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RESPONSE OF DIODIA VIRGINIANA (RUBIACEAE) APPLIED TO DAM RESERVOIR SLOPES AS A COVER PLANT, JAPAN

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ABSTRACT: Reservoir slopes of dams are typically bare or sparsely vegetated due to their steep inclination, long-term submergence, marked fluctuation of water levels and impact of waves, which promote soil erosion and cause water turbidity, deterioration of the landscape, and disrupt ecosystem functioning. Using plants to stabilize slopes and prevent erosion is difficult, and the introduction of plants for this purpose has been extensively debated. This study examined the effectiveness of Virginia buttonweed (Rubiaceae: *Diodia virginiana* L.) for stabilizing the exposed slopes of the Matsubara Dam in western Japan- *Diodia virginiana* was originally introduced to a 0.1-hectare experimental area on the dam slopes from 1994 to 1997. Since that time, *D. virginiana* flourished; in 2008 it was widespread around the dam, growing in harsh environments such as steep slopes and shoreline, and by 2016, the distribution and density of the species increased. These characteristics of *D. virginiana* growth mean that the species is well suited for use as a cover plant for preventing erosion on dam reservoir slopes.

Keywords: Cover plant, Dam, Erosion control, Reservoir slope, Virginia buttonweed

1. INTRODUCTION

Dams have a variety of functions, including the storage of water for drinking and agriculture, generating electricity, and providing habitats for wildlife. In addition, dams are important for mitigating floods in Japan, particularly in the rainy season in June and July, and the typhoon season in August and September. Dams used mainly for flood control exhibit marked fluctuations in water levels during the year as the water level of reservoirs is typically lowered artificially approximately two months before the onset of the rainy and typhoon seasons. Since these fluctuations in water levels can be in the order of dozens of meters, extensive reservoir slopes can be exposed when the water level is lowered (Photo 1).

These slopes are typically bare or sparsely vegetated due to their generally steep gradient, extended submergence and impacts of waves as well as marked fluctuation of water level, which have a negative effect on landscape appearance, ecosystem integrity and water quality [3], [6], [10], [11], [14], [16] (Photo 1). Although slopes can be stabilized using a variety of methods, the artificial introduction of cover plants for purposes of erosion control is difficult.

It was previously reported that the reservoir slopes of some dams on Kyushu Island in western Japan had spontaneously become covered by Virginia buttonweed (Rubiaceae: *Diodia virginiana* L.); for example, Midorikawa Dam, Ichifusa Dam, and Tsuruta Dam [8], [10]. From 1994 to 1997, therefore, test areas on the reservoir slopes of Matsubara Dam were stabilized with *D. virginiana* to prevent erosion and related problems [6], [10], [16]. Here we examine the current state of the slopes and discuss the utility of using *D. virginiana* as a cover plant for erosion control on reservoir slopes.

Photo 1 Reservoir slopes exposed when the water level of dam was lowered (reproduced from the River Bureau, Min. of Land, Infrastructure, Trans. and Tourism [14]).

2. METHODS

2.1 Study Site

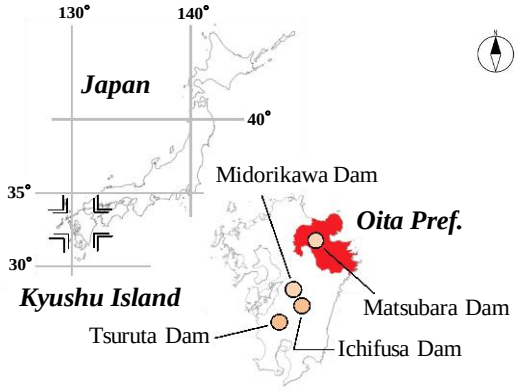

Fig. 1 Location of the study site, Matsubara Dam, in Oita Prefecture, and some dams the reservoir slopes of which are spontaneously covered by *Diodia virginiana*.

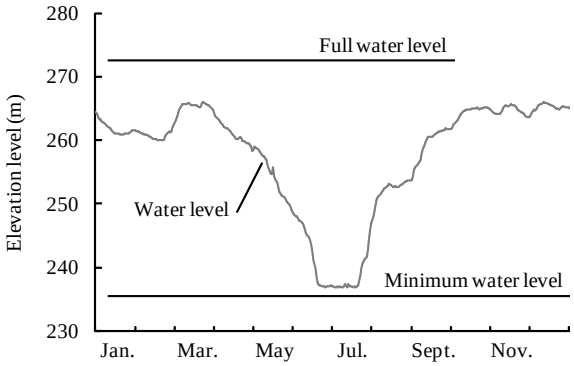

Fig. 2 Seasonal change of the average fluctuation in water level of reservoir of Matsubara Dam in recent years.

