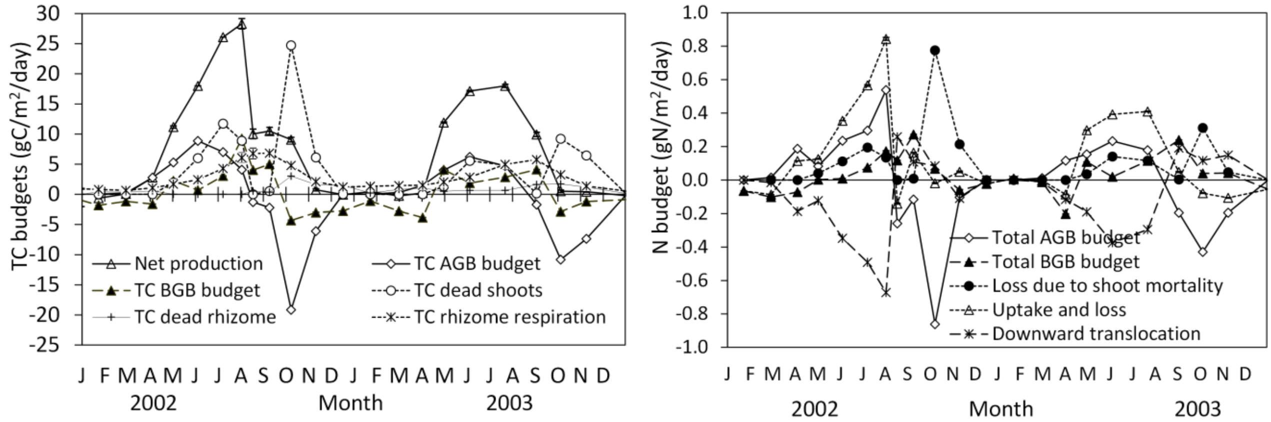


Figure 7: Annual total carbon, (a), and total nitrogen, (b), budgets of each organ of *Zizania latifolia* [25]

Figure 7 indicates the nutrient budget of rhizome system of *Typha angustifolia* [25]. It shows the observed total carbon and total nitrogen budgets of each organ of *Zizania latifolia*. A large fraction of photosynthesized materials are translocated to rhizomes and belowground biomass and nutrient contents substantially increase during summer time. Nutrients are reserved in the rhizome system until rhizomes die and then are released into water. Rhizomes live two to five years depending on species [24-26]. Therefore, the above- and below-ground biomass and their ratio substantially affect the efficiency of the nutrient removal.

Figure 8(a) and 8(b) show the annual maximum total biomass and the above- to belowground biomass of *Phragmites japonica*, and the ratio of root biomass to rhizome biomass of the belowground biomass is shown in Figure 9. With increasing substrate sediment size, total biomass and AGB/BGB decrease, while root rhizome biomass ratio increases [27,28].

