EFFECTS OF FLOW REGIME ON THE VEGETATION RECRUITMENT AND ESTABLISHMENT IN AN UNREGULATED SANDY STREAMS IN KOREA –FOCUSED ON THE LIMITING SURVIVAL CONDITION OF PIONEER PLANT BY HYDROCHORY

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ABSTRACT

We investigated the effect of flow regime on the riparian vegetation recruitment and establishment in an unregulated sandy stream, focusing on the limiting condition of pioneer plants that are recruited on the stream shore mainly by hydrochory. For this study, we used the factor of the critical bed shear stress, the dominant physical factor affecting the stability of sediment bars with pioneer vegetation. This study focuses on a sharply curved, almost 180-degree curved reach in a sandy stream, which had maintained white sand bars along the curved channel in the reach, since probably before 1965, when the oldest aerial photo is available, without virtually allowing any recruitment of vegetation. We used a verified numerical model to evaluate the two-dimensional distribution of bed shear stresses at the study reach at some critical periods of recorded years. Soil moisture, another critical constraint on the germination and survival of pioneer plants, was not considered, for saturated shorelines and hydrochory are primary concerns in this study. By this study, we have found that the Shields number, or the dimensionless critical shear stress, to bury and wash away pioneer vegetation of node smartweed (Persicaria nodosa) varies with the age of the vegetation; smaller than 0.4 for a two-month-old plant and larger than 1.2 for a four-month-old one. This result substantiates the hypothesis that, in the monsoon climate zone, floods in late spring and early summer are critical to the change from “white river” to “green river."

Keywords: vegetation recruitment, unregulated stream, flow and sediment regime, hydrochory, Shields number

1. INTRODUCTION

Rivers in the world, including Korea, are being changed, to a different extent in a different region, with or without human impacts, from “white” rivers to “green” or “greenery” rivers, i.e., from the rivers with white sand and gravel bars to those with green vegetation. This phenomenon is especially prevailing in Korea (Choi et al., 2005; Egger et al., 2012; Woo et al., 2014) and also in Japan (Asaeda et al., 2013), both of which are located at a similar latitude and commonly affected by a monsoon climate. Those changes cause engineering problems of a decrease in river safety as well as ecological impacts (Gurnell, 2014).

Since Williams and Wolman’s pioneering study about 35 years ago (Williams and Wolman, 1984), accelerated recruitment and establishment of vegetation on the riparian bottomland along the streams have been investigated by many researchers, too many to mention about all here. Relatively recently, there have been some state-of-the-art reviews of the studies on the interactions among flow and sediment, vegetation and geomorphology, including among others, Osterkamp and Hupp (2010), Gurnell et al. (2016), and Solari et al. (2016). They have all concluded in general that the common factors influencing the riparian vegetation processes are the flow regime and soil moisture.

This study investigates the effect of flow regime on the riparian vegetation recruitment and growth in an unregulated sandy stream, focusing on the limiting condition of stability of pioneer plants that are recruited on the stream shore mainly by hydrochory. It is the latest one in the series of the authors’ similar studies on the effects of changes in flow regimes and soil moisture on vegetation recruitment and growth on riparian bars after

Woo et al. (2014) and Lee et al. (2019). In this study, we consider a sharply curved, almost 180-degree curved reach called Hoeryongpo, in the sandy stream of the Naesung-cheon (Fig. 1). The Hoeryongpo had maintained the white sand bars along the curved channel in the reach, since the first aerial photo available in 1965, without virtually allowing any single patch of vegetation (See the study reach bounded with red lines up- and down-streams in Fig. 3). We have observed, for three years, from 2013 through 2015, the germination and growth of the target species, node smartweed, along the shorelines in the study reach. Weights and heights of the plants after germination in April until weathering in fall after pollination and seed-spreading were measured about once a month, separately for the upper part and root part of the vegetation. A numerical analysis was conducted on the study reach to calculate the distributions of flow and bed shear stress focusing especially on the shorelines. The vegetation, mostly node smartweed (Persicaria nodosa) (Fig. 2), was recruited along the shorelines in spring by hydrochory and survived during mild floods in 2014 and sustained in the next years.

