2016 Water Quality and Ludwigia Monitoring Report for Stewart Slough, Collins Bay, and Scatter Bar Pond




BENTON SOIL AND WATER CONSERVATION DISTRICT

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For Benton SWCD

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

Overview

In the summer of 2015, a monitoring program was established at sites in the Stewart Slough complex and at Collins Bay in Benton County, and at Scatter Bar Pond at Horseshoe Lake in Linn County (project area) to provide information related to the large scale control of the invasive macrophyte, Ludwigia; Uruguayan primrose-willow (*Ludwigia hexapetala*) and floating primrose-willow (*Ludwigia peploides*). The monitoring program, established by Benton Soil & Water Conservation District (SWCD) in 2015, represents the second year of the program and builds upon the lessons learned of the 2015 pilot study. The goal of the monitoring program is to track annual population shifts of Ludwigia in response to control efforts and to assess the effect of Ludwigia on water quality.

The monitoring effort was conducted to inform Benton SWCD of the possible impacts the presence of Ludwigia and associated control efforts may have on water quality in the project area. Monitoring was not required by the 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 improved upon in 2016 and considerations for future years were made.

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 project area. Monitoring occurred before and after herbicide treatment from July to November within waterbodies that possessed different physical characteristics and varying Ludwigia populations. Distribution and density of Ludwigia within four distinct water bodies were mapped and Ludwigia abundances were compared to pre-treatment levels. Water quality data was collected by a handheld YSI meter in three distinct water bodies in 2016 and compared to available data from the 2015 pilot study. The data presented in this report focuses on dissolved oxygen with discussion on the effects to aquatic organisms.

Of the three sites mapped for Ludwigia distribution and cover in both 2015 and 2016, Lower Kiger Pond (formerly referred to as “Gravel Pond”) and Stewart Slough #2, experienced a 99% and 96% reduction respectively of heavy Ludwigia cover (>50%), with light (<5%) and moderate cover (5-50%) becoming the dominant classes one year after initial treatment. The third site, Collins Bay did not exhibit a similar shift in cover classes. Within the project area, observations of Ludwigia regrowth appeared to be most prominent in thick floating mats of decaying plant material and silt that remained intact after initial treatment. Mean DO was lower in Ludwigia infested waters compared to adjacent open water habitat. Monitored sites showed a decrease in DO within open water environments as the season progressed even as water temperatures decreased. DO values within some Ludwigia infestations were below the minimum thresholds known to impair aquatic organisms. In some cases, these values were low enough to cause acute mortality to major aquatic groups.

Monitoring Goals

1. Assess changes in Ludwigia distribution and cover one year after 2015 control efforts.
2. Assess how Ludwigia affects water quality (WQ) with and without herbicide treatment.
3. Provide recommendations for future WQ monitoring and associated Ludwigia control.

Background

Ludwigia in Project Area

Native to Central and South America, *Ludwigia hexapetala* and *L. peploides* are invasive aquatic plants that are rapidly increasing in prevalence in Oregon, most notably in the Willamette 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 populations throughout the Willamette Valley (City of Eugene 2013). After initial surveys showed extensive infestations within some side channels, oxbows, riverine wetlands and other water bodies in the Corvallis to Albany reach of the Willamette River, Benton SWCD acquired grant funding from the Oregon State Weed Board, the Bonneville Power Administration, the Oregon Watershed Enhancement Board, and Meyer Memorial Trust in order to greatly reduce Ludwigia in over 4 miles of infested habitat in the project area.

The first full scale treatment within the project area occurred in late-June to early-July of 2015, with follow up applications occurring in August and October 2015. During the same year, the first water quality and mapping data were gathered at five sites in the project area. In 2016, one round of chemical application occurred across the same sites in late-July to early-August. Contractors applied a formulation of aquatic label Rodeo (glyphosate) at a concentration of 2-3%, with a water soluble indicator dye 0.5-1% of the aquatic label surfactant Agri-dex. 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. Roughly four weeks after the chemical application during both treatment years, large masses of Ludwigia were observed dying as leaf and stem tissue browned, curled and sank to decay at the water bottom.

