2015 Water Quality and *Ludwigia* Monitoring Report for Stewart Slough Project Area, Benton County




Prepared by Mosaic Ecology LLC
For Benton Soil & Water Conservation District
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This report is meant to be utilized by staff of Benton Soil & Water Conservation District as well as interested members of the natural resource community

Overview

In July of 2015, in association with the on-going control of Uruguayan primrose-willow (*Ludwigia hexapetala*) within the Willamette River system of Benton County, Oregon, Benton Soil & Water Conservation District (BSWCD) developed a pilot monitoring program. Monitoring was conducted in order to track annual population shifts of *Ludwigia* in response to control efforts and to assess the effect of herbicide treatments for the control of *Ludwigia* on water quality.

Aquatic plants are known to affect water quality. Dense populations of aquatic plants alter diurnal fluctuations of dissolved oxygen (DO) and large-scale die-offs can create anoxic conditions detrimental to aquatic life. Monitoring compared DO within open water and *Ludwigia* infested areas of waterbodies within the Stewart Slough Project Area. Monitoring occurred before and after herbicide treatment from July to November in an attempt to capture the rapid reduction of DO in response to *Ludwigia* decay. Range and density of *Ludwigia* within three distinct water bodies were mapped to record baseline *Ludwigia* cover. Generated maps will assist applicators to target areas of regrowth and adjust management methods accordingly. Water quality data was collected by a handheld YSI meter in four distinct water bodies up to four times during the 2015 growing season. Presented data focused on dissolved oxygen with an emphasis on the effect to aquatic organisms.

Ludwigia infested sampling sites possessed lower DO than open water environments even prior to herbicide application. The presence of *Ludwigia* resulted in DO values exceeding thresholds that impair aquatic organisms, in some cases low enough to cause acute mortality. Open water areas contained elevated DO levels, providing refuge for fish in water bodies containing *Ludwigia.* A clear reduction of DO resulting from mass decay was not observed across all sites. Due to varying physical variables between sampled water bodies, sites showed varying baseline DO values and trends over time.

The monitoring effort was conducted to inform BSWCD of the possible impacts the *Ludwigia* control may have on water quality in the Stewart Slough Project Area. Monitoring was not required by Oregon Department of Environmental Quality (DEQ) or the US Environmental Protection Agency (EPA), though a Pesticide General Permit was required and obtained through DEQ for treatment of *Ludwigia* infestations. Field and data analysis methods from the 2015 monitoring effort were evaluated and recommendations for the following years have been made.

Monitoring Goals

1. Measure pre-treatment *Ludwigia* range and cover values for annual comparisons.
2. Assess how the presence of *Ludwigia* affects water quality with or without herbicide treatment.
3. Develop a replicable monitoring methodology that can be used for data collection in future years.

Background

Ludwigia in Stewart Slough Project Area

Native to Central and South America, *Ludwigia hexapetala* and *L. peploides* ssp. *montevidensis* are invasive aquatic plants that are rapidly increasing in prevalence in Oregon, most notably in the Willamette River Valley (ODA 2015). In the past 10 to 15 years, *Ludwigia* populations have occupied high profile sites such as Delta Ponds Park of Eugene, leading to an increased local awareness and the discovery of established *Ludwigia* populations throughout the Willamette River Valley (City of Eugene 2013). From 2012 to 2015, surveys by boat and remote sensing showed that *Ludwigia* had become "widespread" within Linn, Benton and Marion Counties, and was expanding the its range in Oregon to the north and south (ODA 2011; ODA 2015) Listed as a Class B noxious weed in the State of Oregon, intensive management is encouraged on a case-by-case basis (ODA 2014).

After initial surveying showed extensive infestations within side channels, oxbows, riverine wetlands and other water bodies of the Willamette River, BSWCD acquired funding from the Oregon State Weed Board, the Oregon Watershed Enhancement Board and other sources in an attempt to eradicate or greatly reduce *Ludwigia* in over 4 miles of infested habitat in the Stewart Slough Project Area of Benton County. Collins Bay, located north of the Stewart Slough Project Area, was initially chemically treated in 2014 for *Ludwigia*. Collins Bay was mapped in 2015 to assess the efficacy of the previous year's control methods. The first year of full scale treatment within the Stewart Slough Project Area occurred in late-June to early-July of 2015, with follow up applications occurring in August and October of 2015. Contractors applied a formulation of aquatic label Rodeo (glyphosate) at a concentration of 3%, with dye and Agri-dex surfactant. Herbicide formulations were selected for their known effectiveness in treating *Ludwigia* and relatively low toxicity to fish, mammals and invertebrates in comparison to other formulations. Due to the large scale of the project area, sections of the four mile slough system were treated over a period of 15 application days. Roughly four weeks after the July 2015 chemical application, large masses of *Ludwigia* were observed dying as leaf and stem tissue browned, curled and sank to decay at the water bottom (Figure 1.).

Figure 1. *Ludwigia* within Stewart Slough #1 Site (Asbahr Lake) of project area, 7/6/2015 (A) prior to chemical application and four weeks after chemical application, 8/11/2015 (B).

Effects of Plants to Dissolved Oxygen

Water chemistry is greatly affected by the abundance and composition of plant life in aquatic systems. Aquatic plants exchange gases with the water column, affect water temperature, can reduce turbidity, alter evapotranspiration rates, and influence microbial communities. This monitoring effort was intended to assess how large-scale herbicide treatments and the resulting decay of high *Ludwigia* densities affects DO within the Stewart Slough Project Area.

Major sources of DO within aquatic systems include: direct diffusion from the atmosphere, wind and wave action, and photosynthesis. Photosynthesis from plant and algal species exchange CO_2 for O_2 within the water column when sunlight is available, while respiration from animals, including microbial organisms remove O_2 from the aquatic system through respiration (Francis-Floyd 2003). Although plants are known for photosynthesis, which produces oxygen, they also consume oxygen through respiration. In the absence of light respiration in plants occurs at a higher rate compared to photosynthesis. Temperature also greatly affects DO as higher temperatures reduce the capacity of water to hold gases such as O_2 and CO_2 (ODFW 1999) There is a large amount of conflicting information supporting both the increase and reduction of DO caused by aquatic plants (Frodge et al. 1990; Caraco & Cole 2002; Francis-Floyd 2003; Tanner & Headley 2011). A plant's influence on DO is largely dependent on plant growth habit (submerged, floating, emergent, etc.). Submerged plants can more efficiently exchange CO_2 directly with O_2 increasing oxygen in the water column and floating-leaved plants release O_2 to the atmosphere, depleting DO (Caraco et al. 2006). But how exactly emergent plants such as *Ludwigia* affect DO can be unclear.

In communities dominated by emergent aquatic plants, zones of dense vegetation provide significant submerged structure, but result in nearly or completely anoxic water conditions (Rose & Crumpton 1996). Reduction of DO in emergent plant beds have been attributed to large quantities of decaying leaf litter and reduced diffusion of oxygen from the atmosphere (Caraco & Cole 2002; Rose & Crumpton 2006;). Even more directly related to the Stewart Slough WQ Pilot Study, anoxic zones have been found in emergent plant communities of *Ludwigia palustris* and *L. hexapetala* within the backwater channels and bays of a major riverine system in the southeast United States (Miranda & Hodges 2000). Besides direct influences to DO, seasonal or human caused plant die-offs pose the risk of reducing DO as respiration rates of microbes increase during the decay process (CDBW 2001; Jewell 1971; ODFW 1999).

The degree of oxygen consumption in decaying plant communities varies in regards to plant densities, species, and microbial community composition. Oxygen demand, or depletion of DO is directly related to the initial biomass of plant communities (Tang et al. 2013). Numerous *in-situ* and *ex-situ* experiments have showed hypoxic conditions result from plant die-offs related to both chemical and mechanical control of aquatic plants (Hellsten et al. 1999; Jewell 1971; Tang et al. 2013). Hypoxia related to weed control can occur locally within regions of a larger waterbody or occur throughout the entirety of a small waterbody. One study in particular showed a reduction of DO to zero within a small pond four days after Canadian elodea (*Elodea canadensis*) was chemically treated (Owens and Maris, cited from Jewell 1971).