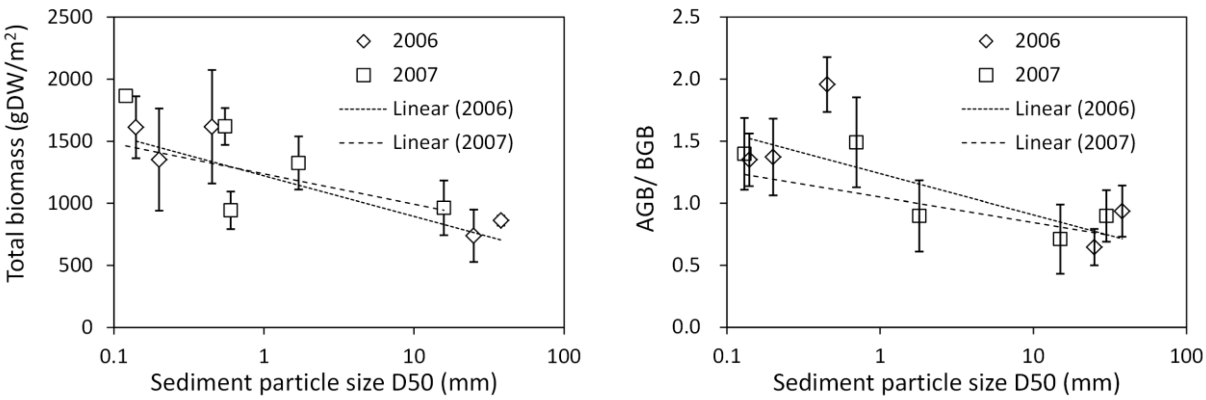


Figure 8: The substrate sediment size effects on the total biomass and the AGB and BGB ratio of *Phragmites japonica* [27]

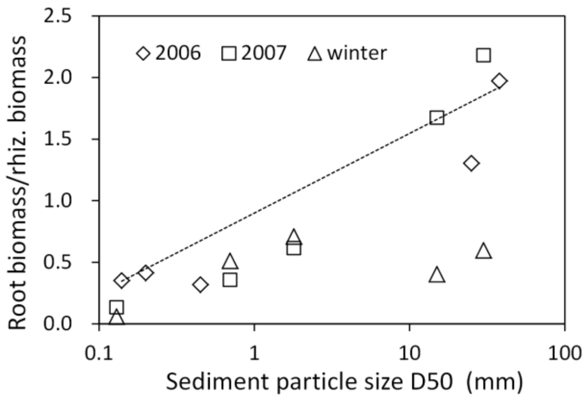


Figure 9: The substrate sediment size effect on the fraction of root biomass of *Phragmites japonica* [27]

The large belowground biomass, particularly rhizome system, contributes to survive under harsh meteorological condition [29], and the uptake rate increases by larger root system at the low moisture and nutrient concentration in the substrate [30]. Generally, at the preferable condition, such as with sufficient nutrient concentration, moisture in the sediment and finer sediment size of the substrate, the fractions of aboveground biomass in the total biomass increases [24,27].

4. CUTTING/MOWING

Harvesting has been an attractive approach to the management of aquatic macrophytes for a variety of ecological and practical reasons and has attracted much attention [31,32]. The rationale behind cutting as a potential control mechanism stems from the fact that it will retard the subsequent growth and development of the stand because reserves produced during that season are removed by cutting the aerial part of the plant, thus reducing its vigor.

The growth of the stands, as indicated by the aboveground biomass, showed a significant decline due to cutting in June but did not show a significant difference due to cutting in July, compared to that of the control stand [24]. The timing of harvesting of aboveground biomass affected the annual rhizome resource allocation. A similar trend was observed for the pattern of resource allocation, as described by biomass variation of different rhizome-age categories for July-cut and control stands. However, the biomass of June-harvested rhizome categories tended to be smaller than the other two stands, indicating substantially reduced resource storage as a direct result of harvesting the aboveground biomass during the previous growing season [33]. This implies that cutting of aboveground biomass in June is a better option for control of *P. australis* stands than cutting later in summer [34].

5. EVALUATION BY NUMERICAL SIMULATION MODEL

Mathematical models are available to evaluate the nutrient cycle in the treatment wetlands [9,35]. Figure 10 indicates the carbon flows of emergent perennial macrophytes, including growth, mortality and decomposition processes [24,36,37]. All these processes are given by differential equations with empirically obtained coefficients.

