INTERANNUAL FLOOD IMPACT ON AQUATIC PLANT COVER IN A GRAVEL-BED RIVER

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The invasion and overgrowth of alien aquatic species in rivers are serious concerns in river management. The physical removal of plant bodies from river beds is a viable procedure for reducing the biomass of overgrown aquatic plants. However, since the entire area of the river covered by the aquatic plant of interest must be addressed, this type of approach requires significant effort and a substantial budget. Floods are crucial events that reduce the amount of aquatic plant biomass in rivers. Therefore, combining the impact of natural and/or controlled floods with physical plant removal in rivers may be a promising approach for controlling aquatic plant growth. To understand interannual changes in the spatial distribution of aquatic plant patches in a river, we recorded pictures of plant cover for the invasive aquatic plant *Egeria densa* using time-lapsed cameras fixed to a bridge crossing over a river section. Based on these recorded images, we estimated interannual changes in aquatic plant cover. We also developed a numerical model that allows us to represent the interannual changes of aquatic plant cover within a river reach.

1 INTRODUCTION

The invasion of alien aquatic species in rivers is a serious concern in river management. Compared to controls in ponds and lakes, aquatic plant control in rivers is difficult due to water flow. In ponds and lakes, chemical and biological measures have been utilized to control unfavorable aquatic plants. In rivers, such controls are ineffective or nearly impossible to conduct because chemical and biological agents flow out from the treatment area. Running water in rivers also disperses plant body segments, naturally or artificially detached from settled plant patches. Dispersed plant body segments settle within downstream reaches in rivers and grow again to form new aquatic plant patches. The physical removal of plant bodies from river beds is a viable procedure for reducing aquatic plants. However, since the entire area of the river covered by the aquatic plant of interest must be addressed, this approach requires significant effort and a substantial budget. Floods are crucial events that regulate the amount of aquatic plant biomass in rivers. Therefore, combining the impact of natural and/or controlled floods with physical removal may be a promising approach for controlling aquatic plants in rivers, especially for management programs with limited resources.

Egeria densa is a native aquatic plant in South America, but has widely settled in Japan and other parts of the world. In Japan, a large number of *Egeria densa* communities have settled within the Gono River system. Other river systems in Japan have also been impacted by invasive aquatic plants including *Egeria densa*. For our study, we examined a river reach of the Jyouge River, a tributary of the Gono River system, located downstream from the Haizuka dam. Within this reach, the overgrowth of *Egeria densa* has caused serious problems to the local and downstream aquatic ecosystem. Since 2013, to understand the characteristics of growth and wash-out due to flood disturbances within this reach, we have been recording pictures of aquatic plant cover in the river bed using time-lapsed cameras fixed to a bridge crossing over the river reach. Based on these recorded images and other field records, we investigated interannual changes in the spatial distribution of *Egeria densa* patches. We then developed a numerical model in order to represent the interannual change of *Egeria densa* cover within this reach.

2 METHODS

We surveyed a river reach within the Jyouge River located 10 km downstream from the Haizuka Dam. Time-lapse cameras were fixed to the parapet of the bridge. Images were intermittently recorded at noon from 15 June 2012 to 10 September 2015. Prior to obtaining the first picture, a number of floats with anchors were placed within the river reach then the position of each float was measured using a Real Time Kinematic Global Positioning System (RTK-GPS). The arrangement of floats in the first picture was used for the Ground Control Points (GCPs) that are required for correcting the spatial distortion of recorded images. Consecutive pictures taken from the bridge were then converted to orthoimages (distortion corrected images) in order to evaluate the spatial distribution of the aquatic plant patch in physical dimensions. Floats used as GCPs were removed from the river reach after the first pictures were obtained.

Orthoimages obtained prior to and following events (flushing flows, natural floods, and low flow periods during summer) were selected and the area of aquatic plant cover was calculated from each selected image. The aquatic plant cover area was manually selected from an approximate 300 m^2 area in orthoimages using the Magic Wand Tool in Photoshop (Adobe Systems Inc). The cover area of orthoimages changed with date due to the difference in camera alignment, so the percentage of aquatic plant cover divided by the total image cover area of each snapshot was calculated.

Flow rate and water temperature at the discharge site of the Haizuka dam, recorded by the dam authority, was used as a reference for flow disturbance and the seasonal change in water temperature.