It is clear that *Ludwigia* has the potential to greatly reduce available oxygen in aquatic environments of the Stewart Slough Project Area. With evidence of anoxic conditions being present in areas of both living and decaying plant material, it is important to assess how *Ludwigia* affects the varying waterbody types within the Stewart Slough System before and after treatment. Waterbodies may possess system wide anoxic conditions or contain open water areas that provide refuge for fish species. Thresholds have been established to indicate the minimum concentration of DO within water that results in detrimental impact to fish.

Effects of Dissolved Oxygen to Fish

Within scientific literature, there are numerous thresholds of minimum DO for both salmonid and non-salmonid fish species. The generally accepted threshold for most fish species is 5 mg/L of DO (Yeakley et al. 2013; Francis-Floyd 2003). At a concentrations below 5 mg/L, embryonic and larval development can be greatly impaired, weight loss can occur, avoidance may take place, and survivorship of certain species is decreased. In a study of non-salmonid fish, a majority of species tested experienced zero survivorship in water less than 2.4 mg/L of DO (EPA 1986). Coldwater species or members of the family *Salmonidae* (salmonids) are even more sensitive to reduced DO.

In the State of Oregon, criteria for minimum DO in water bodies is administered by DEQ. For water bodies identified by DEQ as providing cold-water life, the absolute minimum for DO may not be less than 8.0 mg/L (OAR 340-041-0016(2)). In waters identified as providing cool-water aquatic life, DO may not be less than 6.5 mg/L at any given time (OAR 340-041-0016(3)). The absolute minimum is increased to 11.0 mg/L in water bodies identified as active spawning areas during designated times (OAR 340-041-0016 (1)). Standards set by DEQ are based on criteria established by the EPA (EPA 1986).

Ludwigia infested areas within the Willamette River Valley include ponds, bays, oxbows and sloughs that may or may not have connectivity to the main channel of the Willamette River. It is important to gauge how DO within infested water bodies such as those monitored in the Stewart Slough Project Area could affect both salmonid and non-salmonid species present. Two DO thresholds will be applied to the results of WQ monitoring to assess suitability for fish development and survivorship. Although more imperative to stream environments, the cool-water criterion of 6.5 mg/L of DO will be applied to account for possible salmon or trout rearing and migration in the "Willamette River and Tributaries Gallery Forest" ecoregion, which the Stewart Slough Project Area is located within (DEQ 2010). A threshold of 5 mg/L will be used as reference for non-salmonid species where moderate to slight production impairment is known to occur based on life stage (EPA 1986). These thresholds have been applied to the figures simply as a reference for data interpretation and do not identify impaired waters of the State.

Methods

Site Selection

A total of five sites within the project area were selected for monitoring (Figure 2.). Selected sites represent the diverse water body types that persist within the project area (gravel pit, slough, oxbow lake, bay). Access, perennial water presence, permission of entry, distance from one another and degree of infestation were taken into account to select sites. In total, three sites were mapped by GIS and four sites were sampled for water quality. Originally, four sites were selected for density and range mapping, but due to time constraints, the Oxbow site was not mapped. Due to an uncharacteristically dry and warm water year, the sampling location of Stewart Slough #1 completely dried for the first time in local memory. The Stewart Slough #2 site was added to maintain data collection within the immediate Stewart Slough Project Area and preserve the number of sites being sampled during each sampling period. Collins Bay is the only site that was chemically treated in 2014. All sites except for Oxbow were chemically treated in summer of 2015.

Figure 2. Sites within Stewart Slough Project Area that were mapped and/or monitored for water quality.

Range & Cover Mapping

Stewart Slough #1, Gravel Pit and Collins Bay were mapped on July 2, 2015 before chemical application took place at the three sites. Mapping was carried out by a research technician on foot using a hand held GPS instrument (Garmin Oregon 450). Percent cover estimates of *Ludwigia* were used to generate cover class polygons within surveyed sites: Light (<5%), Moderate (5 – 50%) and Heavy (>50%). Total range of *Ludwigia* was measured first by GPS and polygons of Moderate and Heavy cover were then collected within the population extent.

GPS data was projected and analyzed within ArcGIS 10.3 to calculate acreage of individual polygons and total acreage of each cover class. All data was projected in the NAD_1983_UTM_Zone_10N coordinate system. Maps were generated to provide comparisons for future treatment years as it is expected that range and density mapping will occur within the three sites on an annual basis. Variables affecting *Ludwigia* density patterns within mapped sites were summarized.

Water Quality Monitoring

Water quality was monitored within the Stewart Slough Project Area on 7/6, 8/11, 9/21, and 11/2/2015. Dates were selected in an attempt to capture the seasonal fluctuations of WQ conditions in response to widespread *Ludwigia* die-off (Table 1). Monitoring occurred at roughly the same time on each date to minimize daily variations in WQ values. Monitoring at specific sites did not vary more than 1.5 hours from other sampling dates. On specific sampling dates, some sites were not monitored for WQ due to uncharacteristically dry conditions or in one case, instrument error (Table 1).

Table 1. Sampling dates at sites within Stewart Slough Project Area. Successful sampling periods indicated by "Yes", otherwise restrictions to WQ monitoring are indicated.

Site	Sampling dates and relation to herbicide treatment			
	July 6	**Aug 11**	**Sept 21**	**Nov 2**
	Before Treatment	2 Weeks After	2 Months After	Fall Senescence
Gravel Pond	Yes	Yes	Yes	Yes
Stewart Slough #1	Yes	Dry Conditions	Dry Conditions	Limited Sampling
Stewart Slough #2	Not yet selected	Yes	Yes	Yes
Oxbow (No Chemical Treatment)	Instrument Error	Yes	Yes	Yes

Two technicians collected data by foot or boat using a YSI Professional Pro Plus Multiparameter Water Quality Meter (https://www.ysi.com/proplus). The WQ variables of temperature, DO, pH, conductivity, and oxidation reduction potential (ORP) were measured. Prior to each monitoring date, temperature, pH, conductivity and ORP were calibrated and DO was calibrated prior to each site. For each sample, depth, max depth and percent cover of *Ludwigia* were collected. Sampling points were recorded by GPS (Garmin Oregon 450). Samples were collected in areas of open water and >50% *Ludwigia* cover. Percent cover was assessed for the total area within one meter of the sample. As plants began to die back after herbicide application, the GPS was used to reference previous monitoring points infested with *Ludwigia* and utilized the range and cover data from the July 2nd mapping effort. Readings were collected at the surface (0.13 meters) and slightly above the water bottom (0.10 to 0.25 meters from bottom surface). Data was logged within the YSI meter and recorded manually by technician simultaneously. Both electronic generated and written data have been provided to BSWCD with calibration data.

Data was summarized to account for four distinct categories: Surface/Open Water, Surface />50% *Ludwigia* Cover, Bottom/Open Water, and Bottom/>50% *Ludwigia* cover. Technicians attempted to collect at least four readings within all categories, but was not possible at all times due to absence of open water areas, access restrictions or time constraints. Comparisons of WQ were made between categories within the same site. Inter-site comparisons would be difficult to make since each site represents varying physical and hydrologic conditions.

Results

Data collected by GPS, YSI meter and manually have been supplied to BSWCD staff. Range and density of *Ludwigia* within the three mapped sites have been presented in map form with calculated acreage. The six measured WQ variables have been summarized and provided to BSWCD for further analyses and interpretation. Within the report only DO (mg/L) and temperature (°C) have been graphically displayed and summarized.