Results of the 2015 control efforts varied across sites. In July of 2016 (prior to 2016 control efforts) some treated water bodies experienced little regrowth in areas previously at 100% Ludwigia cover. Other sites experienced a reduction in overall plant height and mass, but cover did not decrease substantially from July 2015 to July 2016 (Figure 1).

Figure 1. In July of 2016, Ludwigia cover varied across sites. The Lower Kiger Pond site showed minimal regrowth of Ludwigia, with native plants beginning to colonize open areas (A). Sections of Stewart Slough in July 2016, exhibited Ludwigia cover similar to the pre-treatment levels of 2015 (B).

Effects of Plants on 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. The monitoring effort was intended to assess how large-scale herbicide treatments and the resulting changes of Ludwigia densities affect DO within water bodies of the 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 than photosynthesis (Arun & Bowers 1983). 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. Counteractive to increasing DO within the water column, 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;). 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). Indirect influences of aquatic plants to DO include seasonal or human caused plant die-offs which reduces DO as respiration rates of microbes increase during the decay process and consume available oxygen (CDBW 2001; Jewell 1971; ODFW 1999).

The degree of oxygen consumption in decaying plant communities varies with 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 shown that hypoxic conditions result from aquatic plant die-offs related to both chemical and mechanical control (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 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. With evidence of anoxic conditions being present in areas of both living and decaying plant material, it is important to assess how Ludwigia affects DO within varying waterbody types in the Willamette River 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, minimum thresholds DO have been established 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 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).

Data in this report were summarized in order to gauge how DO within infested water bodies of the project area could affect both salmonid and non-salmonid species. Two DO thresholds were 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, within which the project area is located (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

Five sites within the project area were selected for some type of monitoring in 2016 (Figure 2). In total, four sites were mapped for Ludwigia distribution by GIS and three sites were sampled for water quality in 2016. Selected sites represent the diverse water body types that exist within the project area (pond, slough, side channel). Access, perennial water presence, permission of entry, distance from one another and degree of infestation were taken into account during site selection.