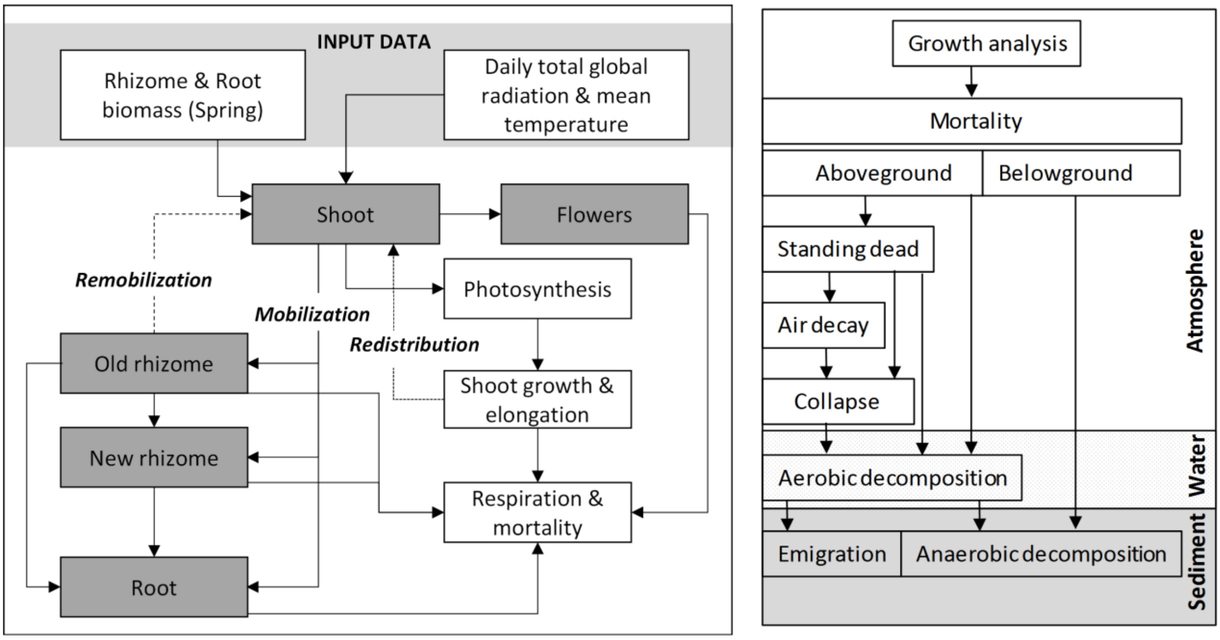


Figure 10: Structure of (a) growth model and (b) decomposition of perennial emergent plants [36,37]

The model was applied to describe the carbon and nutrient cycles at *Phragmites australis* bed of Neusiedlersee in Austria. Some of the results are shown in Figure 11 [37]. Carbon and nutrient cycles through plants are adequately simulated by the model. As empirical coefficients are reported for many plants [3], the model is applicable for various aquatic plants [24]. Cutting effects are also evaluated by the model [24].