Oxbow

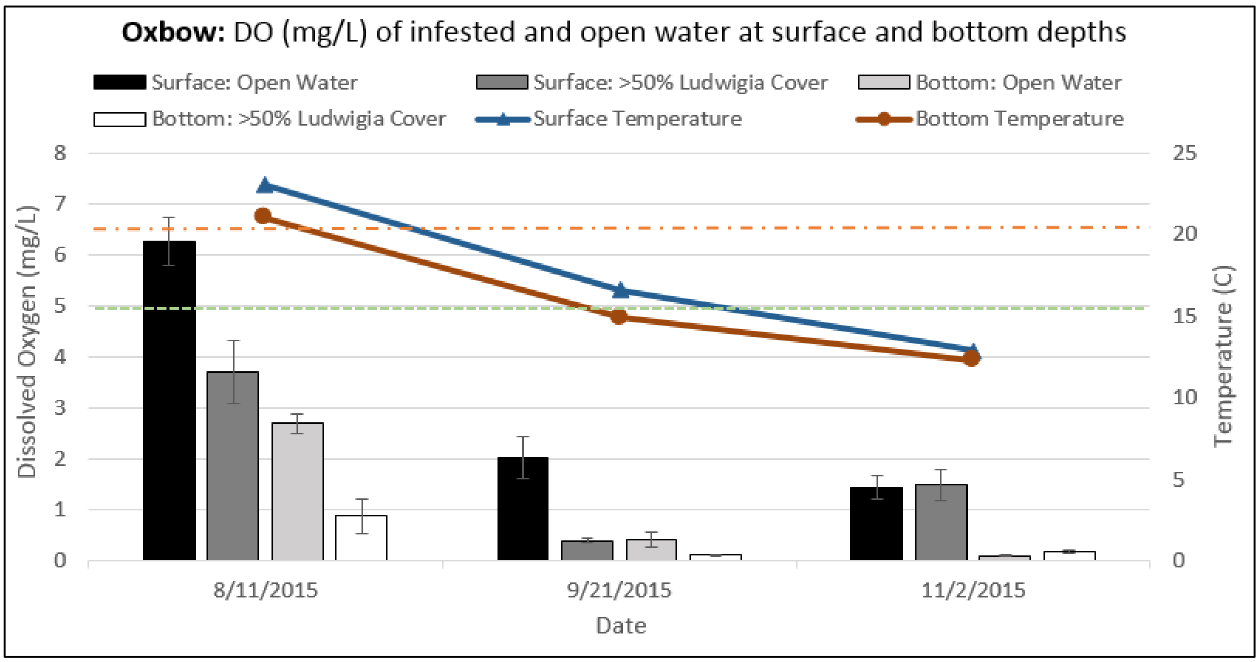

Figure 3. DO comparison between surface and bottom layers in open water and *Ludwigia* infested areas of Oxbow Site. Oxbow acted as a control and **no herbicide application occurred**. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green).

Acting as the control site, the Oxbow was heavily infested with *Ludwigia* in roughly 90% of the water body except for an open water area adjacent to an irrigation pump and some areas <10m^2 in which no cause was attributed. In August, surface values of DO in open water possessed an average value of 6.25 mg/L in comparison to 3.70 mg/L in infested areas (Figure 3). Surface values of DO remained lower in infested sample sites compared to open water sites in September. By November, surface DO was similar in infested and open water areas. Values of DO decreased in open water as the season progressed with the lowest DO occurring within open water areas in November. Temperature measurements each month decreased from August to November in both surface (23.0 °C to 12.9 °C) and bottom readings (21.0 °C to 12.3 °C) supporting evidence that reduced DO was not attributed to temperature decrease. DO and temperature were lower within bottom samples for both open water and infested samples when compared to surface readings. The largest difference in temperature between surface and bottom samples was 2.0 °C which occurred in August.

Average DO in the Oxbow was below both cool-water criterion and non-salmonid thresholds in all sampling categories except for surface readings in open water during the August sampling date. In August only the non-salmonid threshold was met. However, one open water surface sample and one sample with 60% *Ludwigia* cover exceeded the 6.5 mg/L cool-water criterion with DO of 6.72 mg/L and 8.73 mg/L respectively. Across all sampling dates, only five surface samples exceeded 5.0 mg/L of DO, all in August.

Gravel Pond

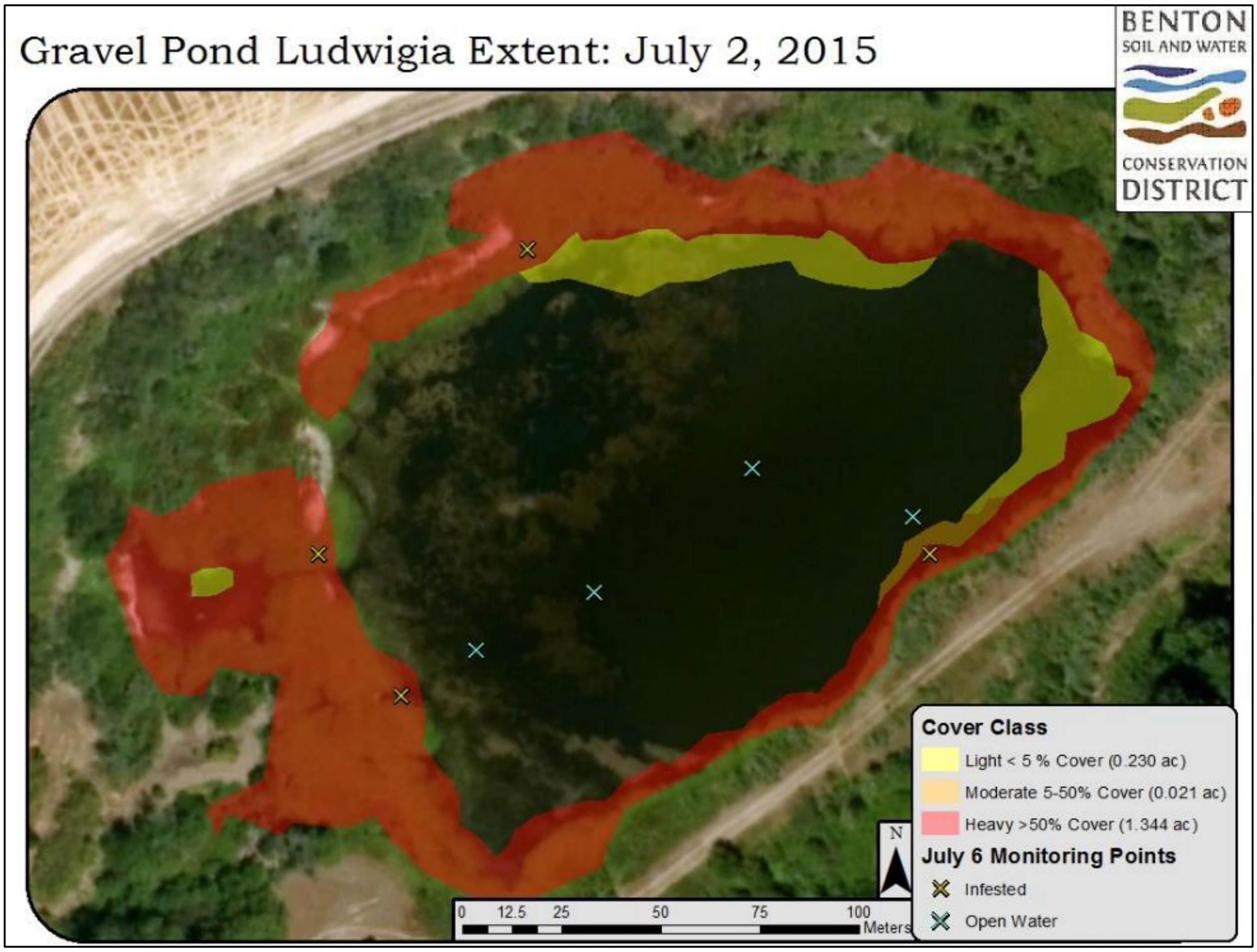

Figure 4. Range and cover class summary of *Ludwigia* within Gravel Pond before first herbicide application with sampling points for July 6 monitoring.

