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# FIRST-YEAR RESPONSES TO MANAGED FLOODING OF LOWER COLUMBIA RIVER BOTTOMLAND VEGETATION DOMINATED BY *PHALARIS ARUNDINACEA*

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*Abstract:* Managers at Smith and Bybee Wetlands Natural Area (SBW), an 800-ha preserve in Portland, Oregon, recently installed a water control structure to suppress invasive reed canarygrass (*Phalaris arundinacea* L.) with spring and summer flooding. We hypothesized that greater depth of flooding would decrease *Phalaris* growth and percent cover. We randomly established 27 transects throughout SBW before completion of the water control structure and measured percent cover of vegetation prior to flooding in autumn 2003 and then after one growing season in autumn 2004. We also monitored phenological characteristics of individual stands of reed canarygrass growing in different depths during 2004. Overall reed canarygrass cover decreased from 43.7% in 2003 to 41.2% in 2004 (McNemar's test; $p < 0.001$). Where inundation was $> 0.85$ m, reed canarygrass cover declined 6.1%. Where this deeper inundation coincided with regenerating willow forest, reed canarygrass cover declined 10.7%. Both before and after higher inundation, reed canarygrass cover was negatively correlated with plant species diversity (before: Spearman's rho = $-0.67$, $p < 0.001$; after: Spearman's rho = $-0.41$, $p = 0.036$). Cover of several native taxa (e.g., *Polygonum* spp., *Bidens* spp., *Salix lucida*) increased in 2004. After flooding, reed canarygrass stands grew more slowly and changed their structural growth pattern. These findings suggest that managed flooding might be operationally useful in suppressing reed canarygrass.

*Key Words:* ecosystem management, invasive species, native plant restoration, reed canarygrass, wetland ecology, wetland hydrology

## INTRODUCTION

Reed canarygrass (*Phalaris arundinacea* L.) is an invasive grass species that contributes to wetland degradation across North America. A long-lived, cool-season, perennial grass, it has a vigorous growth habit supported by an extensive underground rhizome system. Due to its prolific growth, reed canarygrass develops dense, monotypic stands (Naglich 1994, Barnes 1999). Monocultures may dominate wetlands for decades, reducing overall floral diversity, especially of late-season emergent species (Emers 1990, Barnes 1999).

Ecologists and wetland managers are seeking ways to suppress reed canarygrass to restore native species, overall biodiversity, and natural ecosystem functions. Invasive plants such as *Phalaris* can alter habitat structure, food webs, and nutrient cycling (Werner and Zedler 2002, Kao et al. 2003, Zedler and Kercher 2004). Efforts to control the spread of reed canarygrass have included tilling, flooding, herbicides, mowing, grazing, shading, biocontrol with pathogens, and/or scalping (removal of topsoil) (Stannard and Crowder 2001, Hovick and Reinartz 2007). Paveglio and Kilbride (2000) suggest maintaining consistent water levels through winter and early spring, in conjunction with other control measures, to prevent the spread of reed canarygrass.

Responses of reed canarygrass to flooding, however, have been equivocal. Reed canarygrass can produce high biomass in flooded areas (Rice and Pinkerton 1993). Lefor (1987) reported that reed canarygrass forms adventitious roots at its nodes in response to flooding, spurring vegetative reproduction, and Coops et al. (1996) found an increase in the number of nodes with flooding depth up to 80 cm. Conversely, Coops et al. (1996) also found a reduction in reed canarygrass biomass when plants were growing in water depth $> 30$ cm, with stem density decreasing in depths $> 5$ cm. Miller and Zedler (2003) found that flooding to 15 cm reduced both belowground and overall biomass for this species.

Duration and timing of flooding can both influence reed canarygrass. Frequent flooding and drying (alternating weeks from May to September) produced more and longer shoots, while long-duration flooding produced fewer shoots (Miller and Zedler 2003). In contrast, Rice and Pinkerton (1993) found that tiller production was reduced when reed canarygrass was subjected to cyclic inundation lasting more than three days. Molofsky et al. (1999) found that aboveground biomass increased with higher soil moisture in June, but in July the pattern reversed. In light of these conflicting results, Lavergne and Molofsky (2004) emphasized the need for more empirical studies on hydrological management on reed canarygrass.

Altering historic hydrological patterns can degrade ecological function, and contribute to the establishment and spread of reed canarygrass (Warren et al. 2002, Kercher et al. 2004). In cases where a return to natural hydrology is impractical, managed flooding could approximate the ecological benefits of natural flooding (Michener and Haeuber 1998). Specifically, a drawdown after spring and early summer flooding might benefit native emergent vegetation (Harris and Marshall 1963).