Figure 1. Location map of the study stream, the Naesung-cheon and study reach, Hoeryongpo

Figure 2. Node smartweed (Persicaria nodosa) and their seeds (Sources are shown at Reference)

2. HYDRO-GEOMORPHOLOGICAL AND VEGETATIVE CHARACTERISTICS OF THE STUDY STREAM

2.1 Hydro-geomorphic traits

The Naeseong-cheon stream, selected as a case study, is a tributary of the Nakdong-gang River, the longest river flowing through the southeast of Korea and merging the South Sea at the port city of Busan. The stream is 108.2 km long, and the basin is 1,815 km^2 wide. It is a typical sandy stream in Korea with its median bed material size of about 1.6 mm. With its channel slope of 9/10,000~1.7/1,000, the river valley of the stream is relatively narrow with its ratio of valley width over channel width being 1.5~3.0, and transverse movements of the channel are restricted by uplands and hills.

The annual average temperature at the basin is 11.4℃, and the annual average precipitation is 1,231 mm. The annual precipitation increased slightly until the early 2000s and since then has decreased slightly. The stream itself is considered an unregulated stream, although a dam was constructed upstream in the late 2000s, for any water impoundment has not been made since the completion of the dam. Two-year return period flood of the stream at the river mouth is 690 m^3/s by daily discharge.

The stream could be one of the best examples of changing its vegetative characteristics from "white" to "green" rivers, i.e., from the rivers with white sand and gravel bars to those with greenery bars along the narrow stream corridor (Woo et al. 2016). Nevertheless, the study reach in the stream had maintained its white sand bars along the channel until December 2013, as shown in Fig. 3, which seems uncommon in the study river. However, as shown in Fig. 4(a) taken at the transect marked "A" in Fig. 4(a) in March 2016, patches of vegetation are found on the edges of sand bars along the channel. These are obviously new vegetation recruited mainly by hydrochory after December 2013 and before March 2016. Fig 4(b) is the photo taken in 2017 right after the vegetation in the reach was much removed by river manager in that year for restoring the aesthetic value of the place. The Hoeryongpo, the name of the study reach, can sustain the unique aesthetic and cultural value with the white sand bars along the almost 180^o-curved channel.

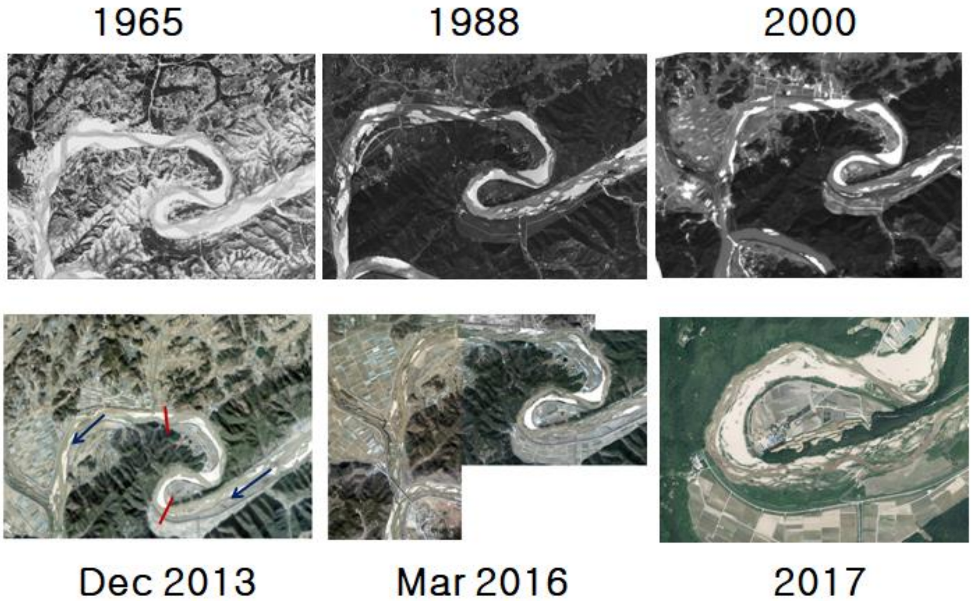
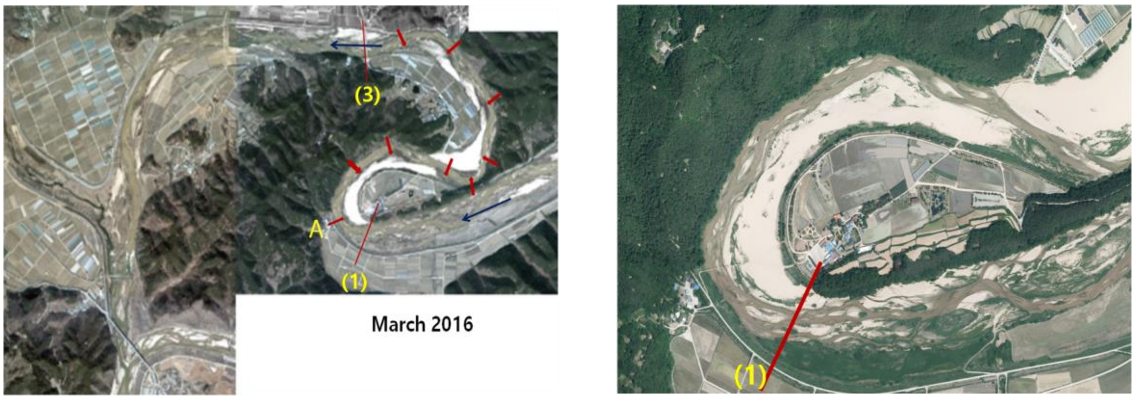