In the Gravel Pond, *Ludwigia* was limited to heavy cover along the perimeter due to soil saturation, water depth, and substrate type (Figure 4). The Gravel Pond has historically been mined for gravel, creating a steep drop off along the bank. The open water area accounted for 4.401 acres in comparison to the 1.595 acres of *Ludwigia* present. Max depths during WQ sampling exceeded 2.5 meters in July. Banks and water bottom were dominated by course gravel with minimal organic matter visible. Although the extent of water at flood stage was not measured, a distinct line existed between bare ground and heavy *Ludwigia* infested areas, indicating where soils are saturated for at least part of the year. The extension of heavy *Ludwigia* cover to the southwest portion of the pond is due to a depression where water was present until July. The light and moderate densities of *Ludwigia* were attributed to stolons or "runners" extending from the dense bank populations with few individuals rooting within the aquatic environment. Brazilian elodea (*Ergeria densa*) was the other dominant aquatic plant species occurring at high densities in the western portion of the site.

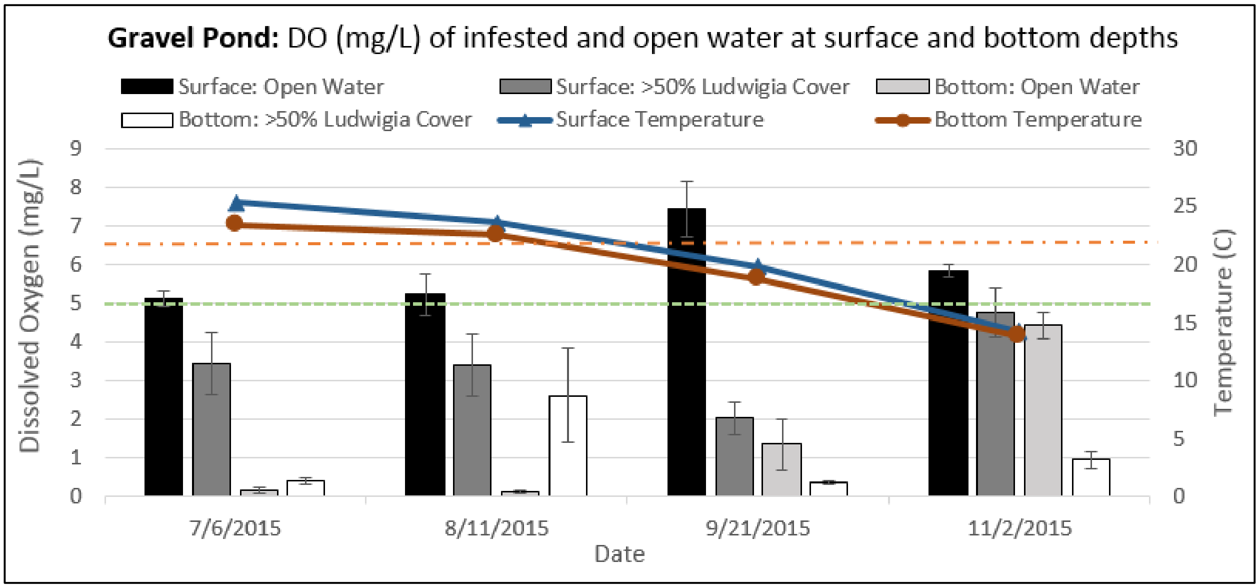

Figure 5. DO comparison between surface and bottom layers in open water and *Ludwigia* infested areas of Gravel Pond. Herbicide application occurred during the week of August 2nd. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green).

There was not a pronounced decrease in surface DO over time within the Gravel Pond as seen in the Oxbow Site (Figure 5). However from August to September, surface DO within infested sampling sites decreased from 3.41 mg/L to 2.03 mg/L, while open water surface values increased substantially from 5.22 mg/L to 7.41 mg/L. In November, all sampling categories increased except for open water surface values which decreased to 5.83 mg/L. Temperature decreased over time in both surface (25.3 ^{o}C to 14.2 ^{o}C) and bottom readings (23.3 ^{o}C to 13.9 ^{o}C). Temperature could be partially attributed to the elevated values of DO in November, but cannot necessarily account for the decrease of DO within *Ludwigia* infested sampling sites from August to September.

Average DO within open water surface samples met the non-salmonid threshold of 5 mg/L on all four sampling dates, exceeding the cool-water criterion threshold only in September. One individual open water surface sample exceeded the cool-water criterion threshold in August, with

7 of 11 samples exceeding the 6.5 mg/L DO threshold in September. The trend was similar in relation to the non-salmonid threshold with 6 of 10 open water samples exceeding 5 mg/L in August and 11 of 11 samples exceeding the threshold in September. *Ludwigia* infested areas had a much lower frequency of samples exceeding either threshold at the surface. Only 1 of 5 samples exceeded the non-salmonid threshold in August with no sample exceeding 4.0 mg/L in September. In November, surface values in *Ludwigia* infested areas exhibited a broader range of DO values (0.58 to 9.72 mg/L) in comparison to open water areas (4.95 to 6.50 mg/L). The open water surface samples only met 6.5 mg/L DO once in 10 samples, with 4 of 16 samples exceeding the cool-water threshold in infested areas. However, open water areas contained conditions less harmful to non-salmonid fish species with 9 of 10 samples exceeding the non-salmonid threshold in comparison to the 7 of 16 samples exceeding the threshold in infested areas. The large range in DO values within infested areas could have been caused by varying levels of *Ludwigia* decay. Since initial herbicide treatments occurred over 3 months prior, with follow up herbicide treatments in August and October, there may have been sampling areas that decay had ceased and other areas in which decay was still occurring from the October herbicide treatment. Regardless of the lower DO average compared to open water areas, it is promising that the frequency of DO values >5 mg/L and total average greatly increased in infested sites three months after initial herbicide treatment.