In the urbanizing areas of the lower Columbia River, human activities have accounted for extensive loss of wetlands and a fundamental change in the hydrologic cycle (Holland et al. 1995). The Smith and Bybee Wetlands Natural Area (SBW), located in the Columbia Slough area of north Portland, has experienced a reduction in both the depth of spring flooding and the duration of summer drying. Reed canarygrass has also increased at SBW, changing from 25% to over 45% cover in the emergent zone between 1992 and 2001 (E. Stewart, unpublished data). In December 2003, Metro (the regional metropolitan governing authority headquartered in Portland, Oregon) finished the construction of a new water control structure at SBW. This structure featured removable stoplogs, enabling managers at SBW to mimic historic flooding and drying patterns. Management objectives included: 1) controlling reed canarygrass by flooding during spring and early summer growth periods; and 2) supporting native emergent and bottomland hardwood plant communities via late summer drawdown. The purpose of our study was to determine the effectiveness of this strategy.

## METHODS

### Site Description and Water Management

Smith and Bybee Wetlands Natural Area, an 800-ha complex of wetland and riparian habitats, is located in north Portland, Oregon (lat 45°37′N; long 122°45′W) near the confluence of the Columbia and Willamette rivers (Figure 1). Off-channel bottomlands in the Columbia River floodplain such as SBW historically experienced seasonal flooding and drying periods. Human activities have altered the hydrology of these wetlands since the late 1800s. Water level management on the Columbia River itself has reduced flow during the spring flooding season by 43% (Bottom et al. 2005). In 1982, an earthen dam was erected where Columbia Slough enters SBW, further limiting seasonal variation in wetland lake levels at the site. With lake levels higher throughout the year, much of the willow forest along shorelines surrounding the lakes died back. Several dry years in the early 2000s, when lakes temporarily dried, permitted some recolonization by Pacific willow (*Salix lucida* Muhlenb. ssp. lasiandra [Benth.]) along lake shores.

In December 2003, Metro replaced the earthen dam with the present water control structure (Figure 1). The water control structure is managed to mimic historic hydrology, particularly spring flooding and summer drying, by retaining as much water as possible through late spring and drawing down the wetlands through summer. During our study period, water was retained until early June 2004, when drawdown was initiated (Figure 2). Drawdown proceeded slowly, at approximately 15 cm/week, until drying in August. By early August, the structure was open to the tidal fluctuations of the Columbia River via North Slough, although tides were only sufficient to affect low-lying areas. The control structure remained open until 10 November 2004, when the stoplogs were placed to capture precipitation and high river levels.

### Vegetation Distribution and Change

*Experimental Design.* Using aerial photographs and GIS software, we created a grid of 10 × 10 m cells over a 50 m band around the perimeter of the SBW wetlands. We randomly selected 27 points from this grid for study (Figure 1). We entered decimal latitude and longitude for each point into a GPS unit (Trimble TDC 1 Asset Surveyor), and installed transects perpendicular to the shoreline through these points. We sampled transects in random order.

*Physical Measurements.* We used the line intercept method (Brower et al. 1997) to measure plant cover along each transect at 10 cm intervals over the 2.5 km cumulative length of the 27 transects. We identified plants to species when possible. Transect