Figure 3. A series of aerial photos of study reach since 1965 until 2017 (No vegetation found along the channel shores, within the study reach between the red-color marked lines at up- and down-stream ends in the 2013 photo)



(a) Aerial photo in 2016 (b) Aerial photo in 2017

Figure 4. Aerial photos of the study reach in March 2016 (left) and 2017 (right) (Vegetation found along the channel lines, shores, marked with arrows within the study reach in 2016 photo; Some vegetation were removed for aesthetic purpose as shown in 2017 photo)

2.2 Vegetative traits

We observed that the target species, node smartweed, started germination usually in late April in this reach and grew up to about 30 cm in late June. By this time, the diameter of the above-ground stem was 4~9 mm, and the root grew about 26 cm long. The dry weight of the above-ground part was 3.9 g, while that of roots was 0.8 g. In late August, passing the maximum growth period slightly, the height of the above-ground part was large than 50 cm in average, root length was 45 cm, stem diameter was 13.2 mm, dry weight of the upper part was 75.6 g, and that of the root part was 11.5 g. From then, they started to make pollination and seed-spreading and withered in brown color.

Fig. 5 shows changes in the average growth (height) with time for three different years, 2013, 2014, and 2015. As shown in this figure, in 2013, they germinated in April and grew to about 7 cm tall, and then they did not survive after early June. On the other hand, the vegetation both in 2014 and 2015 grew large than 50 cm tall on average, and decreased in height from mid-September and withered in late fall. Our interest is in the growth and mortality of the vegetation in 2013 by flood and the survival in 2014 enduring flood. In 2015, there were no floods.

Fig. 6 shows photos that were taken in 2013, 2014, and 2015, respectively. As shown in Fig. 6(a), no node smartweeds are found in the transect “A” until at least August 15, 2013, while it appears that they were recruited along the shore about six months before September 4, 2014, as shown in Fig. 6(b). In Fig. 6(c) taken on September 24, 2015, it appears that they were fully established. It is known that the plant’s seeds, shown at the inside picture of Fig. 2, can disperse by wind, although not far, and also can disperse in flowing water, half-submerged. It can germinate whenever temperature and moisture conditions are satisfied, mostly observed from March through October.