Stewart Slough #1

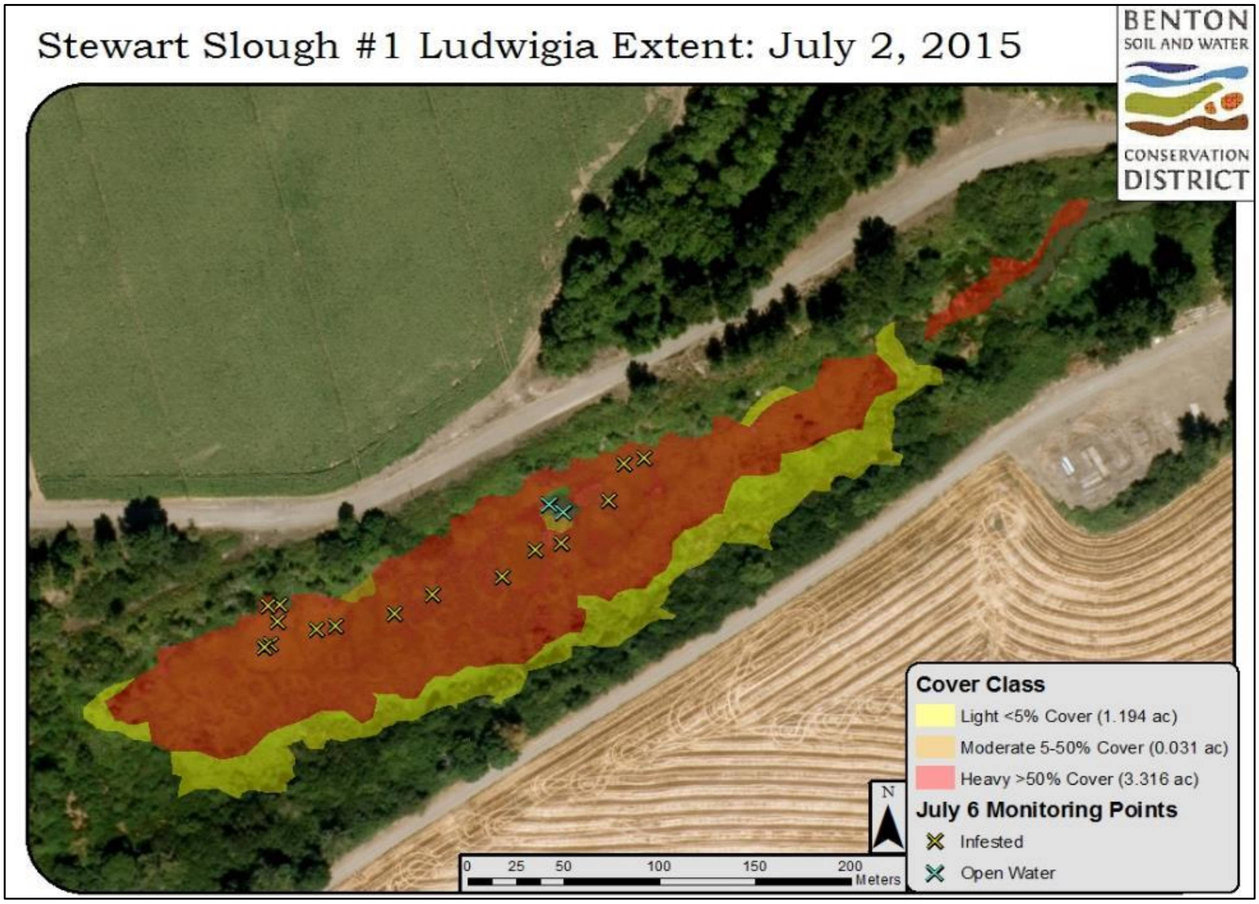

Figure 6. Range and cover class summary of *Ludwigia* within Stewart Slough #1 before first herbicide application with sampling points for July 6 monitoring.

The Stewart Slough #1 site demonstrated heavy *Ludwigia* cover throughout the entire waterbody (Figure 6). At the time of GPS collection, the entire system was walkable, not exceeding depths of 1 meter. Different from the Gravel Pond, the site contained local populations of Western pond lily (*Nuphar polysepela*) and bur-reed (*Sparganium eurycarpum*) species which competed with *Ludwigia*. The areas of moderate cover were associated with populations of *N. polysepela* while the extent of light cover along the southeastern edge of the site can be partially contributed to a healthy stand of *S. eurycarpum.* Areas where trees extended over the water surface and provided shade had reduced cover and in some cases no *Ludwigia* cover.

Of the sites surveyed for mapping or WQ, the Stewart Slough #1 Site had the highest presence of channels created through burrowing activity of aquatic mammals such as nutria and beaver, throughout the water body. Channels of deeper water provided cover to *Ludwigia* during chemical application. Regrowth of healthy individuals were observed within the channels by August as water subsided.

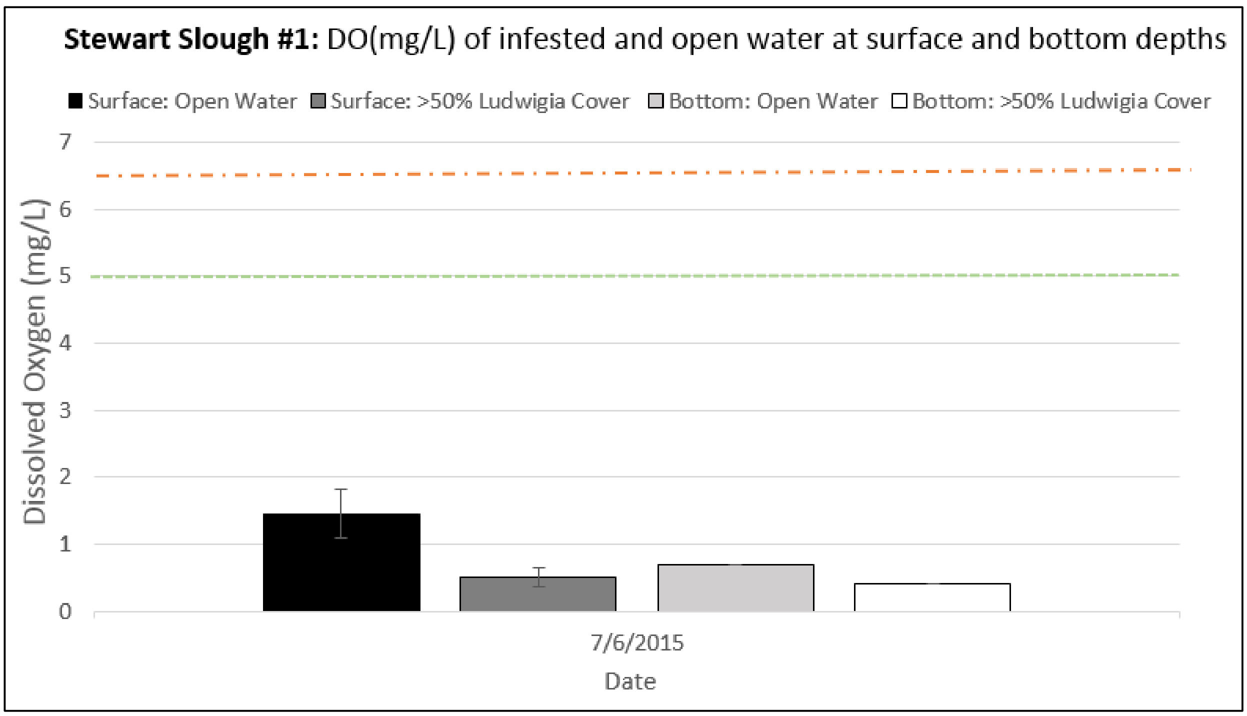

Figure 7. DO comparison between surface and bottom layers in open water and *Ludwigia* infested areas of Stewart Slough #1 prior to treatment. Dry conditions in summer months made WQ monitoring not possible. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green).

The Stewart Slough #1 location provided very few opportunities for open water samples (n = 2). Nearly the entirety of the water body with >0.2 m depths was infested with heavy cover making it difficult to find sampling sites representative of open water environments (Figure 6). Average depth of samples were 0.33 meters providing optimal environments for *Ludwigia* growth. The shallow depths made it difficult to collect bottom samples independent of surface samples. Open water samples were taken in areas of thick *N. polysepela* growth. The shallow nature of the water body lead to rapid drying in the months after July data collection occurred.

Regardless of challenges in collecting diverse categories of data, the Stewart Slough Site #1 represented a waterbody type that is relatively common in the Stewart Slough Project Area. July sampling provided an insight to DO conditions within these infested water bodies. The shallow, stagnant nature of the site, with dense *Ludwigia* growth resulted in low DO values (Figure 7). It is important to note however that water temperature was surprisingly low (19.4°C) in comparison to Gravel Pond Site (25.3 °C) indicating possible groundwater recharge or immediate runoff from adjacent irrigation activity.

Within infested sample sites, surface DO ranged from 0.06 mg/L to 2.03 mg/L, averaging 0.50 mg/L. Of the 17 samples collected, only five exceeded 0.50 mg/L DO. Although only two open water samples were collected, DO values were 1.05 and 1.78 mg/L. A larger sample size for open water samples is needed, but there is support that even small open water areas can result in increased DO within heavily infested water bodies.

In November, about a third of the Stewart Slough #1 Site contained standing water due to recent rains. Samples were collected in a restricted region of the water body. All samples were collected where large mats of decaying *Ludwigia* were still observed. Samples in *Ludwigia* infested areas exhibited a similar pattern in November as *Ludwigia* infested areas of the Gravel Pond. Average DO was 2.89 mg/L with a large range of 0.24 to 8.25 mg/L. In total 4 of 16 samples exceeded the non-salmonid threshold, with two values exceeding the cool-water criterion.