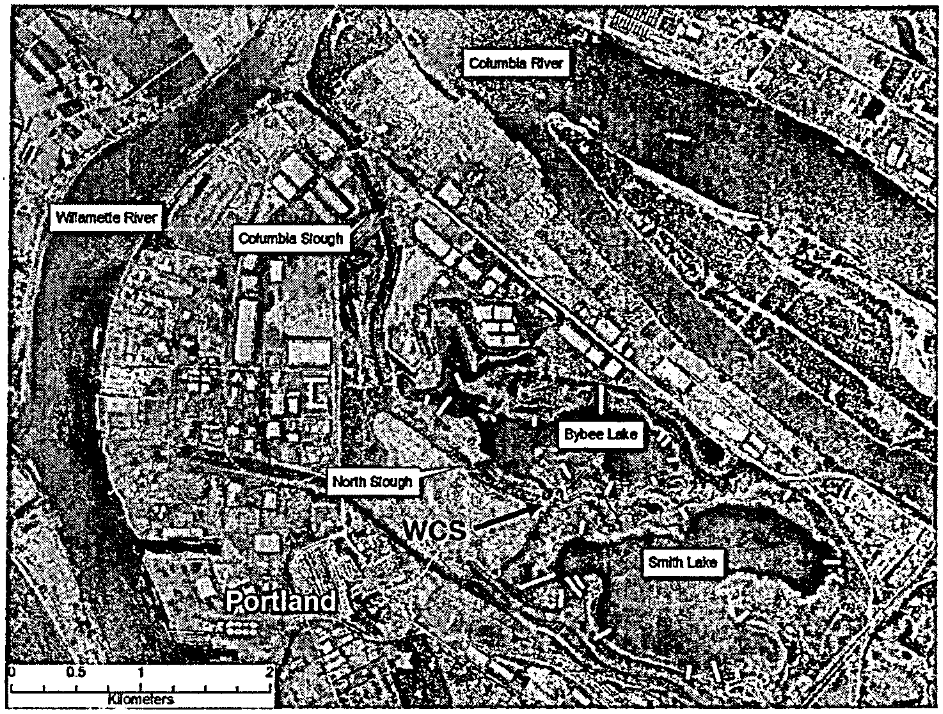


Figure 1. Aerial photograph of the Smith and Bybee Wetlands Natural Area (SBW). Transects for the present study are marked in white, shown to scale. The location of the water control structure (WCS) is shown by the black arrow. The photo was taken during July 2006.

measurements began during the driest part of the year. Initial measurement began on 20 October 2003, and 17 transects were completed without complication. In November, however, rising water levels in low-lying areas and killing frosts that caused leaf fall from the willow forest hindered measurements in the remaining 10 transects. Beginning on 20 November 2003, we limited sampling on

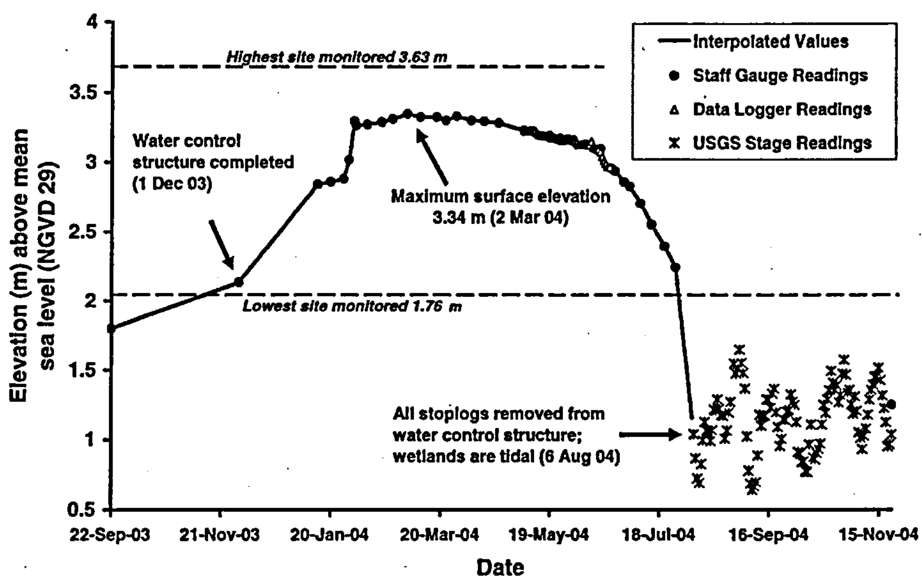


Figure 2. Hydrograph of Smith and Bybee Wetlands Natural Area (SBW) from 22 September 2003 to 22 November 2004. Daily interpolated values are based on a linear interpolation between staff gauge readings. Dashed lines indicate the highest and lowest elevations where vegetation was sampled during the present study.

those 10 transects to sections that were upland of the willow forest (Figure 1). Work was completed on 3 December 2003. We repeated those measurements the following year, between 9 September 2004 and 8 November 2004, collecting data at all points sampled in 2003. Using the same personnel both years ensured consistent data collection.

We surveyed ground elevations ($\pm$ 0.15 cm) for all 27 transects with a Topcon AT-G2 autolevel (Precision Instruments, Portland, OR) with a tripod and a survey rod, following methods in Herubin (1982) for differential and profile leveling. We ran level circuits to the transects from known-elevation benchmarks. Once we had established an elevation on a transect, we performed profile leveling at 3 m intervals to develop a topographical profile of the transect.

Water level readings were obtained weekly from a staff gauge at the point where North Slough enters the wetland lake system (Figure 1) from 1 December 2003 through 27 July 2004. The staff gauge was located on the impounded side of the control structure. Because transects were hydrologically connected, these readings reflected surface water-level data for all transects. A pressure transducer installed next to the staff gauge from 6 May to 21 June 2004 recorded water level data at daily intervals. On 6 August 2004, the last stoplogs in the water control structure were removed, leaving the wetland lakes subject to tidal fluctuations; thereafter lake levels were assumed to be the same as readings for Columbia Slough (available from USGS website, http://waterdata.usgs.gov/or/nwis/dv/?site_no=14211820andagency_cd=USGS).