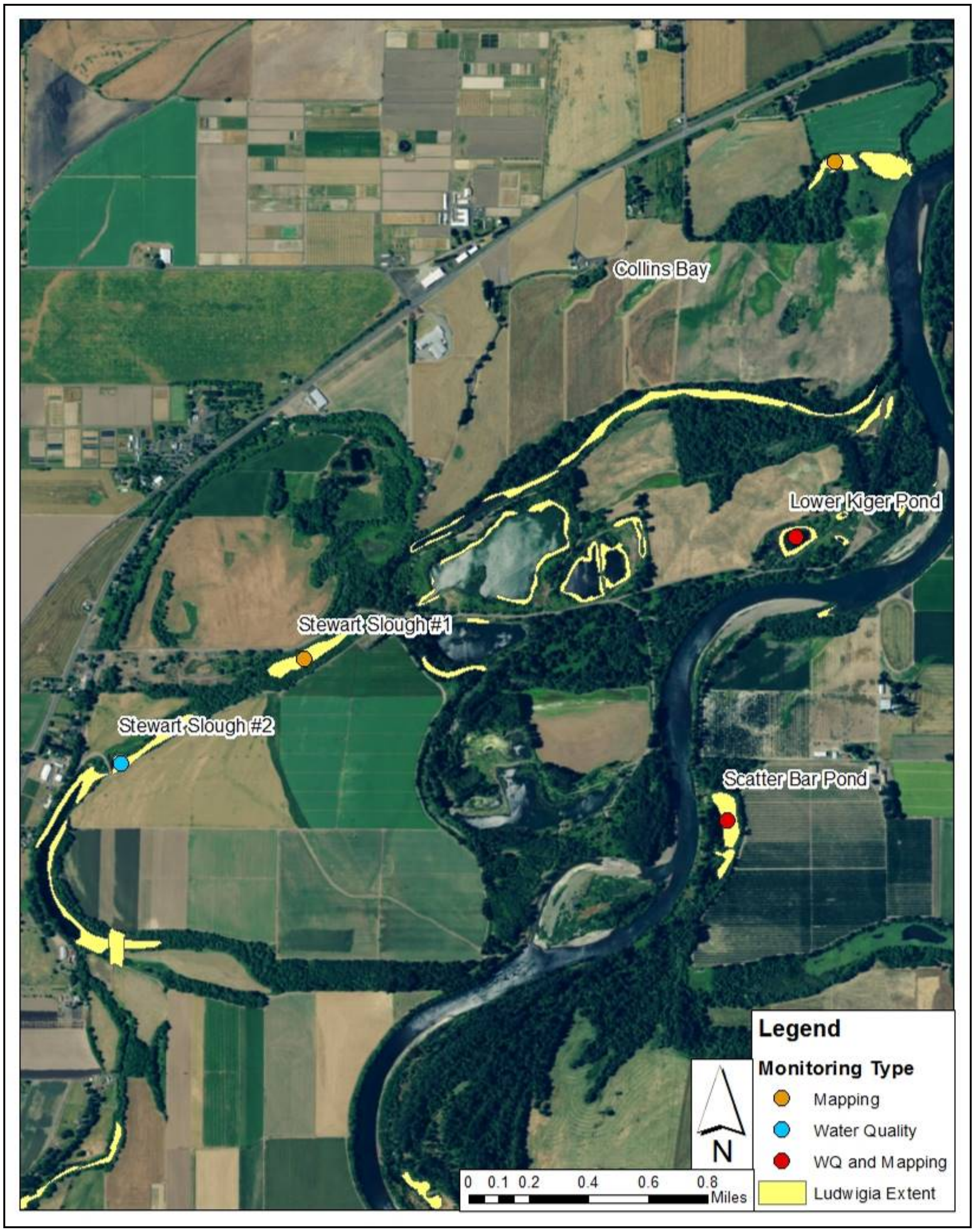


Figure 2. Sites within the project area that were mapped and/or monitored for Ludwigia cover and water quality in 2016. Ludwigia extent represents 2014 distribution.

Collins Bay, Lower Kiger Pond, and Stewart Slough #1 were mapped in both 2015 and 2016 to provide information regarding changes in Ludwigia cover in response to one year of control treatments (Table 1). Scatter Bar Pond at Horseshoe Lake in Linn County (formerly referred to as "Oxbow") was mapped for the first time in 2016 to create baseline data for expected Ludwigia control in 2017.

Table 1. Herbicide application dates and summary of data collection at all five sites monitored during 2015 and 2016. Partial WQ monitoring in 2015 is due to uncharacteristically dry conditions. Dates and ranges are approximate, with not all dates included in ranges representing full days of applied control.

Site	Chemical Treatment by Year			Data Collection by Year			
	2014	2015	2016	Mapping 2015	WQ 2015	Mapping 2016	WQ 2016
Collins Bay	9/15-9/17	6/30 - 7/2; 8/15 - 8/19	8/15-8/16	Yes	No	Yes	No
Stewart Slough #1	No	7/15 - 7/23; 10/15 - 10/16	7/27	Yes	Partial	Yes	No
Lower Kiger Pond	No	7/28 - 7/29; 10/8	7/27-7/28	Yes	Yes	Yes	Yes
Stewart Slough #2	No	7/15 - 7/23; 10/15 - 10/16	7/27	No	Partial	No	Yes
Scatter Bar Pond	No	No	No	No	Yes	Yes	Yes

Lower Kiger Pond and Scatter Bar Pond sites were successfully monitored for water quality in 2015 and 2016 allowing general comparisons to be made regarding dissolved oxygen between years (Table 1).

All sites except Scatter Bar Pond were chemically treated in summer of 2015 and 2016. Sites were able to be treated twice in 2015, while sites were only able to be treated once in 2016. Collins Bay is the only site that was chemically treated in 2014.

The initial study design in 2015 intended to carryout both Ludwigia cover mapping and WQ monitoring over numerous years at Stewart Slough #1, Lower Kiger Pond, and Scatter Bar Pond. Unexpected drying of the Stewart Slough #1 water body caused WQ monitoring to be moved to the Stewart Slough #2 site in late 2015 and subsequent monitoring years. Water quality monitoring is yet to be planned for Collins Bay. Collins Bay was selected for mapping due to being the only site receiving chemical treatment in 2014. Mapping will still continue at Stewart Slough #1. Scatter Bar Pond has acted as a control for WQ monitoring, receiving no herbicide application in either monitoring year.