Matsubara Dam is situated in Oita Prefecture, Kyushu Island, in western Japan in an area that is dominated by andesite soils [9] (Fig. 1). This dam is located in the warm temperature zone where the mean annual temperature and annual precipitation for the last decade (2007-2016) ranged from 15.1 to 16.8°C and 1,561 to 2,481 mm, respectively [4].

Matsubara Dam, which was constructed in 1973 as a multipurpose dam for water supply, flood control and generation of electricity, is a concrete gravity-type dam with a wall measuring 83.0 m high (elevation level (meters above sea level): 192.0 - 275.0 m) and 192.0 m long [9]. The basin area, reservoir area and gross capacity are 491 km^2, 1.9 km^2 and 54,600,000 m^3, respectively [9]. Seasonal fluctuations in the water level of Matsubara Dam in recent years are shown in Fig. 2. The water level decreases most from the middle of June to the end of July, and the reservoir slopes are highly exposed in this period.

Introduction of *D. virginiana* to the reservoir slope was conducted on three occasions from 1994 to 1997 using seeds, rhizomes and seedlings. A total area of approximately 0.1-hectare was used for all trials [6], [10], [16].

2.2 Vegetation Survey

Permission for the study on the reservoir slopes of Matsubara Dam was obtained from the Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism. The steepest (steep slope) and gentlest (gentle slope) slopes were selected for analysis in the permitted areas.

A transect was set up along the slope perpendicular to the dam shore in early July 2008 when the water level was lower than usual (at 237 m, see Fig. 2). After conducting a topographical survey along the transect, survey quadrats (1 × 1 m each) were placed on the transect at approximately 2-m intervals. The species composition of the plants in each quadrat was recorded using the Braun-Blanquet cover-abundance scale [1]. Vegetation on the slopes was classified by TWINSPAN calculated using the PC-ORD statistical software package (ver. 4.0 for Windows, MjM Software Design, OR). The Braun-Blanquet cover-abundance scale (r, +, I, II, III, IV, and V) was transformed as follows: r and + were taken as 0.1%; I as 5.0%; II as 17.5%; III as 37.5%; IV as 62.5%, and V as 87.5%.

In addition, coverage of *D. virginiana* along the reservoir shoreline was also surveyed and mapped early in September 2008 and 2016 when the water level was 263 and 265 m, respectively; these surveys were conducted using a boat and Braun-Blanquet cover-abundance scale.

3. RESULTS

3.1 Reservoir Slope Vegetation

The reservoir slopes of Matsubara Dam were extensively vegetated (Photo 2 [A-H]). The vegetation (2008) was classified into six vegetation types (I, II, III, IV, V and VI) using TWINSPAN (Fig. 3); Types I, II, III and IV were dominated by *D. virginiana*, which had been applied to the slopes as cover plant for erosion control, together with *Oenothera laciniata* Hill and *Cynodon dactylon* (L.) Pers. Types V and VI were dominated by *Xanthium occidentale* Bertoloni and *C. dactylon*. The former group was typically found on a steep slope and/or near the top of both the steep and gentle slopes, which is where the shoreline is when the dam is full (Fig. 2), and the latter group

[A-H]: Reservoir slopes when the water level was lowered; [G, H]: Areas used as rice paddies before construction of the dam; [I-M]: *Diodia virginiana* on the slopes; [I, J]: Flowers; [K]: Seeds and young seedlings; [L, M]: Rhizomes and adventitious roots, and [N]: Vegetation survey of reservoir shoreline using a boat.

Photo 2 Matsubara Dam from July to September.

was restricted to the gentle slope (Fig. 4).

3.2 *Diodia virginiana* along the Reservoir Shoreline

Diodia virginiana was observed over most of the reservoir shoreline of Matsubara Dam in 2008 (Fig. 5), and distribution and density of this species increased in 2016.

4. DISCUSSION

The effects of fluctuations in water level, extended submergence and wave action constitute serious barriers to the colonization and establishment of plant species including cover plants [3], [11], [14]. The findings of this study showed that the stands of *D. virginiana* introduced approximately 10 years previously had expanded considerably beyond the 0.1 ha study plots to cover vast regions of exposed dam shore (2008) (Photo 2; Fig. 5), and that the distribution and density of this species had increased over time (2016) (Fig. 5). In addition, most of this growth was observed on a steep slope and along the shoreline (Figs. 2, 4), and the latter is vulnerable to wave impact.