### Reed Canarygrass Phenology

*Experimental Design.* We defined a "stand" of reed canarygrass as a patch between 1 and 5 m across that occurred contiguously along a transect during initial sampling in the autumn of 2003. Independent stands were separated by at least 1 m. Using this definition, 87 stands occurred over the 27 transects, and we selected 36 of these stands for study, giving equal representation to different water depths.

*Physical Measurements.* We monitored the 36 stands every two weeks, from 19 May–21 July 2004. On each of four visits, we measured the straightened height, water depth, and number of branches for six plants. During the final visit, we collected data on plant height without straightening, before recording the straightened plant height. We used the ratio of these two measurements as an indicator of plant erectness, which is related to the health of stands (Northup and Nichols 1998).

### Statistical Methods

We used McNemar's test (Zar 1998) to analyze differences in the percent cover of individual plant taxa between 2003 and 2004 ($\alpha = 0.05$). We used the same test to determine whether a given taxon replaced, or was replaced by, reed canarygrass. We then examined the effects of flooding on reed canarygrass in the willow forest portions of the transects to determine whether changes in reed canarygrass cover might be associated with the presence of willows. We defined the willow zone as all sample points between the lowest and highest elevations where young willow was present in both years of the study. Using a chi-square test, we compared the net loss of reed canarygrass under willow canopy to that of unshaded areas in the willow zone on the 17 complete transects.

We interpolated elevation values for each 1 dm interval along the transects, assuming a linear trend between survey points. We calculated maximum depth of inundation at each point by subtracting its elevation from the maximum surface water elevation recorded at the water control structure for 2004. We estimated duration of flooding at each point on the transects using water-level data and interpolated elevations. We used multinomial logistic regression (Systat 11 Software Inc., Richmond, CA) to assess the relationship of two variables, maximum inundation and presence or absence of willows, to the response of reed canarygrass at each survey point from 2003 to 2004. After ranking growth and inundation data from stand measurements, we used Spearman's Rho to examine relationships between plant erectness and water depth, and used a t-test to determine significance.

Most analyses used data from all 27 transects ($n = 24{,}742$ points). However, we eliminated one transect from the analysis of reed canarygrass response by degree of inundation due to survey error. The analysis of willow presence/absence on reed canarygrass was limited to 17 transects ($n = 17{,}484$), as rising water levels and willow senescence precluded data collection from low-lying areas of 10 transects. Our methods were both intensive, taken at a fine sampling interval, and extensive, collected throughout the preserve (Figure 1).

## RESULTS

### Hydrological Conditions

The installation of the water control structure, combined with a year of average rainfall, produced a sustained water level in the lake for the spring and early summer (Figure 2). This water level was higher

Table 1. Total duration of flooding and duration and timing of 0.6-m inundation for points with maximum flooding of 0.7, 0.75, 0.8, 0.85, and 1.15 m.

| Maximum Flooding | Total Duration of Flooding | Duration and Dates of > 0.6 m Depth |
|---|---|---|
| 1.15 m | 241 d | 177 d (Jan 11–Jul 4) |
| 0.85 m | 207 d | 137 d (Jan 31–Jun 15) |
| 0.80 m | 202 d | 125 d (Feb 1–Jun 4) |
| 0.75 m | 197 d | 104 d (Feb 1–May 14) |
| 0.70 m | 191 d | 89 d (Feb 2–Apr 30) |

than experienced by SBW in recent years, although it was 0.5 m below the maximum elevation the structure can support. Water levels during February–May 2004 were 115–120 cm higher than the same months in 2001. While the level of the wetland lakes during winter and spring was noticeably higher, the ability to fully draw down the wetlands resulted in lower water levels during the latter part of the growing season. For example, the mid-August water level was 22 cm higher in 2001 than 2004. Once all the stoplogs had been removed from the water control structure on 6 August 2004, the lakes were subject to tidal fluctuation. Because the highest tide was below the lowest elevation of transects (Figure 2), tides did not affect duration of flooding.

Duration of inundation ranged from 0–305 days. Sample points that were subjected to deep inundation were under water for long periods of time; plants at these points also spent more time under "intermediate" flooding of 0.6 m (Table 1). The differences in time spent under these conditions were due primarily to later drying at lower elevations (Table 1). Points that received at least 0.85 m maximum inundation remained under 0.6 m of water until late June or July.

### Plant Cover Response

Baseline data from the initial round of sampling in 2003 indicate that percent cover of reed canarygrass was negatively correlated with emergent plant diversity at SBW (Spearman's rho $= -0.67$, $p < 0.001$; Figure 3). This relationship was weaker, although still significant, in 2004 (Spearman's rho $= -0.41$, $p = 0.036$). The overall Shannon Diversity index (H') was 3.06 in 2003 and 3.18 in 2004 ($p < 0.001$).