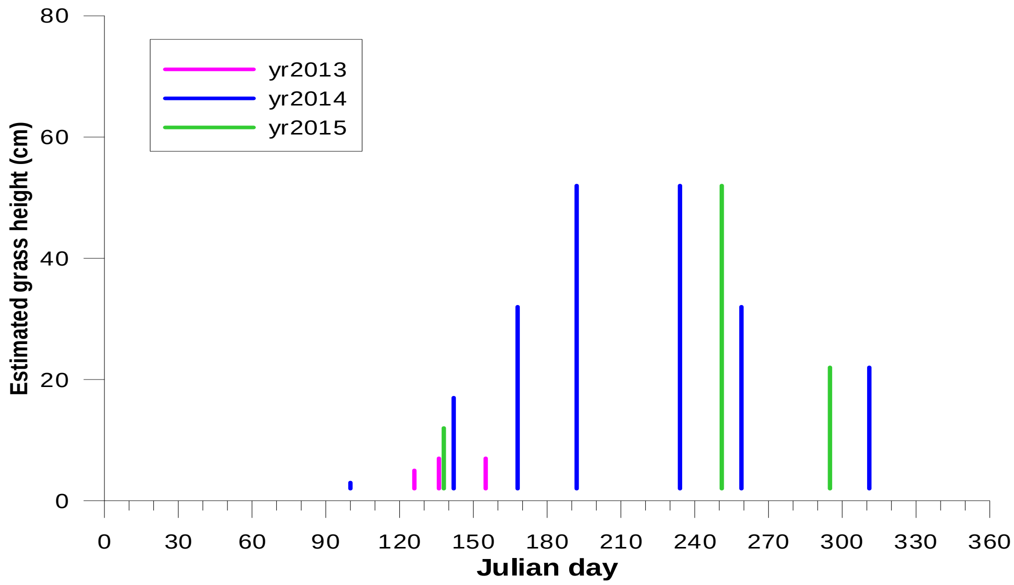


Figure 5. Changes in plant heights with time for the years of 2013, 2014, and 2015

(a) (b) (c)

Figure 6. Series of photos of the study transect "A" in Fig. 4(a) (Photo (a) taken on August 15 2013, (b) taken on September 4 2014, (c) taken on September 24 2015); Node smartweeds not seen in the photo (a), while they were recruited along the shore in photo (b), they are established in photo (c).

The conceptual model of hydrochory (Nilsson et al 2010) starts from floating propagules, including seeds, which are dispersed from the further upstream, riparian zone, and uplands mostly by wind. They are temporarily stranded on the stream shore but further dispersed before germination takes place. Stranded propagules can be dispersed further to riparian bars and floodplain depending on the magnitude of floods.

3. MODELING OF FLOW AND BED SHEAR STRESS

3.1 Numerical model

We used the Nays2D model, which is loaded on the iRIC model (Shimizu et al., 2014). The model utilizes the boundary-fitted coordinates, especially fitting irregular boundaries like the stream in this study. In this model, the CIP (Cubic Interpolated Psuedoparticle) method is used for the advection term at the staggered grid, and the Central Difference Method is utilized for the diffusion term. Water and sediment discharges are used as upstream boundary conditions, while normal depth is adopted as a downstream boundary condition. Velocities vertical to stream bank is assumed zero, and slip-condition is assumed for the velocities in the flow direction on it.

3. 2 Data for numerical model

The study reach starts from the line (1) and ends at the line (3) in Fig. 4(a). The study reach contains a sharply-curved channel upstream, followed by another mildly-curved one, and followed by a relatively straight one, and then followed by another mildly-curved one. It is about 3.8 km long, with its channel varies from 406 m to 209m. The channel slope is about 0.0009, and the median size of the bed material is 1.5 mm.

Fig. 7 shows daily discharge variation at the reach from 2012 to 2018, showing typical summer floods and large temporal variations in river discharge affected by a monsoon climate. In this study, we selected four large flows marked in dot circles in Fig. 7, representing the maximum flood each year during the period of vegetation recruitment in the study reach. They are listed in Table 1. Within this period, the largest flood occurred on July 7, 2016, which far exceeded the 2-yr return-period flood of 690m^3/s at the reach, while the smallest one did not exceed it on August 4, 2014.