Distribution & Cover Mapping

Stewart Slough #1, Lower Kiger Pond, Scatter Bar Pond, and Collins Bay were mapped on July 20, 2016, prior to chemical application. Mapping was carried out by technicians with the mobile GIS program, Arc Collector. A portable receiver (Garmin GLO) was used to improve accuracy and precision of data collection. Percent cover estimates of Ludwigia were used to generate cover class polygons within surveyed sites: Light (<5%), Moderate (5 – 50%) and Heavy (>50%).

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. Comparison maps of Ludwigia from 2015 to 2016 were generated for Stewart Slough #1, Lower Kiger Pond, and Collins Bay. It is expected that distribution and density mapping will occur within the four sites on an annual basis. Observed variables affecting Ludwigia density patterns within mapped sites were summarized.

Water Quality Monitoring

Dates for water quality monitoring were selected to capture DO prior to treatment and at specific time intervals after treatment (Table 2). Dates for 2016 were selected to closely match those of the previous year. Monitoring at each site varied by no more than two hours on each date to minimize diurnal variations in WQ values.

Table 2. Water quality monitoring dates at select sites within the project area.

Sampling Period *	2015	2016
Pre-Treatment	7/6	7/21
2 Weeks Post Initial Treatment	8/11	8/11
2 Months Post Treatment	9/21	9/20
Fall Decay	11/2	11/3

**Sampling periods were target dates and do not represent exact time intervals after treatment across all sites.*

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 probe integrity was measured in accordance with manufacturer's standards. DO was calibrated prior to each site (YSI 2009; YSI 2010). For each sample, depth, max depth and percent cover of Ludwigia were collected. Sampling points were recorded by GPS.

Within each site, permanent sampling points were selected in two categories which included "open water" areas (n = 8) with 0-15% Ludwigia cover, with no other emergent or floating plants present, and "Ludwigia infested" areas (n = 8) with >50% Ludwigia cover. Sampling points were recorded by GPS and returned to during each sampling date. Percent cover was assessed for the total distribution within one meter of the sample. In the Lower Kiger Pond site, minimal regrowth occurred in 2016, and "Ludwigia infested" samples were taken in areas that possessed >50% Ludwigia in 2015. Sampling depths were adjusted from 2015 procedures to better adhere to DEQ monitoring methods (DEQ 2009). 2016 was the first year sampling occurred at a depth of 0.5 meters from the surface. Three depths were recorded at each sampling site: 0.13 meters (surface), 0.5 meters from surface (0.5 m depth), and 0.5 meters from bottom. Data was logged within the YSI meter and recorded manually by the technician.

Samples were collected at the surface and at a depth of 0.5 meters in both open water and *L. hexapetala* infested sampling points. Eight readings at each depth, at each sampling point were recorded when possible. Dissolved oxygen and temperature of Ludwigia infested and open water samples across dates were displayed graphically. Mean temperature at each depth was displayed to indicate possible shifts of DO in relation to temperature. Only samples at surface and and 0.5 meter depths were graphically displayed and summarized.

Results

Distribution and cover of Ludwigia within the four mapped sites have been presented in map form with calculated acreage (Figures 3, 6, 9, and 10). Raw data of the six measured WQ variables have been provided to BSWCD for further analyses and interpretation. Data from 2016 was summarized and for the 6 variables and three depth collected (appendix A). Within the report only DO (mg/L) and temperature (°C) have been graphically displayed and summarized.