### Response of Reed Canarygrass

Reed canarygrass cover decreased from 43.7% in 2003 to 41.2% in 2004 (McNemar's test, $p < 0.001$). Erectness (the ratio of plant height *in situ* to plant height when straightened) was inversely correlated (Spearman's rho $= -0.48$, $p = 0.003$; Figure 4) with the late-spring water depth, i.e., the depth measured on 19–21 May.

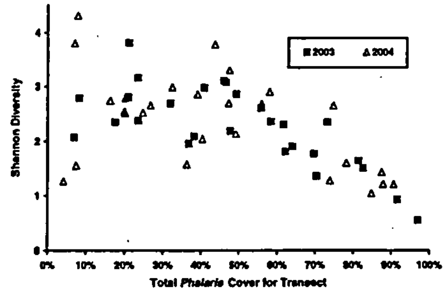


Figure 3. Relationship of the Shannon diversity index for wetland plant cover to percent cover of reed canarygrass. Data are from 27 transects sampled at Smith and Bybee Wetlands Natural Area (SBW) in fall 2003 and fall 2004.

Flooding in areas of regenerating Pacific willow forest canopy reduced reed canarygrass cover to a greater extent (10.7%) than flooding in areas of similar elevation without willow (3.5%) (Chi-square test, $p < 0.001$; Figure 5). In those same areas in 2003, reed canarygrass had been equally likely to occur in areas with or without willow.

Odds ratios for multinomial logistic regression also demonstrated the significant effects on reed canarygrass of increased inundation and presence of willow (Table 2). We assessed a reference case and three outcomes. The reference case indicates control of reed canarygrass by inundation or willow presence, i.e., reed canarygrass was present in 2003 but absent in 2004. The odds ratios indicated that deeper levels of inundation were more likely to produce a decrease in reed canarygrass cover than either an increase or no change in cover. However, most deeply-inundated areas did not support reed

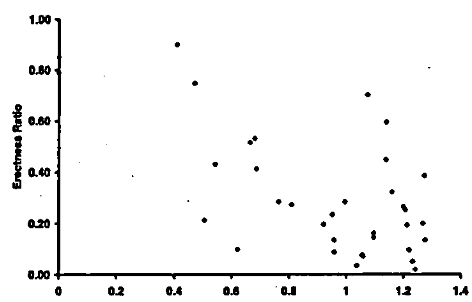


Figure 4. Relationship between erectness at mid-growing season (21 July) and late-spring (19–21 May) water depth in 2004 (Spearman's rho $= 0.49$; $p < 0.05$). Erectness ratio is plant height *in situ* divided by plant height after straightening (i.e., plant length).

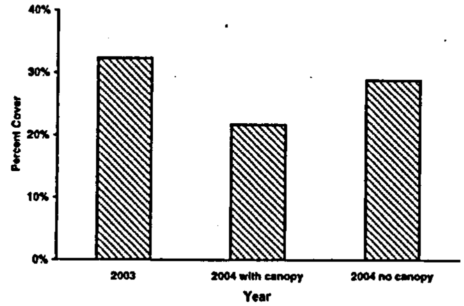


Figure 5. Reed canarygrass cover and change at elevations that support regenerating willow forest at Smith and Bybee Wetlands Natural Area (SBW). Data are shown for areas along the vegetation transects both under willow canopy and without willow canopy. Data show cumulative change in each category from all transects.

canarygrass to begin with. In every comparison, it was more likely for reed canarygrass cover to decline from 2003 to 2004 if willow was present than for it to increase or remain the same.

While in areas flooded to > 0.85 m in late spring, reed canarygrass cover generally declined, it often increased in areas flooded to < 0.85 m (Figure 6). This result suggests a threshold depth for effective control of this species. Reed canarygrass cover dropped by 6.1% in areas flooded to at least 0.85 m; this loss was significantly ($p < 0.001$) more than the overall loss of this species (2.5%) during the study.

## Interaction of Reed Canarygrass with Other Taxa

Several native taxa increased cover, notably *Polygonum* and *Bidens* species, as well as *Salix lucida* and *Veronica* species, ($p < 0.05$; Table 3, Figure 7). *Ludwigia palustris* and *Rumex maritimus* were the only common native species to decline in cover after flooding (Table 3). Two non-native *Solanum* species also benefited. Conversely, reed canarygrass moved into spaces previously occupied by some taxa, both native and non-native, under the new water regime. Comparing individual sample points indicated that *Eragrostis hypnoides* and the two *Eleocharis* species were replaced by reed canarygrass, as were non-native bird's foot trefoil (*Lotus corniculatus*) and Canada thistle (*Cirsium arvense*) (Figure 7).