3 RESULTS

The discharge hydrograph and the water temperature of outflow from the Haizuka Dam are provided in the upper graph of Figure 1. Aquatic plant cover percentages for selected events are plotted in the lower graph of Figure 1. In the discharge hydrograph shown with a blue line, one-hundred cubic meter per second events were observed each March, corresponding to the flushing flows conducted by Haizuka Dam that mimic snowmelt floods. During summer, spikes in discharge were observed to occur as a result of natural flooding.

In general, the cover area increased from spring to late summer and decreased from autumn to early the next spring. The cover area was reduced following floods and flushing flows.

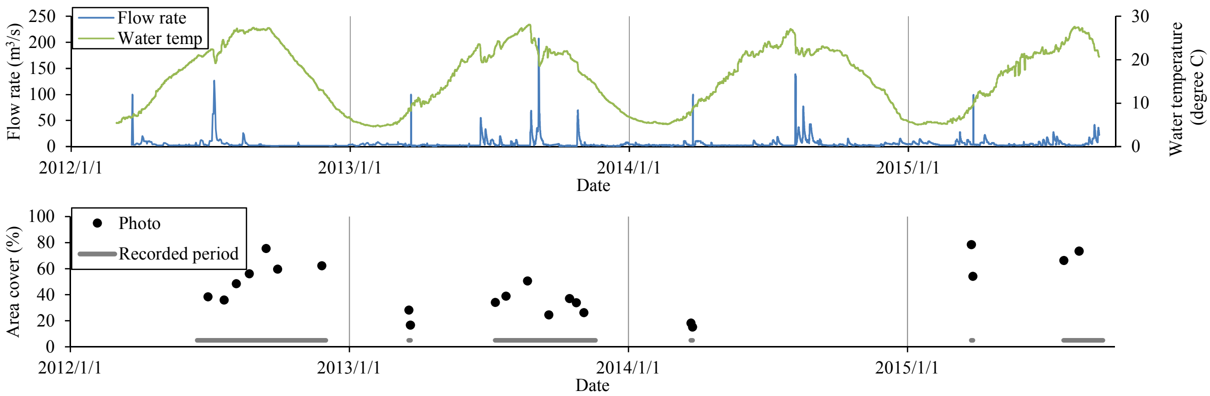

Figure 1. The interannual change of discharge (blue line in the upper graph), the water temperature (green line in the upper graph), the aquatic plant cover area percentage for selected dates (filled circles in the lower graph), and the duration recorded by the camera (gray lines in the lower graph).

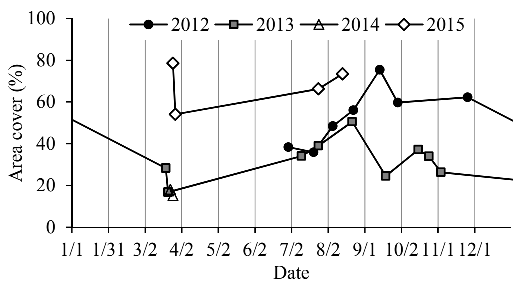

Figure 2. Seasonal change in aquatic plant cover percentage.

In Figure 2, the seasonal change in aquatic plant cover area is plotted using a different configuration from that of Figure 1. In Figure 2, the horizontal axis corresponds to elapsed days from the 1st day of January each year. Drops recorded in March of each year correspond to a response due to flushing flows. The rate of reduction was 40%, 17%, and 31% for flushing flows conducted during 2013, 2014, and 2015, respectively. The cover area increased from April to July, corresponding to the growth of *Egeria densa*. During this period, the cover area increased by 103% over 111 days in 2013, and 23% over 119 days in 2015. From August to September, the cover area was increased (e.g. a 34% increase in 22 days during late August 2012, a 30% increase in 28 days during August 2013, and a 11% increase in 20 days during August 2015). Discontinuous reduction in the cover area occurred during summer, corresponding to a response to flood disturbance. In July 2012, the cover area dropped by 7% following a 126 m^3/s peak discharge flood event. A twenty-one percent reduction in the cover area was observed during Sept 2012, but no flow rate increase was observed during this period. In early September during 2013, a relatively large flood, with a peak discharge of 207 m^3/s, flowed within this reach and the cover area dropped by 51%. From late September to December, the cover area displayed some fluctuation due to the temporal growth and senescence of the local aquatic species *Hydrilla verticillata* and another large filamentous green-algae (including *Cladophora fracta*). Both *Hydrilla verticillata* and the large filamentous green-algae vanished during winter, and the cover area of *Egeria densa* was observed to have a gradual reduction during winter (from December to the following March).