Scatter Bar Pond

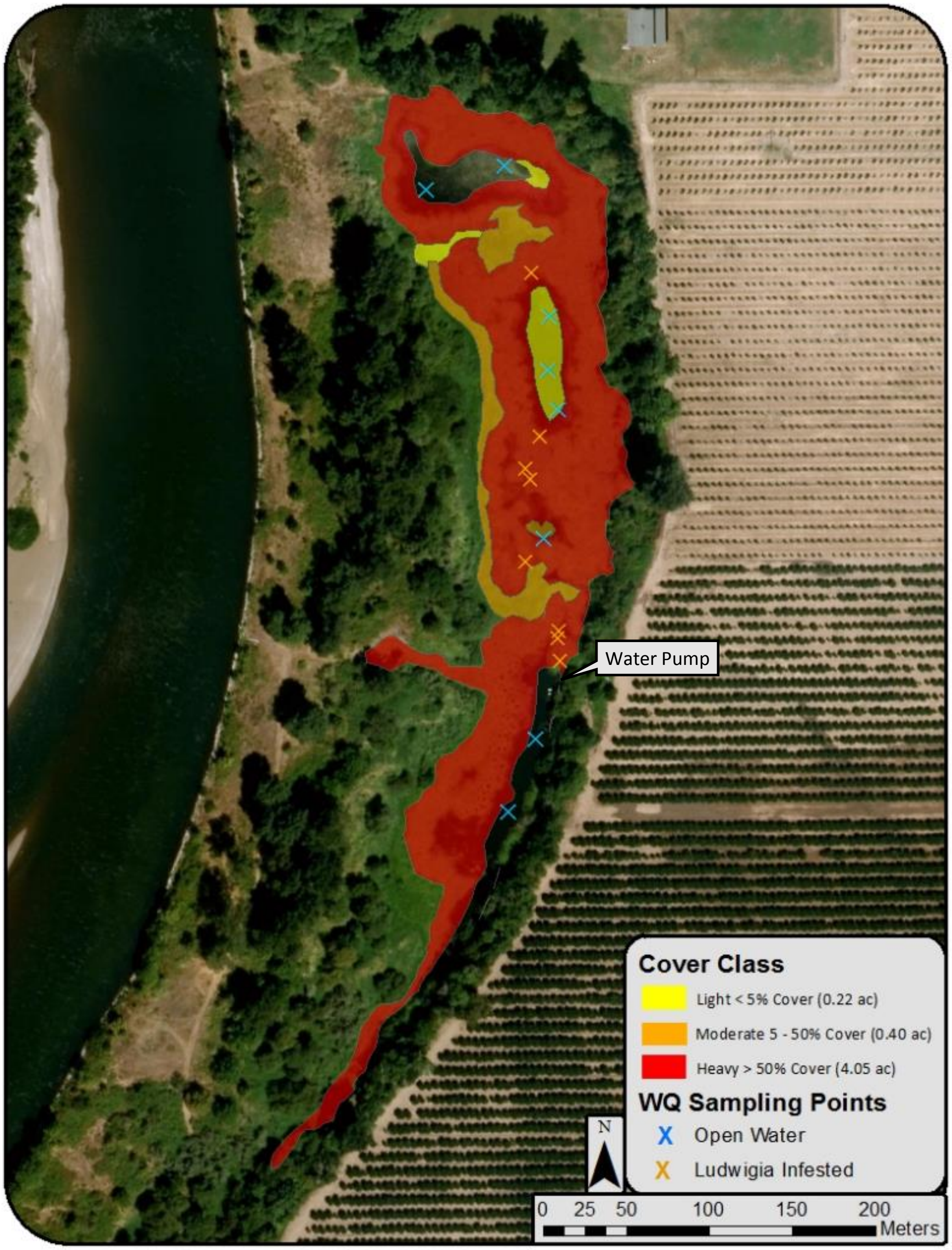


Figure 3. Distribution and cover class summary of Ludwigia within Scatter Bar Pond on July 20, 2016 with associated monitoring points.

