

Population dynamics of water hyacinth (*Eichhornia crassipes*)

Nimal P.D. GAMAGE and Takashi ASAEDA

Department of Environmental Science and Human Engineering, Saitama University, 255, Shimo-okubo, Saitama 338-8570, Japan

ABSTRACT: Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is a perennial, herbaceous, aquatic weed of the family Pontederiaceas. Water hyacinth is considered as a serious pest in many part of the world in the tropical and sub-tropical regions due to its prolific growth affecting water resources adversely by blocking canals and pumps in irrigation projects; interfering with hydroelectricity production; wasting water in evapotranspiration; hindering boat traffic; increasing waterborne disease; interfering with fishing and culture; and clogging rivers and channels so that drainage is impossible and floods results.

A dynamic numerical model was developed to simulate the growth dynamics and production of water hyacinth. Two state variables, shoots and roots, were considered to illustrate the growth of the water hyacinth. The net growth of the shoots was imperative effects of photosynthesis, respiration, mortality and allocation for root growth. Biomass data reported in literature was used to calibrate the model. Model parameters were allowed to vary as a result of acclimation, following experimental data reported in literature. Model simulations show a good agreement with observed data with a similar biomass temporal dynamics.

Key Words: Water hyacinth (*Eichhornia crassipes* (Mart.) Solms)

Introduction

Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms) is considered to be the most important aquatic weed in the world (Center and Spencer 1981). It was first recorded in early nineties in South Africa. Since then the weed is gaining considerable attention in tropical and subtropical part of the world due to its rapid growth causing, clogging of rivers and lakes, incubating pest insects, depleting the oxygen in water, and deterioration of fish habitat (Gopal, 1987). Attempts to control the weed have led to different control options being developed, including chemical control, biological control, and harvesting.

Water hyacinth often grows as floating plants or mats, as islands of plants floating freely on the water, or mixed with other vegetation on banks. The high specific gravity of the submerged portion and the low specific gravity of the bulbous petioles tend to keep the shoot erect. The adventitious root system is usually suspended in the water although the plants may become rooted if stranded in moist soil or in shallow water (Center and Spencer 1981). Water hyacinth has also been studied for their potential in controlling water

pollution, animal feed, manure, mulch, production of biogas, pulp and paper manufacture (Gopal 1987). Among those, water hyacinth is utilized mainly for biogas production and paper manufacture in many countries. The phenology, growth and nutrient storage of water hyacinth have been extensively studied in the field and in laboratories by Center and Spencer 1981, Sato and Kondo 1981, Sato and Kondo 1983, Reedy et. al. (1989,1990, &1991).

Although many experiments have been carried out to analyze the growth dynamics of water hyacinth, few researches have attempted to analyze the growth dynamics using numerical simulation models. Mitsch (1976) developed an ecosystem model of water hyacinth growth on Lake Alice, Gainesville, Florida and found that the water hyacinth population would be reduced by 50% or more if the wastewater was diverted from the lake. Lorber et al. 1984 developed a water hyacinth biomass model to evaluate the biomass management strategies for the water hyacinth crops grown for biomass in a eutrophic lake in Central Florida and found a harvest strategy which maximize the biomass yield.

The objectives of this study are to develop a mathematical model to simulate biomass and productivity of water hyacinth and to use the model to test the importance of some physical and environmental factors in biomass production.

Materials and Methods

Study Site

Field experiments were carried out in an artificial enclosure of 15 ft x 15 ft which was made using a bamboo fences in the Bolgoda Lake, Sri Lanka. Sides were covered with strong nylon net, as shown in Figures 1 and 2, to prevent the escape of plants within the area. The enclosure was filled with healthy younger plants of same size and allowed to grow for 14 weeks. Maintenance of the plants was best achieved in the aquatic environment with minimum disturbance and preserving natural habitat (Fernando et. al. 2002).

A Sampler of one square meter was constructed which could be placed on the Water Hyacinth mat delineating one square meter sample area. The plants in the sample area were removed and washed with running water without damaging to delicate roots. The plants were then air dried for several hours and later oven dried at 105 °C for 48 hours until constant dry weight obtained.