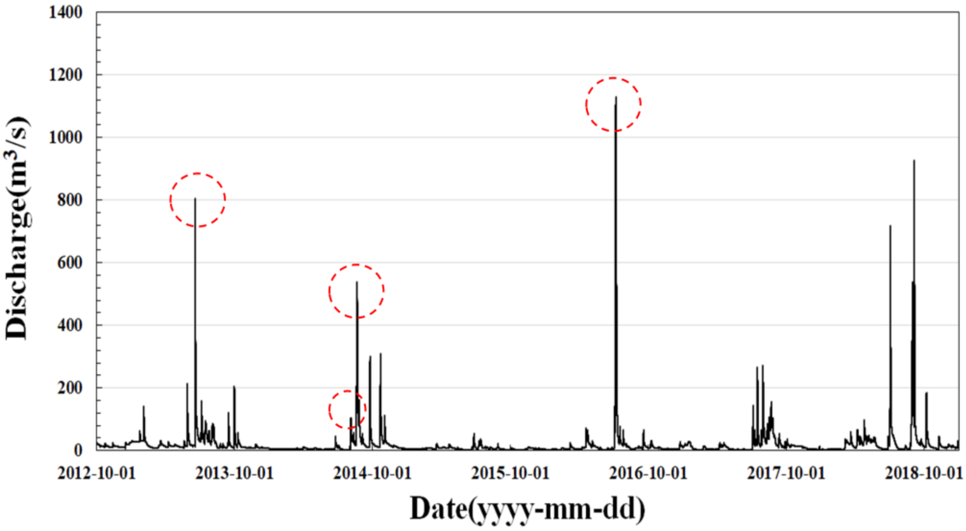
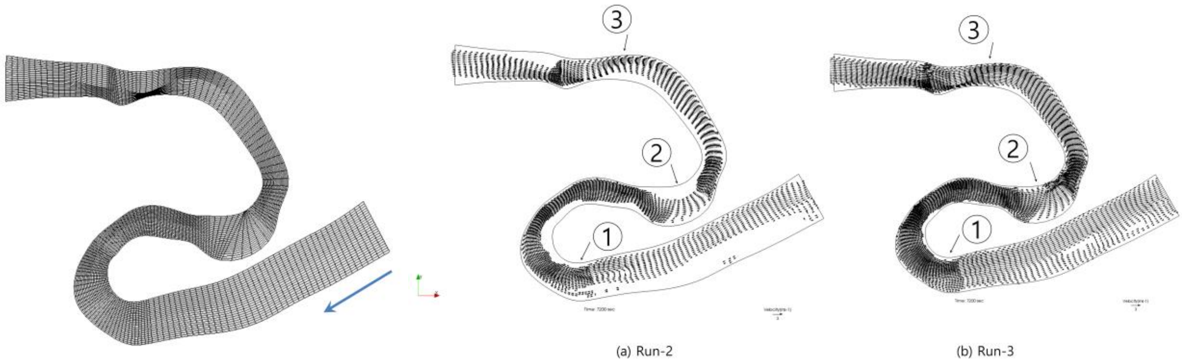


Figure 7. Daily water discharge at study reach (measured at Water gauging station Hoeryongpo)

Table 1. Four selected floods in the study reach during the recruitment period.

Case	Discharge (m^3/s)	Mean diameter of sediment (mm)	Date	Remarks
Run-1	806	1.5	June 19, 2013	> 690 (2-yr return period)
Run-2	103	1.5	August 4, 2014	< 690
Run-3	538	1.5	August 21, 2014	< 690
Run-4	1,090	1.5	July 7, 2016	> 690

Computational reach in this study is larger than the study reach to start from an upstream gauging station, which is located about 2.5 km from the upstream section (1). For this calculation, a set of grids was constructed, as shown in Fig 8(a) with 205x25(=5,125). Cells were made to have dense grids at curved reaches and sparse grids at relatively straight ones to maintain a stable computation. Manning' n was set 0.03 for typical sand streams. Computational time was set at 0.01 seconds.