# DISCUSSION

## Response of Reed Canarygrass

Reed canarygrass has been found in areas that experience hydrologic fluctuations (Galatowitsch et al 2000, Perkins and Wilson 2005) and/or partially flooded conditions (Kellogg et al. 2003); however, prolonged, deep inundation may suppress it (Rice and Pinkerton 1993, Coops et al. 1996). Pot experiments (Klimesova, 1994, Coops et al. 1996, Miller and Zedler 2003) have shown that seedlings and planted rhizomes of reed canarygrass produce lower biomass when flooded, while *in situ* studies produced similar results for established reed canarygrass populations (Rice and Pinkerton 1993, Tanner et al. 2002). Tanner et al. (2002) found that flooding produced by a return to historic hydrologic conditions contributed to the control of reed canarygrass. Our results corroborate these findings.

Stems of heavily-flooded reed canarygrass lacked turgor when we monitored them during the growing season, as seen in the relationship between erectness and inundation. When devoting resources to stem elongation, branching, and the production of adventitious roots, reed canarygrass likely had less energy to store in its rhizomes (Kercher and Zedler 2004). This change comes at the expense of root development (Miller and Zedler 2003) and by the shift of stocks of carbon and nutrients from belowground to aboveground tissues (Conchou and Fustec 1988). This shift has a negative effect on clonal reproduction later in the growing season; tillering is reduced under more prolonged inundation (Rice and Pinkerton 1993). Reduced tillering could affect the long-term survival of reed canary-

Table 2. Odds ratios for multinomial regression of reed canarygrass cover, with increased inundation and with presence of willow. Reference case is reed canarygrass present in 2003 and absent in 2004. Values greater than 1.0 indicate the result listed below is more likely than the reference case. Values less than 1.0 indicate the reference case is more likely, and a value of 1.0 is neutral, i.e., both outcomes are equally likely. All results are significant ($p < 0.001$).

| Case | Increased Inundation | Presence of Willow |
|---|---|---|
| Reference case: present in 2003 and absent in 2004 (desired response to water level management) | 1.0 | 1.0 |
| Absent in 2003, present in 2004 (appeared after first year of water level management) | 0.80 | 0.46 |
| Present in both years (no change after water level management) | 0.72 | 0.32 |
| Absent in both years (no change after water level management) | 1.7 | 0.29 |

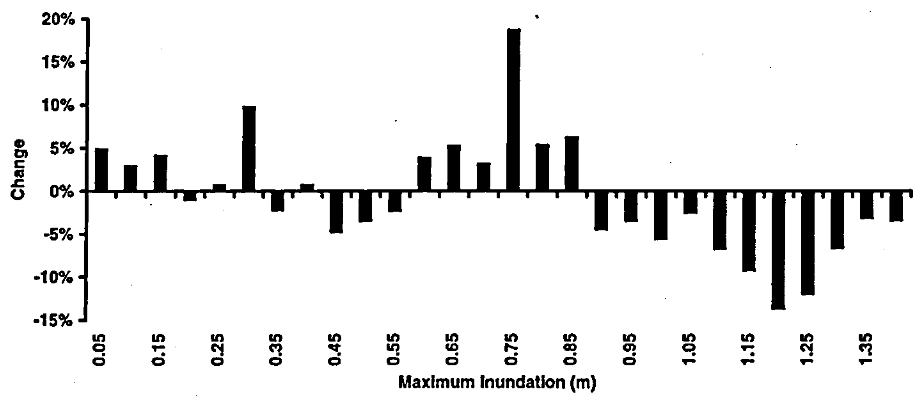


Figure 6. Response to flooding of *Phalaris arundinacea* by inundation category. Change on the y-axis represents the difference in number of occurrences from 2003 to 2004 divided by total number of occurrences in 2003 for each category.

grass, as the majority of new shoots come from rhizomes (Casler and Hovin 1980).

In our study, reed canarygrass was flooded when it typically tillers in late spring and early summer, which may explain the response of reed canarygrass to depth and duration of flooding. Much of the growth of reed canarygrass occurs in mid-spring, with five to seven weeks of vertical growth following germination (Comes et al. 1981). Ordinarily, reed canarygrass undergoes a significant depletion in carbohydrate reserves in late May and June (Decker et al. 1967). Conchou and Fustec (1988) found a reduction in tillering and rhizome growth with spring flooding of mature reed canarygrass plants; Klimesova (1994) concluded that flooding was most effective in controlling reed canarygrass when timed to coincide with rhizome growth and tillering. Our study lends support to these findings.