Fig. 1. Study site during the first week of cultivation



Fig. 2. View of the study site seven weeks after cultivation

Water samples were also collected weekly from the study site and parameters such as temperature, pH, salinity, BOD, dissolved oxygen, nitrate, total nitrogen, total reactive phosphates, total phosphorus, and potassium were measured. Air temperature was also noted during water sampling.

Model Formulation

Two state variables such as biomass per square meter of shoots and roots were considered in the model. The above-ground plant stand was divided into 1 cm thick horizontal layers in which the dry matter budget and elongation were calculated separately. The governing equation of shoots and roots growth are described by;

$$\frac{db_{sh}(i)}{dt} = [Pg_{sh}(i) - R_{sh} - D_{sh}] b_{sh}(i) - G_{ri} \left(\frac{b_{sh}(i)}{B_{sh}} \right) - H_{sh} \left(\frac{b_{sh}(i)}{B_{sh}} \right) \quad (1)$$

$$\frac{dB_{ri}}{dt} = G_{ri} - R_{ri} B_{ri} - D_{ri} B_{ri} - H_{ri} \quad (2)$$

where $b_{sh}(i)$ is the dry weight of above-ground biomass at i th layer (g dry wt. m^{-2} per one cm height); B_{ri} is the root biomass (g dry wt. m^{-2}); $Pg_{sh}(i)$ is gross growth rate of shoots at the i th layer (day^{-1}); R_{sh} and R_{ri} are the respiration rate of shoots and roots (day^{-1}); D_{sh} and D_{ri} are the mortality rate of shoots and roots (day^{-1}); G_{ri} is the supply of photosynthesized material for root growth (g dry wt. $m^{-2} day^{-1}$); H_{sh} and H_{ri} are the harvesting rates of shoots and roots (g dry wt. $m^{-2} day^{-1}$); and B_{sh} is the total shoot biomass (g dry wt. m^{-2}). Total shoots biomass is given by;

$$B_{sh} = \sum_{i=1}^n b_{sh}(i) \quad (3)$$

where n is the number of layers in the plant canopy. The total biomass is equal to;

$$B_{Total} = B_{sh} + B_{ri} \quad (4)$$

and the total harvesting rate is equal to;

$$H_{Total} = H_{sh} + H_{ri} \quad (5)$$

The gross growth rate of the shoot biomass is assumed to be controlled by air temperature, water nutrients, and irradiance. The gross daily growth rate at the i th layer is given by the Michaelis-Menten type equation;

$$Pg_{sh}(i) = Pg_{max} \theta^{(T-20)} \frac{I_{PAR} e^{-k_c F_i}}{K_{PAR} + I_{PAR} e^{-k_c F_i}} f(N) f(P) \quad (6)$$

where Pg_{max} is the maximal photosynthetic growth rate (day^{-1}); θ is the Arrhenius constant; T is the daily averaged temperature; I_{PAR} is the photosynthetically active radiation ($J m^{-2} day^{-1}$) which is about 40-45% of daily total global radiation; k_c is the light extinction coefficient within the canopy; K_{PAR} is the half saturation irradiance; F_i is the cumulative leaf area index of the stand above the layer i .

$$F_i = \sum_{i=1}^i LAI(i) \quad (7)$$

A relationship of shoot biomass and LAI was established ($R^2=+0.97$) using the measured data obtained from Center and Spencer (1981).

$$\sum_{i=1}^i LAI(i) = 0.0047 \sum_{i=1}^i b_{sh}(i) - 1.0 \times 10^{-6} \left(\sum_{i=1}^i b_{sh}(i) \right)^2 \quad (8)$$

Nitrogen limitation and phosphorous limitation for the growth of the plants are given by

$$f(N) = \frac{N}{K_N + N} \quad (9)$$

$$f(P) = \frac{P}{K_p + P} \quad (10)$$

where N and P are concentration of inorganic nitrogen and phosphors in water (mg m^{-3}); K_N and K_p are half saturation constant for nitrogen and phosphors uptake (mg m^{-3}).

$$G_{rt} = g_m \theta^{(T-20)} \frac{K_{rt}}{K_{rt} + Age_{rt}} B_{rt} \quad (11)$$

where g_m is the maximum specific growth rate of roots at 20^0C ; K_{rt} is the half saturation coefficient of root age, and Age_{rt} is the age of roots.