(a) (b) (c)

Figure 8. Grid construction for computation (a), velocity distribution by Run-2 (b), velocity distribution by Run-3 (c)

3.3 Results of computation and discussion

Fig. 8(b and c) shows computed velocity distributions of Run-2 and Run-3. Run-2 shows a velocity (depth-averaged) distribution with concentrated flows near the outer bank of the curved channel with the point bars in the channel not submerged. On the other hand, large floods can usually submerge the point bars, as shown in Fig. 8(c)

Previous studies (Lee et al. 2019, Egger et al. 2012) on the stability of pioneer vegetation have used the dimensionless shear stress,τ_*, or Shields number for the criterion of vegetation mortality by burial and washing away. It is written mathematically as

$$\tau_* = \frac{\tau_0}{(\gamma_s - \gamma)D} \qquad [1]$$

where γ is the unit weight of water, γ_s is the unit weight of sediment, D is the sediment size, and τ_0 is the bed shear stress. The bed shear stress τ_0 is written as

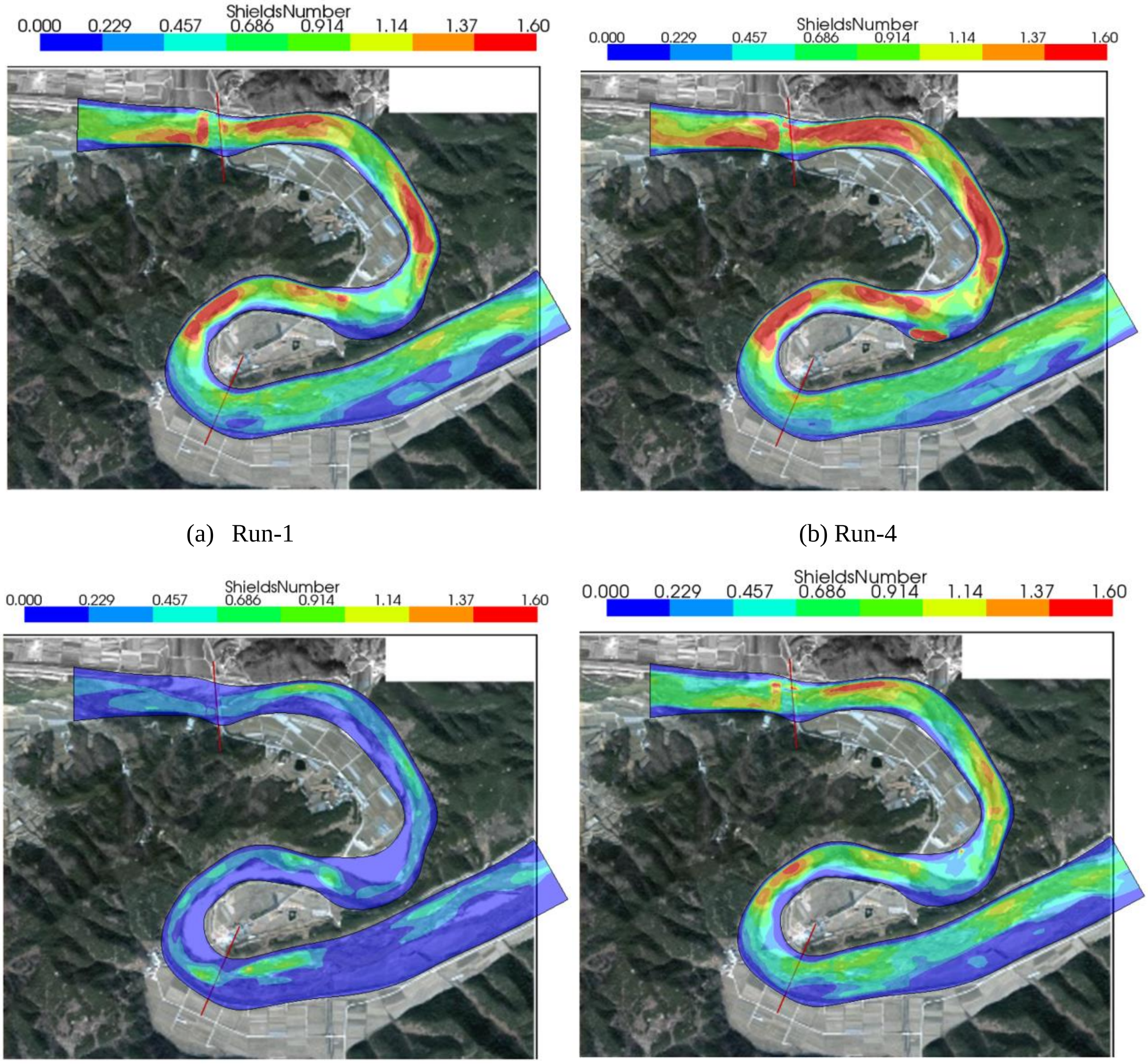
$$\tau_0 = \gamma \, d \, S \qquad [2]$$