Scatter Bar Pond was dominated by dense monocultures of Ludwigia throughout 4.05 acres of the nearly 5 acre water body (Figure 3). In total, Ludwigia occupied 4.67 acres. Ludwigia was at high cover in all areas where depth was less than two meters. Areas where depth exceeded two meters had open water conditions. Large openings in relation to increased depths occurred in the wider northern reach of the water body. The western margin possessed Ludwigia populations below 50% due to apparent Ludwigia die off. The eastern bank of the water body was vegetated, with overhanging tree species that shaded the water body. The absence of Ludwigia directly adjacent to the eastern bank south of the water pump, may have been influenced by shade and the steep gradient along the eastern bank, as well as from intermittent flow created by the water pump (Figure 3). The water pump is used for irrigation in the adjacent farms and was not observed running during the monitoring periods. Plant diversity was low, with very few species growing within the dense *Ludwigia* monocultures. Populations of non-native Brazilian waterweed (*Egeria densa*), native coontail (*Ceratophyllum demersum*), and American waterweed (*E. canadensis*) were present within the deep open water areas.

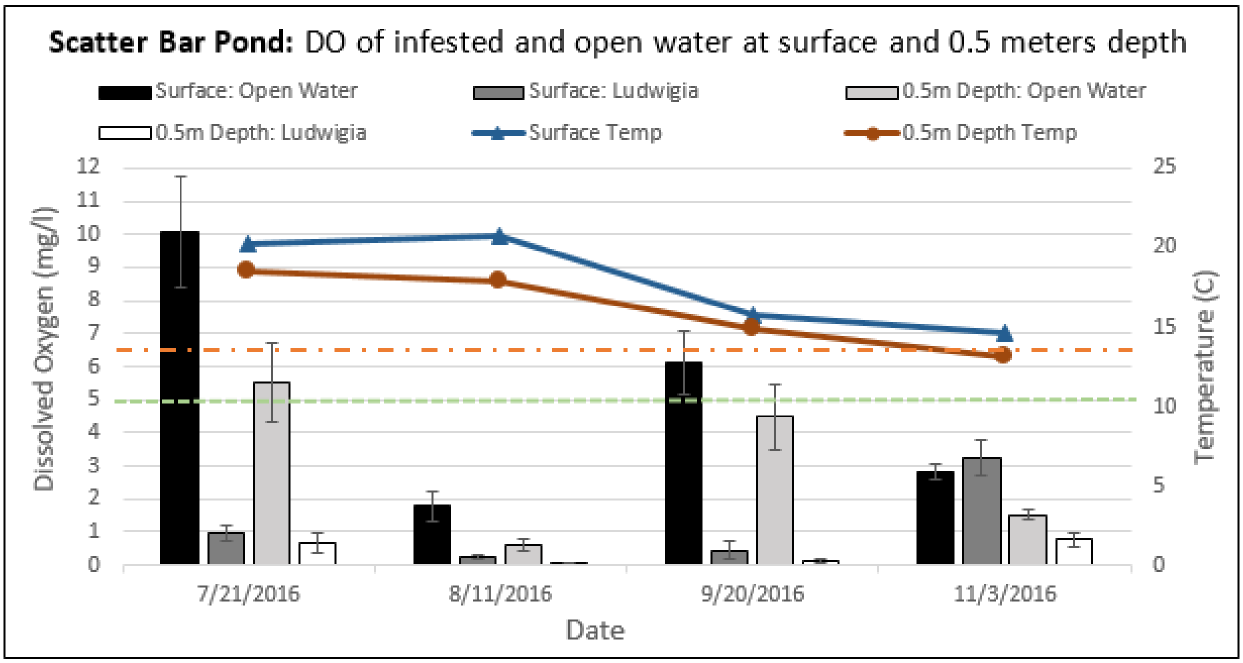
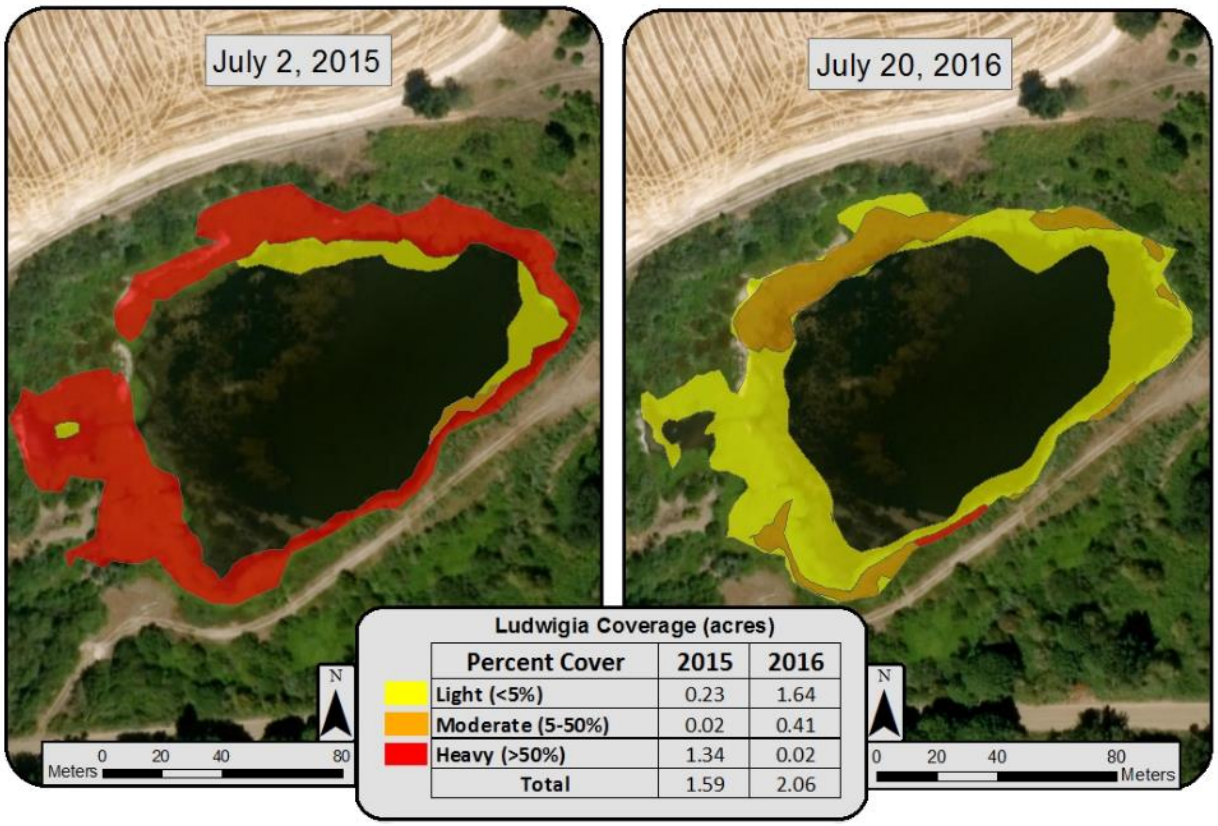