Respiration for shoots and roots are given by;

$$R_{sh} = \beta_{sh} \theta^{(T-20)} \quad (12)$$

$$R_{rt} = \beta_{rt} \theta^{(T-20)} \quad (13)$$

where β_{sh} and β_{rt} are rate coefficients for respiration of shoots and roots (day^{-1}).

Mortality of the shoots and roots are given by;

$$D_{sh} = \gamma_{sh} \theta^{(T-20)} \quad (14)$$

$$D_{rt} = \gamma_{rt} \theta^{(T-20)} \quad (15)$$

where γ_{sh} and γ_{rt} are specific rate of mortality at 20^0C .

A time step of one day was used in the model calculations. Fourth order Runge-Kutta method was used in this model in order to solve the simultaneous differential equations representing state variables.

Results

Model was calibrated using the experimental data from Sato and Kondo (1981). Mineral composition of the solution he used was, in mg/l ; 3.5 $\text{NH}_4\text{-N}$, 24.5 $\text{NO}_3\text{-N}$, 7.7 P, 29.3 K, 18.2 Mg, 20.0 Ca, 2.5 Fe, 0.2 B, 0.2 Mn, 23.0 Na. The initial fresh biomass of each tank was 57.1 g. The fresh weight was converted to dry weight using the dry weight to fresh weight ratio of 3.94 % which was estimated by Sato and Kondo (1981). Several values of each parameter, within an expected range defined by the literature, were tested

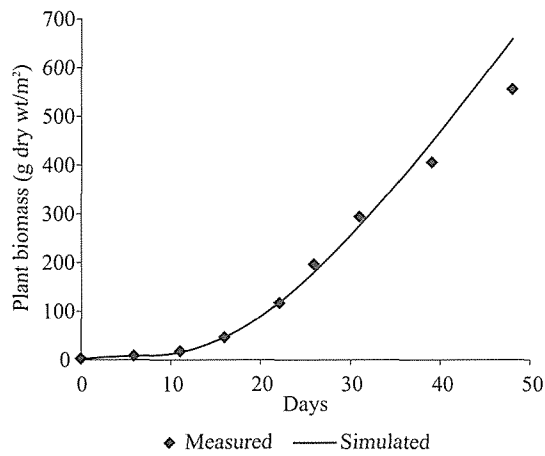


Fig. 3. Calibration of water hyacinth growth model using measured data from Sato and Kondo (1981)

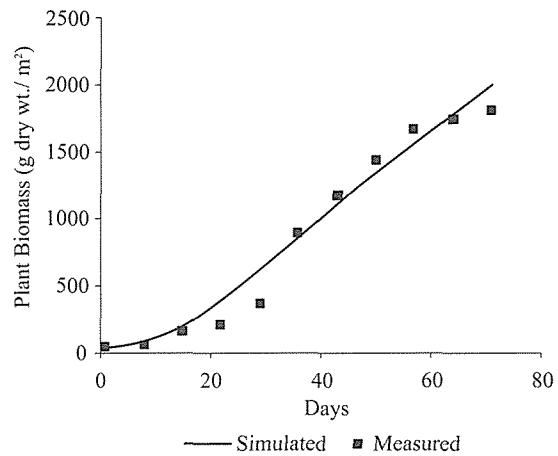


Fig. 4. Simulation of water hyacinth growth model using measured data from Bolgoda Lake, Sri Lanka

before arriving at growth curves which closely matched observed results as shown in Fig. 3.

The model is then used to simulate the growth of water hyacinth in Bolgoda Lake, Sri Lanka. The study site was completely covered with plants after seventh week as shown in Figure 2 and reached the maximum biomass in the eleventh week with a total biomass of 1800 g/m^2 . Growth of the plant was observed to be mainly in the vertical direction after the seventh week. Average $\text{NO}_3\text{-N}$ concentration in the water varied from $0.176 - 0.704 \text{ g NO}_3\text{-N/l}$ with an average of $0.42 \text{ mg NO}_3\text{/l}$. Phosphate phosphorous concentration in water varied from $0.02\text{-}0.16 \text{ mg PO}_4\text{-P /l}$. The The measured and simulated biomass is shown in Fig. 4.