where d is the water depth, and S is the energy slope of flow.

It has been known that besides other specific conditions such as climate and soil moisture, which are also critical to the survival of riparian pioneer vegetation, in general, the physical stability of the bar surface is the dominating factor to the survival of vegetation (Gurnell et al. 2016). In this study, soil moisture, still critically important for the germination and growth of vegetation in most cases, is assumed to be fully satisfied, for saturated shorelines and hydrochory are the main concerns in this study.

Most existing studies on the physical stability of riparian pioneer plants on the bar surface have used the dimensionless bed shear stress of 0.05 or 0.06 at the Shields curve for the critical condition of stability (Egger et al. 2012, Woo et al. 2014). Below that number, the bar surface is considered sufficiently stable without sediment particle motion, while well above the number, it can be unstable, and seeds buried slightly in soil and seedlings are subject to mortality due to burial and washing-away. In reality, no proper range of the critical value has been suggested yet for the riparian pioneer vegetation stability. For a single-species patch, it should depend obviously on the vegetation species and its age.

Fig. 9 shows the distribution of the Shield number of each run, from Run-1 to Run-4, overlapped on the aerial photo of Fig. 4(a) where vegetation appeared first. As shown by Run-1 and Run-4 in Fig. 9 (a and b), most cells corresponding to the vegetated shore patches in Fig. 4(a) are colored in yellow, orange, and red, which indicate the values exceeding 1.0. On the other hand, as shown in Fig. 9(c), Run-2, most cells corresponding to them are colored in dark blue and light blue, which indicates the values to be well below 0.7~0.9. As shown in Fig. 9(d), Run-3, the largest flood after the vegetation was recruited in the spring of 2014, most corresponding cells in the study reach are colored in green and blue, indicating the values over the cells are mostly less than 0.9~1.0. Here, the corresponding cells mean the areas covered with vegetation patch along the channel, as indicated with arrows in Fig. 4(a)



(a) Run-1 (b) Run-4

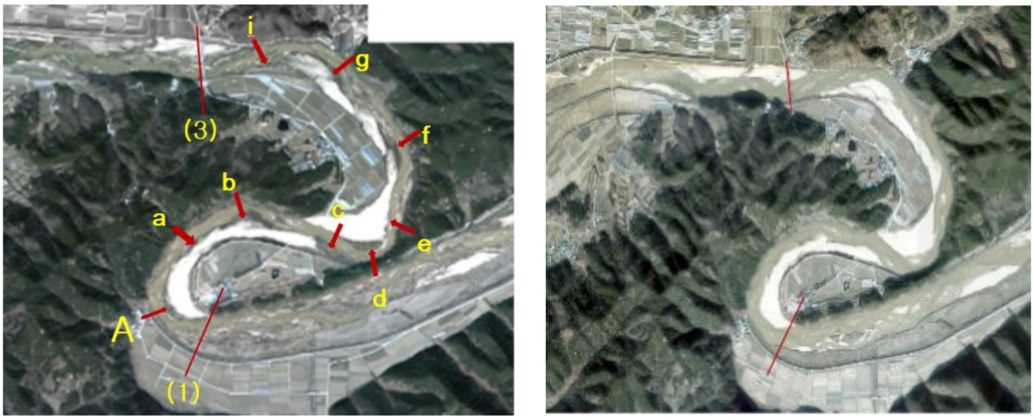
(c) Run-2 (d) Run-3

Figure 9. Distribution of Shields number in the study reach overlapped on the aerial photo of March 2016 (Fig 4a)

To examine the distribution of Shields numbers along the shorelines as indicated with red strips in Fig. 4(a) in 2016, the year of vegetation recruitment in the study reach, a few sub-reaches are identified, as shown in Fig. 10, with “a” to “i ” from upstream to downstream. The average Shields number of each sub-reach calculated is listed in Table 2.