Figure 4. Dissolved oxygen comparison between surface and 0.5 meter depths in open water and Ludwigia infested areas of Scatter Bar Pond. Scatter Bar Pond acted as a control and **no herbicide application occurred**. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green). Error bars represent +/- one standard error. "Ludwigia infested" sampling sites are displayed as "Ludwigia".

Dissolved oxygen in open water at surface and 0.5 meter depths was higher than Ludwigia infested sampling sites during all dates except for November at surface. Mean DO was highest for open water measurements in July, and decreased substantially in August. Ludwigia infested sample sites experienced the highest DO readings in November at both surface and 0.5 meter depths. Mean DO within infested waters at surface ranged from 0.23 to 0.97 mg/l from July to September, but increased substantially to 3.29 in November. Temperature decreased from August to September at surface (20.8^{o}C to 15.8 ^{o}C) and 0.5 meter depth (17.9 ^{o}C to 14.9 ^{o}C). DO and temperature were lower at 0.5 m depths for both open water and infested samples when compared to surface readings.

Mean DO of Ludwigia infested waters was below both cool-water criterion and non-salmonid thresholds in all sampling categories across all dates. Open water mean DO at surface exceeded cool-water criterion once in July and exceeded non-salmonid criterion in July and September.

Lower Kiger Pond



Percent Cover	2015	2016
Light (<5%)	0.23	1.64
Moderate (5-50%)	0.02	0.41
Heavy (>50%)	1.34	0.02
Total	1.59	2.06

Figure 5. Distribution and cover class summary of Ludwigia within Lower Kiger Pond prior to chemical treatment (July 2, 2015) and one year after initial treatment (July 20, 2016).