Stewart Slough #2

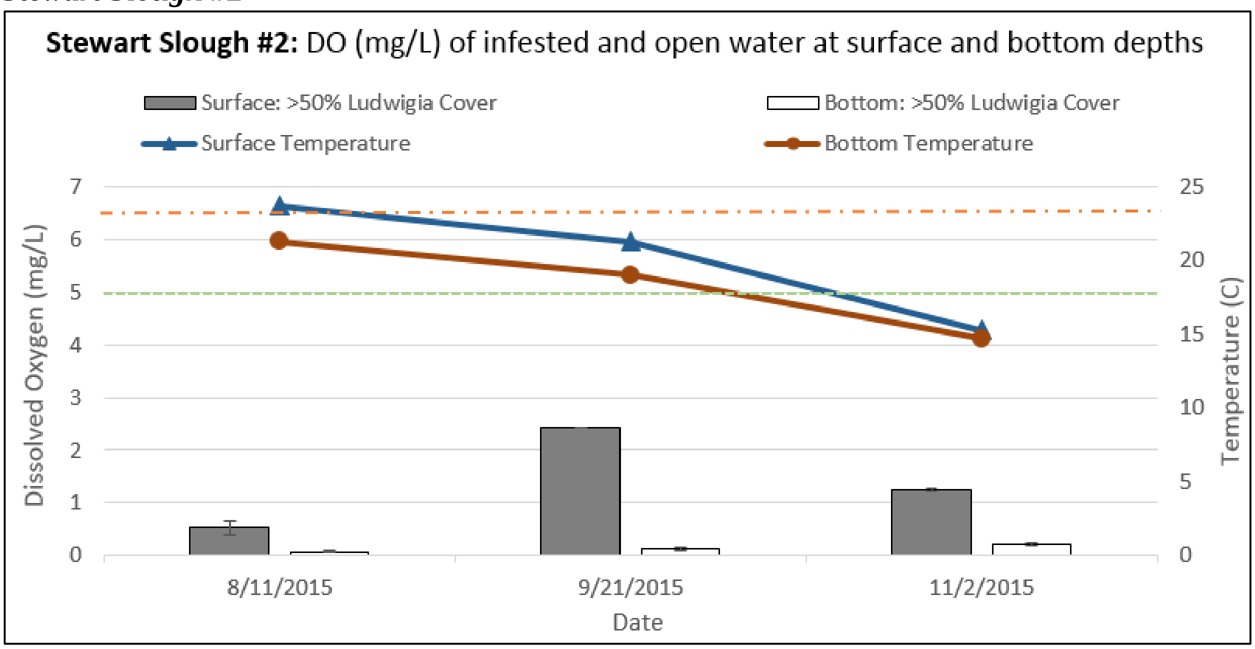

Figure 8. DO comparison between surface and bottom layers in *Ludwigia* infested areas of Stewart Slough #2 after herbicide application. Herbicide application occurred during the week of July 19th. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green).

The Stewart Slough #2 Site was added to the monitoring sites after attempted sampling at the dried Stewart Slough #1 Site was not possible. Due to time constraints and access issues, only *Ludwigia* infested areas were sampled with a target sample number of 3. Samples further demonstrate the relatively low DO within thick beds of *Ludwigia*. The population of *Ludwigia* at sample sites within Stewart Slough #2 were exceptionally dense, with technicians breaking through thick mats of stem and root matter to access bottom samples. Observationally, August surface readings were carried out in decaying leaf and stem tissue that was resting on the dense root mass. DO values in August ranged from 0.31 mg/L to 0.80 mg/L. Surface values of DO increased substantially in September as values ranged from 2.41 mg/L to 2.43 mg/L. The technician noted that by September the *Ludwigia* had sunken into the water column. The open water above the dense root and stem system contained DO values well above the August readings. When the probe was lowered below the root mass, average DO values did not exceed 0.21 mg/L during any sampling date. Neither threshold was exceeded by individual samples.

Collins Bay

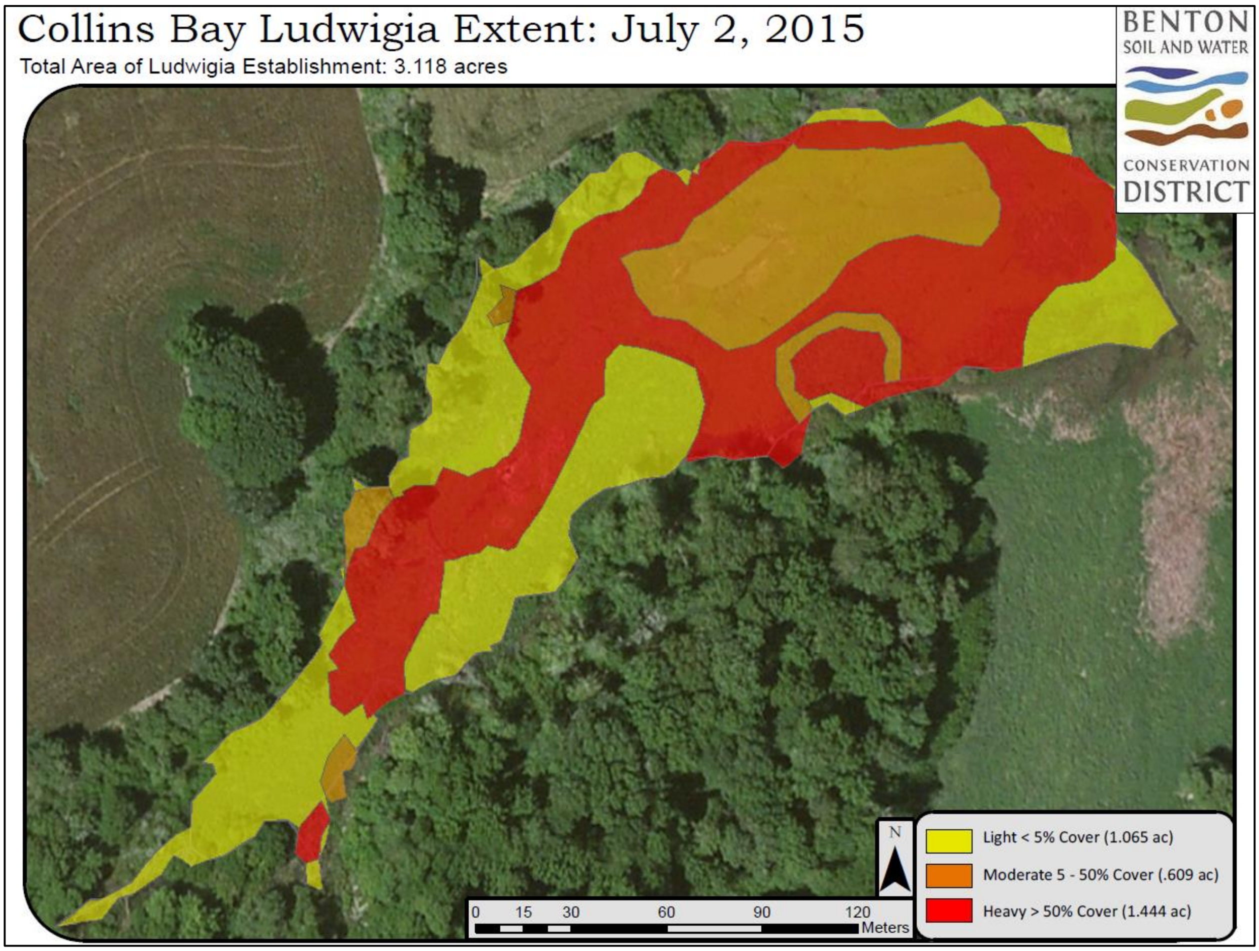

Figure 9. Range and cover class summary of *Ludwigia* in Collins Bay, before second year of treatment.