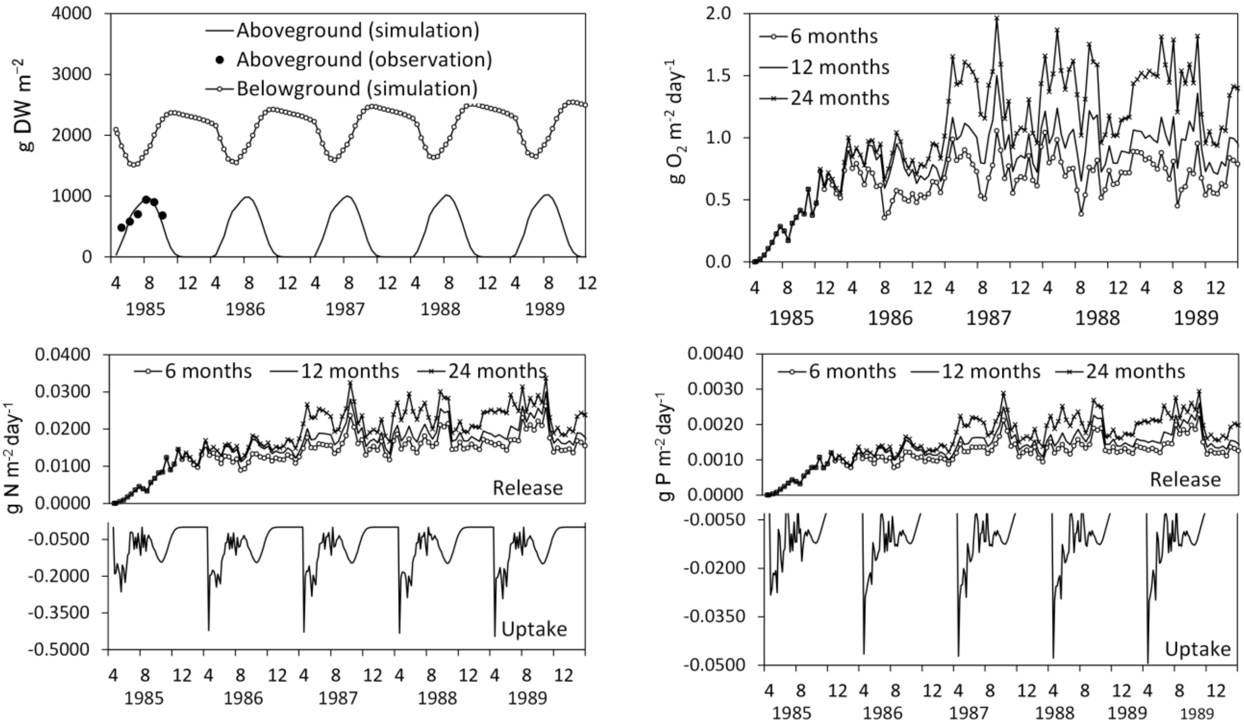


Figure 11: Simulated results of (a) Above and below biomass of *P.australis*, (b) oxygen consumption rate due to decomposition, (c) nitrogen budget and (d) phosphorus budget. Months are the period litters remain in the overlying water [37]

Figure 12 shows the simulated results of shoot cutting of *Typha angustifolia* at every 3 and 6 weeks, compared with experiments. It is found that the maximum aboveground biomass reduces to 4/5 and 2/3 of the uncut case in the previous year. The simulation model is easily available to predict the application of aquatic plants to the treatment wetlands.

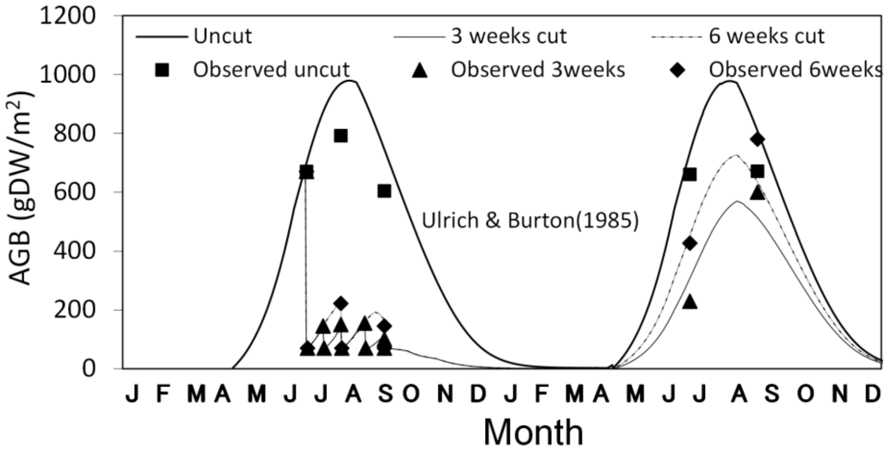


Figure 12: Simulated results of shoot cutting of *T.angustifolia* at every 3 and 6 weeks, compared with experiments [38]

6. CONCLUSION

Aquatic macrophytes preform many important functions in aquatic ecosystem. Due to their role in purifying water, they have been used in many water purification wetlands. For these reasons, aquatic macrophytes have been considered ‘ecological engineer’. Before applying them in management, details knowledge of their biology, phenology, response to changes of environmental parameters and human intervention are necessary.

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