As shown in Fig. 3, the aerial photo taken in December 2013 shows no vegetation along the shorelines. In Fig. 5, vegetation with 7 cm tall appears until early June. There was a flood on June 19 of that year shown as Run-1 in Table 1. Now, it is clear that the vegetation in the study sub-reach died of that flood with the dimensionless Shields numbers ranging 0.4 ~1.5. With this result, we can conclude that the 2-month old node sweetweed with 7 cm tall would die of burial and washing-away by the Shields number at least 0.4, which is far larger than the value of 0.06 for the initiation of particle motion.

Now, we turn to the case of 2014, the critical year for vegetation establishment. At Run-2 with the smaller flood in August 2014, all the Shields numbers are less than 0.4, while at Run-3 with the larger flood in the same critical month and year of 2014, a few places show value larger than 1.0. On average, the Shields number at Run-3 is 0.7. The picture (Fig. 6b) taken on September 4, 2014, is just two weeks after the August 21 flood (Run-3), in which node smartweeds are observed. The vegetation appears to have grown to larger than 50 cm on average for about four months after germination. In this sense, it could be considered that the critical Shield number for the mortality of vegetation of node smartweeds of four-month-old (well passing the seedling stage) is more than 1.2.



(a) March 2016 (b) December 2013

Figure 10. The aerial photo of March 2016 with arrows pointing riparian vegetation patches along the study reach (magnified from Fig. 4a) (For comparison, the aerial photo of Dec 2013 (b) is shown at left)

In 2015, there were no floods at all, as shown in Fig. 7, which would have been the best condition for the recruitment and establishment of the riparian vegetation such as node sweetweed either by the same-site germination or hydrochory.

The above discussions, including those for the years of 2013, 2014, and 2015, substantiate the hypothesis that, for the study reach in the monsoon climate zone, floods in late spring and early summer are critical to the change from “white river” to “green river."

Table 2. Dimensionless bed shear stresses at sub-reaches marked with “a” to “i” in Fig. 9(a) for each run

Case	A	b	c	d	e	f	g	h	I	Mean	Max	Min
Run-1	0.51	1.63	0.95	0.40	0.41	0.76	1.47	0.81	1.22	0.91	1.63	0.40
Run-2	0.19	0.33	0.22	0.23	0.20	0.14	0.37	0.17	0.07	0.21	0.37	0.07
Run-3	0.42	1.25	0.73	0.39	0.39	0.59	1.13	0.62	0.89	0.71	1.25	0.39
Run-4	0.59	1.98	1.15	0.70	0.42	1.16	1.80	0.98	1.53	1.15	1.98	0.42

4. CONCLUSIONS

Based on the field observation, analysis of aerial photos, and analysis of flow calculation, we can conclude, at least for the stream and vegetation adopted as a case study here, as follows:

- A one or two-year abstraction of floods of a certain magnitude at a critical period of the year can cause vegetation recruitment and establishment on bare sandbars along the river channel, which is not quickly restored to the white river with larger floods as shown in this case study.
- For this case study, the critical Shields number, the dimensionless bed shear stress for the mortality of node smartweed of two-month-old by the instability of sediment bar, would be smaller than 0.4, while those of four-month-old would be larger at least than1.2.
- This result substantiates the hypothesis that floods in late spring and early summer are critical to the change from the white river to the green river in the monsoon-affected region.
- The Shields number of 0.06, the critical condition of the initiation of particle motion, is not recommended as a criterion of vegetation recruitment on riparian bars except probably for germination and early seedling period.

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https://m.blog.naver.com/PostView.nhn?blogId=jangsangsig&logNo=220870979148&proxyReferer=https%3A%2F%2Fwww.google.com%2F (for plants)