The decrease in reed canarygrass cover was particularly noteworthy in areas dominated by *Salix lucida*. A recent study in Seattle, Washington found a 45% reduction in total biomass of reed canarygrass over a two-year period due to shading by live willow stakes (Kim et al. 2006). Light transmittance under dense canopies is primarily in the red or far-red regions of the spectrum (Grant 1997); reed canarygrass does not germinate well under far-red light (Lindig-Cisneros and Zedler 2002). Shading reduces

Table 3. Percent cover for selected species at SBW, 2003 vs. 2004. Changes indicated are all significant (McNemar's test, $p < 0.05$).

| Species | % Cover 2003 | % Cover 2004 | Direction of Change | Native? |
|---|---|---|---|---|
| *Phalaris arundinacea* | 43.7 | 41.2 | ↓ | No |
| *Ludwigia palustris* | 22.3 | 20.6 | ↓ | Yes |
| *Polygonum* spp. | 21.4 | 34.8 | ↑ | Yes |
| *Bidens* spp. | 12.6 | 15.2 | ↑ | Yes |
| *Salix lucida* | 10.7 | 14.7 | ↑ | Yes |
| *Cyperus strigosus* | 5.6 | 6.8 | ↑ | Yes |
| *Eragrostis hypnoides* | 4.4 | 4.7 | – | Yes |
| *Eleocharis ovata* | 3.4 | 4.5 | ↑ | Yes |
| *Veronica* spp. | 2.9 | 8.2 | ↑ | Yes |
| *Rumex maritimus* | 2.3 | 1.0 | ↓ | Yes |
| *Lotus corniculatus* | 1.5 | 0.7 | ↓ | No |
| *Solanum dulcamara* or *S. nigrum* | 1.4 | 2.4 | ↑ | No |
| *Myriophyllum aquaticum* | 1.2 | 1.0 | – | No |
| *Cirsium arvense* | 0.9 | 0.4 | ↓ | No |
| *Rubus armeniacus* | 0.6 | 0.4 | ↓ | No |
| *Carex* spp. | 0.4 | 1.0 | ↑ | Yes |
| *Leersia oryzoides* | 0.4 | 0.6 | ↑ | Yes |
| *Cirsium vulgare* | 0.1 | 0.3 | ↑ | No |
| *Myosotis laxa* | 0.1 | 0.3 | ↑ | Yes |
| *Hypericum perforatum* | 0.1 | 0.0 | ↓ | No |
| *Lythrum salicaria* | 0.0 | 0.1 | ↑ | No |