It appears that *D. virginiana* is suitable for use as a cover plant for stabilizing the reservoir slopes of dams. The success of this species for this purpose is considered to be due to the fact that the seeds of *D. virginiana* are covered with suberin, which causes the seeds to float readily and spread

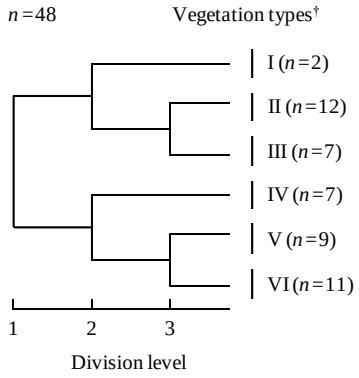

Fig. 3 Classification of vegetation on reservoir slopes by TWINSPAN using species composition (coverage data, %) (2008).
†, on the basis of plant coverage size in each vegetation type (I-VI), the type was defined as follows: I, *Diodia virginiana* - *Oenothera laciniata*; II, *Diodia virginiana*; III, *Diodia virginiana* - *Cynodon dactylon*; IV, *Cynodon dactylon* - *Diodia virginiana*; V, *Xanthium occidentale* - *Cynodon dactylon*, and VI, *Cynodon dactylon* - *Xanthium occidentale.*

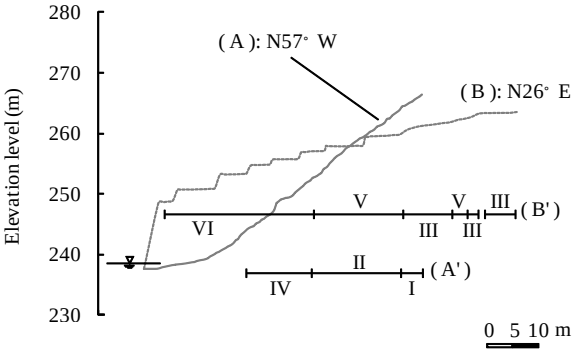

Fig. 4 Vegetation types on reservoir slopes.
(A) and (B) indicate steep and gentle slopes, respectively. (A') and (B') indicate vegetation types on steep and gentle slopes, respectively. Vegetation types: See Fig. 3.

widely [6] (Photo 2 [K]), and even young plants are remarkably resistant to inundation; according to Imamura and Uchida [3], several-month-old seedlings of *D. virginiana* can tolerate submergence for more than half a year.

It is also considered that the presence of other plant species, such as *O. laciniata*, *C. dactylon* and *X. occidentale*, on both types of slopes may have been facilitated by *D. virginiana*, which effectively bound the soil of the dam slopes and trapped the seeds of other grass species (Fig. 4). And furthermore, succession among species would have been promoted on the gentle slope (Fig. 4).

5. CONCLUSIONS

Given the importance of conserving landscapes and biodiversity, the application of cover plants for erosion control on slopes (e.g. Kondo *et al.* [7]; Uchida *et al.* [15]) has become preferable to civil engineering solutions. Under the circumstances, in this study, it is considered that characteristics of *D. virginiana* growth are well suited for use as a cover plant on dam reservoir slopes (Figs. 4, 5). In addition, the dense carpets, attractive flowers and long rhizomes produced by this species (Photo 2 [I, J, L, M]) mean that it could be used to prevent erosion, increase aesthetic appearance, and promote soil binding in areas at risk of soil erosion. However, since *D. virginiana* is an alien species native to "North America", extensive growth of the

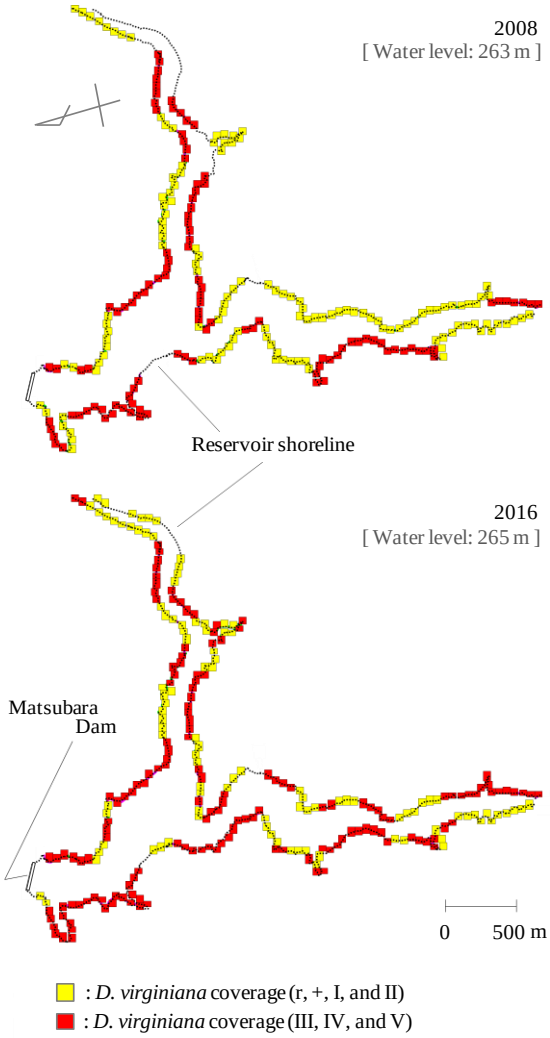

Fig. 5 Distribution of *Diodia virginiana* along the shoreline of Matsubara Dam showing the coverage, Braun-Blanquet cover-abundance scale.