Collins Bay provided a preview of the possible regrowth that may occur in the numerous sites within the slough system to be treated in 2015 (Figure 9). Observations from BSWCD staff indicated that the Collins Bay site was dominated by heavy *Ludwigia* cover prior to herbicide treatment in 2014. There was no evidence during the mapping effort that range of *Ludwigia* had decreased substantially. Dense regrowth was observed through the central portion of the water body. Moderate or light-cover occurred in areas that contained *N. polysepala* and *S. Eurycarpum*, such as the horseshoe shaped polygon observed in the southeastern portion of the surveyed area. Dense mats of dead *Ludwigia* were observed with fresh growth occurring from underneath. This pattern of regrowth was most apparent in the large moderate-cover polygon in the northeastern portion of the site.

Regrowth of *Ludwigia* in Collins Bay highlighted the benefits of native species such as *N. polysepela* and *S. eurycarpum* in reducing local densities of *Ludwigia.* The map product and observations by Mosaic Ecology technicians show that dense populations of *Ludwigia* could shield individuals in the lower water column from herbicide treatment. Regrowth within the dense mats could have come from the nodes of plants not entirely killed through the treatment process or possible recruitment from an established seedbank.

Data Summary and Discussion

Only one site, the Gravel Pond was sampled on all four target dates. Therefore, before/after comparisons regarding the response of DO to *Ludwigia* die-off in response to herbicide treatment can only be made from data collected within that site. However, valuable insight related to how *Ludwigia* can affect DO and subsequently aquatic life at a large scale has been gained from comparing all four sites and dates.

Because all four water bodies possessed varying physical characteristics, hydrologic regimes and degree of *Ludwigia* infestation, initial values and trends of DO varied at each sampling site. In July, the Stewart Slough #1 Site contained anoxic conditions in nearly the entirety of the system prior to massive *Ludwigia* die-off, while the Gravel Pond possessed an average DO value of 3.44 mg/L in infested areas. In July, prior to a potential further reduction in DO due to microbial respiration, the Stewart Slough #1 Site had already exceeded the acute mortality limit for salmonids, non-salmonids and aquatic invertebrates (USEPA 1986).

Even without chemical application, *Ludwigia* infested surface waters contained less DO on average than open water in all comparisons except for the November sampling in the Oxbow Site. Results of reduced DO and anoxic conditions within emergent beds of *Ludwigia* adhere to findings from previous studies focused on emergent vegetation (Caraco & Cole 2002; Miranda & Hodges 2000; Rose & Crumpton 1996). The presence of *Ludwigia* in waterbodies of the Willamette River Valley greatly reduce available DO within non-treated plant beds.

A clear and obvious "DO crash" in response to herbicide application cannot be clearly observed due to difficulty in collecting WQ data across all dates and sites. It is possible that *Ludwigia* at sampled sites decayed at a rate in which our sampling intervals did not capture. Decay rates vary by species and are related to physical, chemical and biological variables of the environment. The time between herbicide application and DO crashes have varied in previous studies (Owens and Maris, cited from Jewell 1971; Wells et al. 2014). It is possible that due to varying characteristics of water bodies sampled and differences in *Ludwigia* distribution, cover, and density, decay rates were different within each sampling site. Furthermore, the Gravel Pond Site received chemical application roughly two weeks after Stewart Slough #1 and Stewart Slough #2 sites. On the August WQ monitoring date, technicians noted that *Ludwigia* within the Stewart Slough #2 location exhibited a more progressed form of herbicide damage. In the Stewart Slough #2 Site large patches of *Ludwigia* possessed brown leafless stems (Figure 10A). On the same date within the Gravel Pond, the first signs of herbicide damage with chlorosis beginning to yellow the leaves was observed (Figure 10B).

Figure 10. Two sites exhibited different degrees of herbicide damage on monitoring date of 8/11/15. *Ludwigia* within the Stewart Slough #2 Site exhibited defoliation, browning, and curling stems (A), while *Ludwigia* within the Gravel Pond possessed yellowing and curling leaves (B).

After the chemically applied plant tissue dies, the structural integrity of *Ludwigia* weakens and the plant mat sinks into the water column, opening the water surface to wind action and increased oxygen diffusion from the atmosphere. Microbial respiration and oxygen consumption may be highest as leaves and stems decay followed by a release of surface water from dense vegetative cover. This pattern may explain why the Gravel Pond and Stewart Slough #2 Sites displayed low DO values followed by a DO increase at different sampling dates. Also of interest is that a similar pattern was observed in the Oxbow Site which did not receive herbicide application. Natural senescence and plant decay may have been occurring during the September sampling period with a natural thinning of the canopy cover by November. Other possible causes of the DO increase within infested areas during the November sampling period are the increased precipitation rates and cooler water temperatures.

The Gravel Pond Site was the only location with significant open water. In September, the open water area experienced a substantial increase in DO two months after chemical treatment. DO within open water environments has been found to be inversely related to the overall vegetative cover of the water body and negatively affected by distant plant beds (Miranda & Hodges 2000). It is possible that the open water area of the gravel pond was no longer being affected by dense populations of functioning *Ludwigia* and subsequently DO within the open water area increased. The presence of *E. densa* may have also increased DO due to the ability of submerged plants to increase O_2 more efficiently than plants with other growth habits (Coraco et al. 2006).

Across all sites and dates, average DO values in *Ludwigia* infested areas were below the 5 mg/L threshold that would moderately impair non-salmonid fish. Only open water surface readings in the Gravel Pond during September resulted in average DO above the 6.5 mg/L cool-water threshold. Even then, numerous samples possessed DO values well below the cool-water criterion for absolute minimum. Even more alarming were the average DO values that fell below the 3.0 mg/L limit of acute mortality for salmonids, non-salmonids and invertebrates. Within the

Oxbow Site during November sampling, only 1 of 20 surface samples were above the 3.0 mg/L threshold for acute mortality of the three major categories of aquatic organisms. Waterbodies in the Stewart Slough Project Area heavily infested with *Ludwigia* such as the Oxbow and Stewart Slough #1 Sites may be unable to maintain annual populations of fish species. The Stewart Slough #2 Site requires sampling across a larger area to properly assess the capacity to maintain fish populations. During monitoring only the Western Mosquito Fish (*Gambusia affinis*), able to tolerate waters as low as 1.0 mg/L DO was observed at each site (Hubbs 2000). The only sampled site known to possess a diverse fish population is the Gravel Pond (BSWCD 2015). The fish present within the Gravel Pond are predominantly game fish, native to the eastern United States. The large open water area of the Gravel Pond provides refuge from anoxic conditions within *Ludwigia* infested areas. The presence of *Ludwigia* within waters of the Stewart Slough Project Area may result in fish kills and inhabitable environments for both native and game species.

In relation to management decisions, it appears that elevated DO values after herbicide treatment can occur. Although more data must be collected in coming years for annual comparisons, both the Stewart Slough #1 and Gravel Pond Sites experienced increases in average DO in *Ludwigia* infested sites by November compared to pre-herbicide values in July. Meanwhile, the Oxbow Site, acting as a control experienced a decrease in DO values in both infested and open water areas from August to November.

Conclusions

Weaknesses exist in the collected data which include non-uniform sample sizes, failure to sample sites during all four dates, varied dates of herbicide application and the absence of accessible open-water. Weaknesses of the pilot study will be addressed in upcoming monitoring years based on experience gained by the project managers and technicians. The preliminary findings must be corroborated by further data collection and more comprehensive study.

Range & Cover Mapping

1. Physical variables such as gravel substrate, steep banks and canopy cover acted as barriers to *Ludwigia* establishment.
2. *Ludwigia* was not found root in water depths >1.9 meters.
3. *Ludwigia* cover decreased in the presence of native *N. polysepela* and *S. eurycarpum.*
4. Dense mats of *Ludwigia* provided adequate cover to underlying individuals for regrowth in the year after initial herbicide application.

