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.

2. METHODS

2.1 Study Site

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]).
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 km², 1.9 km² and 54,600,000 m³, 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 TWINSPLAN 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 TWINSPLAN (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 the steepest 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...
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...
Division level

\[ n = 48 \]

Vegetation types†

| 1 (\( n = 2 \)) | II (\( n = 12 \)) | III (\( n = 7 \)) | IV (\( n = 7 \)) | V (\( n = 9 \)) | VI (\( n = 11 \)) |
|-----------------|------------------|------------------|------------------|----------------|------------------|
| I               |                  |                  |                  |                |                  |
| II              |                  |                  |                  |                |                  |
| III             |                  |                  |                  |                |                  |
| IV              |                  |                  |                  |                |                  |
| V               |                  |                  |                  |                |                  |
| VI              |                  |                  |                  |                |                  |

![Diagram](image)

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.

![Vegetation type](image)

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.

![Distribution](image)

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

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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
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, and Florida. A common practice of 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.

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