4 DISCUSSION

4.1 The impact of flushing flows and floods

The amount of plant cover area reduction was related to the magnitude of flow disturbance. For this analysis, we assumed that: (1) the magnitude of flow disturbance is represented by peak discharge, (2) the area reduction percentage is proportional to peak discharge, and (3) flow rates less than 20 m^3/s, almost equivalent to the normal flow rate, do not contribute to cover area reduction. Figure 2 provides the relationship between peak discharge and area reduction based on our field observations. The regression line is also depicted in Figure 3 and, as later discussed, this line was used for the flood response model.

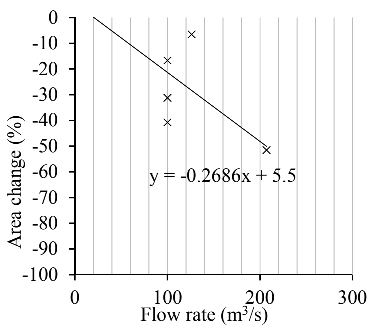

Figure 3. The relationship between the peak flow rate of flow disturbances and area reduction.

4.2 The growth and senescence of *Egeria densa*

We established a logistic-curve model for describing the expansion and reduction of the *Egeria densa* cover area during normal flow periods. The model used was, as follows:

$$\frac{dA}{dt} = r\left(\frac{100 - A}{100}\right)A \tag{1}$$

where A is the cover area in percent, t is the time in days, and r is a parameter corresponding to the growth rate.

We assumed that growth rate is a function of water temperature. Tanimizu and Miura (1976) reported that gross production displayed a peak at 25°C in water temperature and that gross production was reduced for a water temperature above or below 25°C. Haramoto and Ikushima (1988) reported that *Egeria densa* grows in water with a temperature higher than 15°C. Based on the above information, the growth rate is represented by the function shown in Figure 4. Here, T_{c1} is a critical temperature for beginning positive net growth, T_{c2} is the most productive temperature, r_1 is the inclination of the growth rate at a temperature below T_{c1}, and r_2 is the inclination for growth rate at a temperature above T_{c1}. Using the data set of field records described above, the parameters r_1 and r_2 were determined by minimizing square errors. We obtained values of r_1 = 0.00103 and r_2 = 0.000561. Critical water temperatures were set as T_{c1} = 12 and T_{c2} = 25.

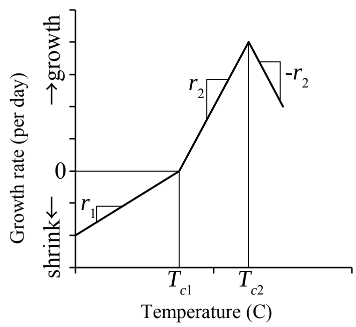

Figure 4. Growth rate function.

4.3 The seasonal cover area change model

Using the response model for flow disturbance as described in Section 4.1 and the growth model described in Section 4.2, we reproduced the seasonal change of aquatic plant cover percentage; shown in Figure 5 using a gray line. Here, the initial area cover percentage was fitted as well as the model parameters r_1 and r_2. Growth during summer, reduction following floods and flushing flows, and gentle reduction during winter are represented by the model. Quantitative agreement between the model and the observed data was limited (the mean absolute percentage error was 15% and the Nash-Sutcliffe efficiency was 0.12), but the model represented trends observed in the field (the statistical significance was $p = 0.042$).

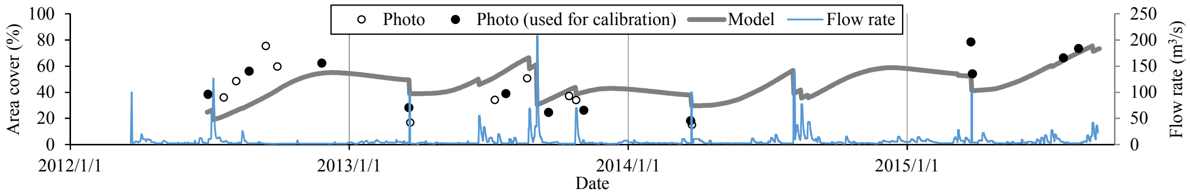

Figure 5. Seasonal change in aquatic plant cover predicted by the model (gray) as compared to observations (circles) and the discharge hydrograph (blue line). Filled circles correspond to data used for model parameter fitting, whereas open circles indicate data not used for the parameter fitting but shown for reference.

Using the established model, we will discuss the impact of dam discharge control on aquatic plant biomass quantities within this downstream reach. The results of this hypothetical case study will be presented at the conference.

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