Dissolved Oxygen Monitoring

1. A “DO crash” related to herbicide treatment of *Ludwigia* was not observed.
2. Regardless of herbicide application, *Ludwigia* infested areas possess lower DO.
3. Heavy *Ludwigia* infestations can reduce DO concentrations resulting in acute mortality to salmonids, non-salmonids and aquatic invertebrates.
4. Water quality varies substantially between different water body types in the Stewart Slough Project Area.
5. Infested waterbodies treated with herbicide may experience a more rapid increase in DO compared to non-treated *Ludwigia* infested waterbodies.

Question Formation

With different methods of WQ monitoring able to provide a diverse array of data to be analyzed and communicated in various ways, BSWCD will work with Mosaic Ecology to further clarify existing goals and answerable questions. By doing so, the scientific method can be better applied to study design, Quality Assurance Project Plans (QAPPs) can be implemented, and resources can be better preserved if only necessary data is collected and analyzed. It is important that posed questions meet the needs of BSWCD. This could involve gathering data in regards to the detrimental impacts to fish species or providing information to change Best Management Practices in relation to herbicide treatment.

There is also a need to better finalize the deliverables of the collected data. Data collected for BSWCD can be used for numerous purposes such as: community presentations, grant reporting, detecting water quality issues, permit or compliance purposes, and scientific publications. Based on the deliverables, methods can be adjusted to meet necessary quality assurance (QA) standards. By adhering to certain QA standards, data can meet specific quality levels which select agencies require for reporting (DEQ 2009).

Site Selection

Due to variable and unpredictable seasonal weather patterns, some waterbodies within the Stewart Slough Project Area experienced unprecedented fluctuations in seasonal water levels. Of the monitored sites, Stewart Slough #1 dried completely in most areas after July 2015 sampling. It is recommended that the Stewart Slough Site #1 is not sampled for WQ in the future throughout the entirety of a monitoring season (July to November). However, data collected in July of 2015 can be used to compare WQ data collected in July of the coming years. An increase in sampling points should occur within the Stewart Slough #2 site to account for dropping Stewart Slough #1. Depending on proposed question and study design, it is recommended that a water body is chosen as a sampling site where *Ludwigia* has never known to be present. By doing so, infested water bodies similar in physical characteristics may be compared to the non-infested water body. Specific micro-habitats and select variables can be measured and compared.

Changes to Water Quality Study Design

The 2015 pilot study has many aspects to improve upon to increase systematic data collection and adhere to DEQ standards. As mentioned in the beginning of this section, posing a specific question will lead to the ability to better design a systematic study and assist in project planning and QAPPs. Regardless of the question to be answered, certain aspects of study design can be improved upon. There were challenges involving access and site selection that prevented such parameters from being applied in 2015. Mosaic Ecology technicians and staff at BSWCD will use experience of the 2015 pilot study to make target methods possible for upcoming data collection periods. Adjusted methods will better adhere to QA protocols of DEQ and increase the efficiency in data analysis.

Samples within sites will occur at the same location throughout the monitoring season. In 2015, samples were collected haphazardly where the most representative sampling points existed (infested/open water) and access was possible. In 2016, technicians will repeatedly return to sampled areas by use of GPS. In addition to GPS points, PVC markers will be placed in areas less than 1 meter in depth to help insure technicians of sample locations.

Contingent on the independent variable(s) to be compared in 2016, 12 samples for each comparable variable will be collected at each site with a target sample size of 10. This differs from the 2015 methods of 4 samples per variable. By increasing the sample size, the measured variable will be better represented, normalization of the data is more likely to occur, and anomalies can be discarded if necessary. Also, by attempting to have the same number of samples for each independent variable measured, statistical tests to detect significant differences are easier to complete and statistical power increases. Adhering to DEQ quality standards, at least 10% of the sample locations will be duplicated to act as an audit to measure precision (DEQ 2009). In 2015 no duplicate samples were collected to evaluate precision.

Measurement depths will be adjusted to adhere to DEQ standards (DEQ 2009). Depth of each sample will be adjusted for both "surface" and "bottom" measurements. In waters <2 m in depth, measurements will be taken at 0.5 m from the surface and 0.5 m from the bottom. In waters >2m, measurements will be taken at depths of 0.5 m from the surface, 1.0 m, then at 1.0 m intervals until a final depth of 0.5 m from the bottom. If proposed question involves depth as a measurable variable, depth will be collected at 0.5 m intervals.

Continuous Monitoring Considerations

The current methods used by Mosaic Ecology involve the use of a YSI meter that collects discrete samples in the presence of an observer. These methods are able to provide comparisons of different variables (Open Water/*Ludwigia* infested, July/September, etc.) between water bodies or within water bodies. Yet, it may be in the interest of BSWCD to look into collecting continuous data by using "permanent" dissolved oxygen data loggers to witness trends in DO as *Ludwigia* decays in mass quantities over time.. Such data collection can account for diurnal fluctuations by averaging days together. One such product that is relatively affordable to collect continuous DO and temperature data is the miniDOT logger (http://pme.com/products/minidot). An example of temperature data collected with a similar type of logger is presented in Figure 11.

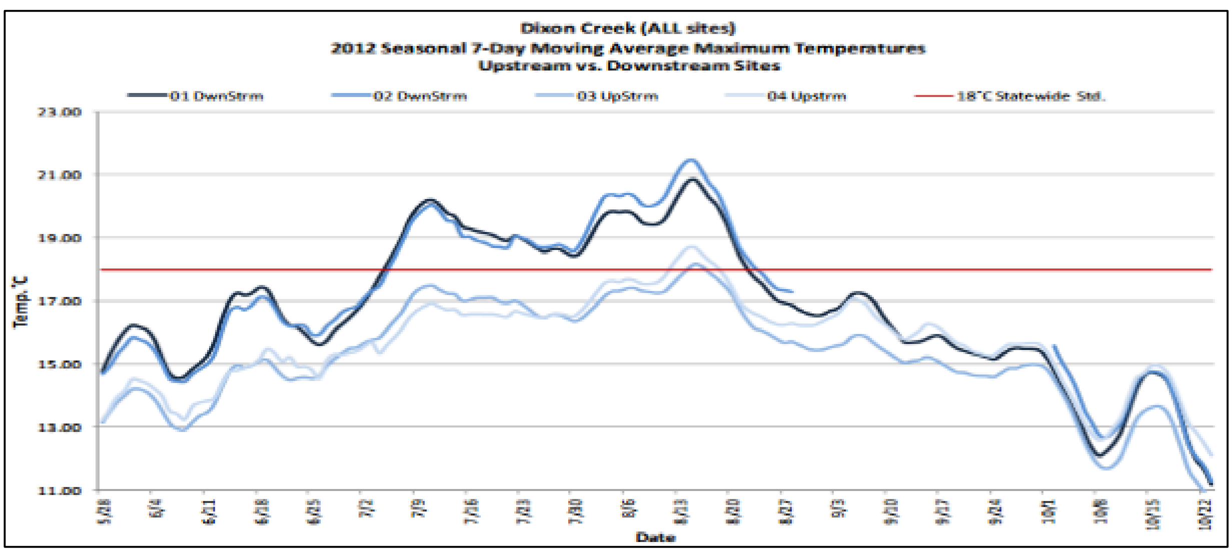

Figure 11. An example of continuous data collected from an instream temperature logger employed by the City of Corvallis, OR (Payne 2012).

Recently, there has been discussion with U.S. Geological Survey (USGS) to collaborate through sharing equipment and utilizing recent water quality data collected on the Willamette. Resources could include stationary water quality data loggers, staff time, and analysis of water samples.

It is important to carryout research before utilizing unsupervised monitoring probes as there are many challenges. Such problems that exist include: stolen probes, detached probes, depth fluctuations over time, algal fouling, or instrument error (Payne 2012; Suplee 2011). Mosaic Ecology is willing to assist in the formation of methods, contacts or even acquire the ability to carry out continuous water quality monitoring ourselves. But at this time, Mosaic Ecology does not possess the monitoring equipment to do so.

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