species could adversely affect ecosystem integrity and biological diversity. Indeed, *D. virginiana* is becoming increasingly troublesome weed even in the US, particularly in Alabama, Georgia, Mississippi, North Carolina, etc., where control using herbicides is currently being investigated [2], [5], [12], [13]. It is, therefore, necessary to overcome a trade-off between the application of *D. virginiana* as a cover plant and the potential negative effects of this species on biological diversity.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Braun-Blanquet J., 1964. Pflanzensoziologie. Grundzüge der Vegetationskunde, 3rd ed. Springer-Verlag, Vienna. 865 pp.

[2] Hutto K.C., Brecke B.J. and Unruh J.B., 2008. Comparison of flazasulfuron to pyridine herbicides for Virginia buttonweed (*Diodia virginiana*) control. Weed Technology 22, 351-353.

[3] Imamura Y. and Uchida T., 2011. Seed germination and seedling growth of Virginia buttonweed- *Diodia virginiana* L. (Rubiaceae). LRJ 74, 479-482. *In Japanese*.

[4] Japan Meteorological Agency, Ministry of Land, Infrastructure, Transport and Tourism [JPN], 2017. Website of the AMEDAS <http: //www.jma.go.jp/jp/amedas/>. *In Japanese*.

[5] Kelly S.T. and Coast G.E., 2000. Postemergence herbicide options for Virginia buttonweed (*Diodia virginiana*) control. Weed Technology 14, 246-251.

[6] Kochi Y., Matsumoto A., Mutsunobu K., Makino A., Yamada M. and Suzuki M., 2007. Application of *Diodia virginiana* L. as the revegetation plant on dam slope. J. Jpn. Soc. Reveget. Tech. 33, 171-174. *In Japanese*.

[7] Kondo K., Uchida T., Hayasaka D., Tanaka J., Sato A. and Arase T., 2016. Vegetation succession on cut slopes covered with exotic grasses for erosion control, Mt. Sakurajima. Int. J. of GEOMATE 11, 2136-2142.

[8] Konno R., 2003. Revegetation of reservoir slope of dam for environmental conservation, using *Diodia virginiana*. Mizutotuti 132, 29-35. *In Japanese*.

[9] Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism [JPN], 2017. Website of the Dam Joint Control Office of Chikugo-gawa River <http://www.qsr.mlit.go.jp/toukan/gshokai/ matsubara.html>. *In Japanese*.

[10] Matsumura M. and Fukuda K., 1996. Conservation of dam reservoir slope by Virginia buttonweed. Engineering for Dams 124, 42-50. *In Japanese*.

[11] Miyake K. and Onishi A., 2005. Study on lake front planting within water level change area of dam reservoirs. Bull. of Water Resources Environment Technology Center, 50-56. *In Japanese*.

[12] Ni H., Wehtje G., Walker R.H., Belcher J.L. and Blythe E.K., 2006. Turf tolerance and Virginia buttonweed (*Diodia virginiana*) control with fluroxypyr as influenced by the synergist diflufenzopyr. Weed Technology 20, 511-519.

[13] Reed T.V., Yu J. and McCullough P.E., 2013. Aminocyclopyrachlor efficacy for controlling Virginia buttonweed (*Diodia virginiana*) and smooth crabgrass (*Digitaria ischaemum*) in tall fescue. Weed Technology 27, 488-491.

[14] River Bureau, Ministry of Land, Infrastructure, Transport and Tourism [JPN], 2006. Draft for re-vegetation of dam reservoir slopes. 96 pp. < http://www.mlit.go.jp/river/shishin_guideline/ dam6/pdf/koganryokuka_tebiki.pdf>. *In Japanese*.

[15] Uchida T., Tanaka J., Kondo K., Hayasaka D., Tomoguchi Y., Arase T. and Okano T., 2017. Evaluating the dynamics of alien species (Poaceae) used for erosion control on Sakurajima volcano. Int. J. of GEOMATE 12, 114-120.

[16] Yamamoto T., Makino A. and Yamamoto K., 1999. Bio-engineering technique with Virginia buttonweed on dam reservoir slope (I). Abstract of 30th Conference of Jpn. Soc. Reveget. Tech., 234-237. *In Japanese*.