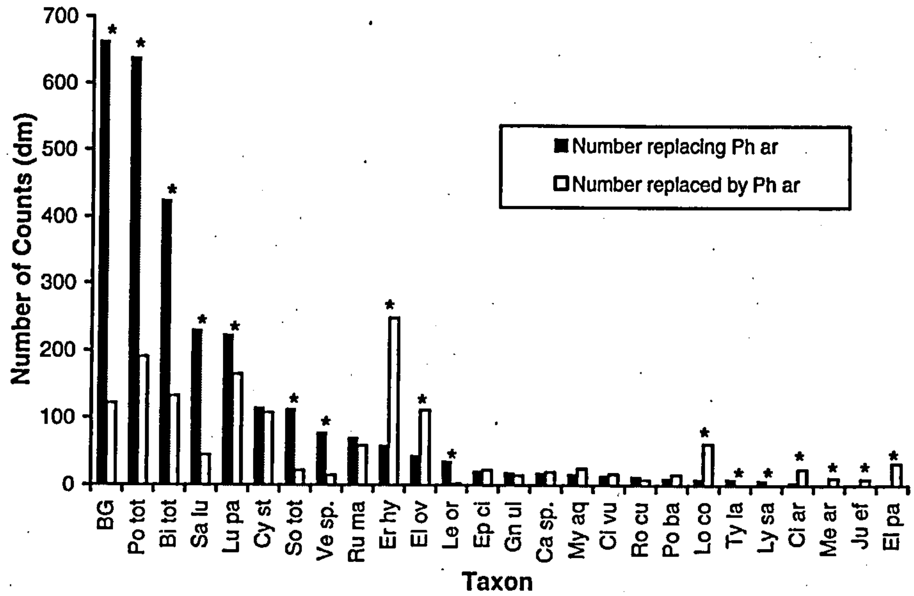


Figure 7. Replacement under managed flooding between reed canarygrass (Ph ar) and other taxa across all elevations sampled. BG= Bare ground; Po tot = all *Polygonum* spp.; Bi tot = all *Bidens* spp.; Sa lu = *Salix lucida*; Lu pa = *Ludwigia palustris*; Cy st = *Cyperus strigosus*; So tot = all *Solanum* spp.; Ve sp. = *Veronica* spp.; Ru ma = *Rumex maritimus*; Er hy = *Eragrostis hypnoides*; El ov = *Eleocharis ovata*; Le or = *Leersia oryzoides*; Ep ci = *Epilobium ciliatum* Raf.; Gn ul = *Gnaphalium uliginosum*; Ca sp = *Carex* spp.; My aq = *Myriophyllum aquaticum*; Ci vu = *Cirsium vulgare*; Ro cu = *Rorippa curvisiliqua*; Po ba = *Populus balsamifera* ssp. *trichocarpa*; Lo co = *Lotus corniculatus*; Ty la = *Typha latifolia*; Ly sa = *Lythrum salicaria*; Ci ar = *Cirsium arvense*; Me ar = *Mentha arvensis*; Ju ef = *Juncus effusus*; El pa = *Eleocharis palustris*. * = Difference is significant ($p < 0.05$).

both total biomass and root:shoot ratios of reed canarygrass (Perry and Galatowitsch 2004); lower light transmission under canopy has also been found to inhibit reed canarygrass survival (Maurer and Zedler 2002). This mechanism may be responsible for reed canarygrass suppression in willow stands.

## Responses of Other Taxa and Interactions with Reed Canarygrass

Emergent plants at SBW appear adapted to the late-spring high-water conditions that historically occurred in the lower Columbia River system. Annual moist soil wetland species can establish quickly after drawdown, once dominant vegetative species are flooded out (Harris and Marshall 1963). Important native taxa at SBW, such as smartweeds (*Polygonum* spp.), water-purslane (*Ludwigia* spp.), willows (*Salix* spp.), spikerushes (*Eleocharis* spp.), beggar's ticks (*Bidens* spp.), annual species of Cyperaceae, and creeping lovegrass (*Eragrostis hypnoides* [Lam.] B.S.P.), all thrive under flooded conditions (Mitchell 1976, Walters et al. 1980, Carter and Grace 1990, Baskin et al. 1991, Baskin et al. 1993, Sultan and Bazzaz 1993, Leck et al. 1994, Weiher et al. 1996, Blanch et al. 1999, Azous and Cooke 2000, Bonyongo et al. 2000, Kercher and Zedler 2004). Our study suggests that managed flooding likewise supported most of these taxa.

Exceptions included *Ludwigia palustris,* which replaced reed canarygrass despite losing cover overall. Most of the cover loss for this species was at flooding depths of 1–1.25 m, while it increased in cover outside those depths. It may be that different populations of *Ludwigia palustris* with differing tolerances for inundation exist at SBW. Conversely, *Eleocharis ovata* and *Eragrostis hypnoides* increased cover overall, but were replaced by reed canarygrass. Both species showed decreased cover at flooding depths $< 1$ m, but increased cover when more deeply flooded. It is likely that reed canarygrass, with increased cover at flooding of 0.5–0.85 m, replaced these species at these depths, while they expanded cover at greater depths.

Non-native taxa other than reed canarygrass had a mixed response to the change in hydrology. *Solanum* species benefited, as did *Cirsium vulgare* and *Lythrum salicaria. Solanum* cover increased less, however, in areas of inundation $> 0.85$ m. Prolonged inundation has been found to promote larger leaf area in *Solanum dulcamara* (Braun and Toth 1994). Other species, such as *Lotus corniculatus, Rubus armenia-*

*cus*, and *Cirsium arvense* were intolerant of flooding and exhibited less cover after the first year of managed flooding; *Hypericum perforatum* disappeared from the transects in 2004. Further research that investigates competition among these taxa under conditions of managed flooding is warranted.

### Management Implications

Managed flooding was effective in its first year at SBW, and thus showed promise as a means of controlling reed canarygrass. This outcome was stronger in the presence of *Salix lucida*. Flooding was effective when depths reached 0.85 m or more in spring; this degree of inundation reduced reed canarygrass cover, and also produced a positive response in many native taxa. *Salix lucida* responded most positively to flooding at these depths; hence, flooding may contribute both directly and indirectly to reed canarygrass suppression. Conversely, spring flooding of between 0.5 m and 0.85 m was related to an increase in reed canarygrass cover. This result suggests that inundation should be implemented to the appropriate threshold or it may prove counterproductive.

These results provide information for wetland scientists and managers on the effects of one year of inundation on invasive reed canarygrass and on the response of the remainder of the vegetative community. Continued study is warranted to determine the effects of multi-annual flooding on invasive reed canarygrass. Future studies may also consider multiple control measures. The effectiveness of the combination of flooding and shading suggests that multiple means of reed canarygrass control may have a greater chance of success than any single approach.

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