Water hyacinth has been employed for treating sewage effluents, agricultural drainage water and eutrophic lake water (Gopal, 1987). Therefore it is required to find an efficient way to harvest the biomass of water hyacinth in order to attain the maximum sustainable yield. By this type of harvest strategy, it is possible to remove maximum amount of nutrients from water and simultaneously remove the aquatic plants to use in beneficial ways. The model was used to asses the growth of water hyacinth after harvesting at different time interval. It was found that if water hyacinth is harvested at 30 days interval the maximum harvest would be $348 \text{ g of dry wt./m}^2$ and if the harvesting interval is 40 days the maximum harvest would be $566 \text{ g dry wt./m}^2$.

The model was then used to study the growth after harvesting to a initial weight of 50 and $100 \text{ g dry wt./m}^2$. If water hyacinth was harvested to a initial weight of 50 and $100 \text{ kg dry wt./m}^2$ the maximum harvest which could be obtain after 20 days were about 259 and $329 \text{ g dry wt./m}^2$.

Conclusions

A growth model of water hyacinth is presented in this study. The model was calibrated using the data from Sato and Kondo (1981) and used to simulate the water hyacinth biomass in Bolgoda Lake, Sri Lanka. The model application shows how the model could be used to evaluate the management option for water hyacinth biomass production for nutrient removal. These options include initial density after harvesting and harvesting interval.

Salinity of the water and pathogen attacks can affect the growth of the plant. Mortality of the plant due

to salinity and pathogen attacks was not considered in this model.

References

- Center, T.D. and Spencer, N.R. (1981) The Phenology and Growth of Water Hyacinth (*Eichhornia Crassipes* (Mart.) Soims) in a Eutrophic North-Central Florida Lake. *Aquatic Botany*, 10, pp. 1-32.
- Fernando, P.U.D, Gamage, N.P.D, and Jayaweera, M.W. (2002) Growth characteristics of water hyacinth; an application to Bolgoda Lake, Proceedings of the 8th annual symposium, Engineering Research Unit, University of Moratuwa, Sri Lanka
- Gopal, B. (1987) Water Hyacinth, Aquatic Plant Studies 1, *Elsevier*, pp. 1-471.
- Lorber, M. N., Mishoe, J. W. Reddy, P. R. (1984) Modeling and Analysis of Waterhyacinth Biomass, *Ecol. Modelling*, 24, pp. 61-77.
- Mitsch, W. J. (1976) Ecosystem modeling of Waterhyacinth in Lake Alice, Florida. *Ecol. Modelling*, 2, pp. 69-89.
- Reddy, K.R., Agami, M. and Tucker, J.C., (1989) Influence of Nitrogen Supply Rates on Growth and Nutrient Storage by Water Hyacinth (*Eichhornia Crassipes*) Plants. *Aquatic Botany*, 36, pp. 33-43.
- Reddy, K.R., Agami, M. and Tucker, J.C. (1990) Influence of Phosphorus Supply on Growth and Nutrient Storage by Water Hyacinth. *Aquatic Botany*, 37, pp. 355-365.
- Reddy, K.R., Agami, M., D'Angelo, E.M. and Tucker, J.C. (1991) Influence of Potassium Supply on Growth and Nutrient Storage by Water Hyacinth. *Bioresource Technology*, 37, pp. 79-84.
- Satho, H. and Kondo, T. (1981) Biomass Production of Water Hyacinth and its Ability to Remove Inorganic Minerals from Water. I. Effects of The Concentration of Culture Solution on the Rates of Plant Growth and Nutrient Uptake. *Japan J. Ecol.*, 31, pp. 257-267.
- Satho, H. and Kondo, T. (1983) Biomass Production of Water Hyacinth and its Ability to Remove Inorganic Minerals from Water. II. Further Experiments on the Relation Between Growth and Concentration of Culture Solution. *Japan J. Ecol.*, 33, pp. 37-46.