After one year of treatment at Lower Kiger Pond, overall distribution of Ludwigia increased by 30%, with distribution expansion dominated by the light cover class (Figure 5). The site experienced a 99% reduction of acreage occupied by heavy Ludwigia cover. Along the western extent of the population where heavy cover previously dominated the relatively shallow environment, Ludwigia regrowth was minimal. Native arrowhead (*Sagittaria* sp.) and burr reed (*Sparganium* sp.) were observed colonizing the shallow open areas previously occupied by Ludwigia. The most prominent regrowth of Ludwigia occurred on mud flats along the bank margins. Due to previous activity of gravel mining within the water body, water depth quickly increased from the banks resulting in the large open water environment at the center of the waterbody. Same as the previous year, the open water environment was absent of emergent or floating species, but submersed plant species of *E. canadensis* and *E. densa*, were abundant at depths up to 3 meters.

Mean DO in open water environments was significantly higher than the areas previously occupied by *Ludwigia* at both depths, across all sampling dates (Figure 6). Similar to Scatter Bar Pond, mean DO was highest in open water samples in July. As the year progressed, mean DO decreased in open water environments, but increased overall in areas previously occupied by *Ludwigia* in 2015. Temperature decreased substantially from August to September at surface (23.1°C to 13.3 °C) and 0.5 meter depth (21.4 °C to 13.1 °C).

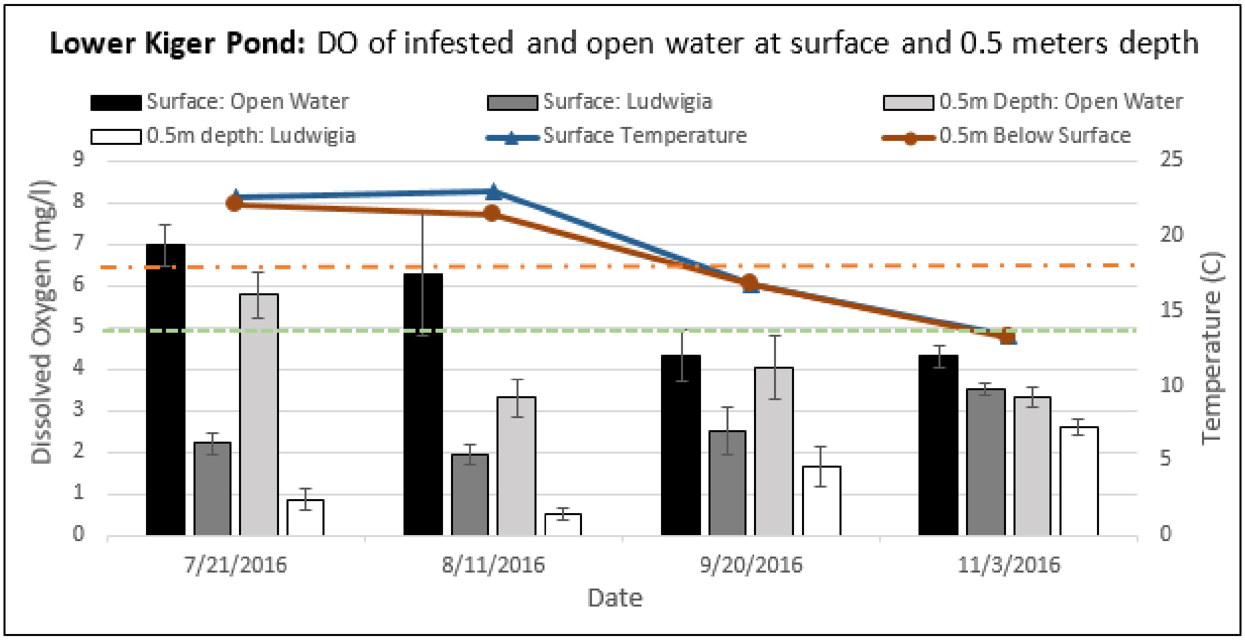
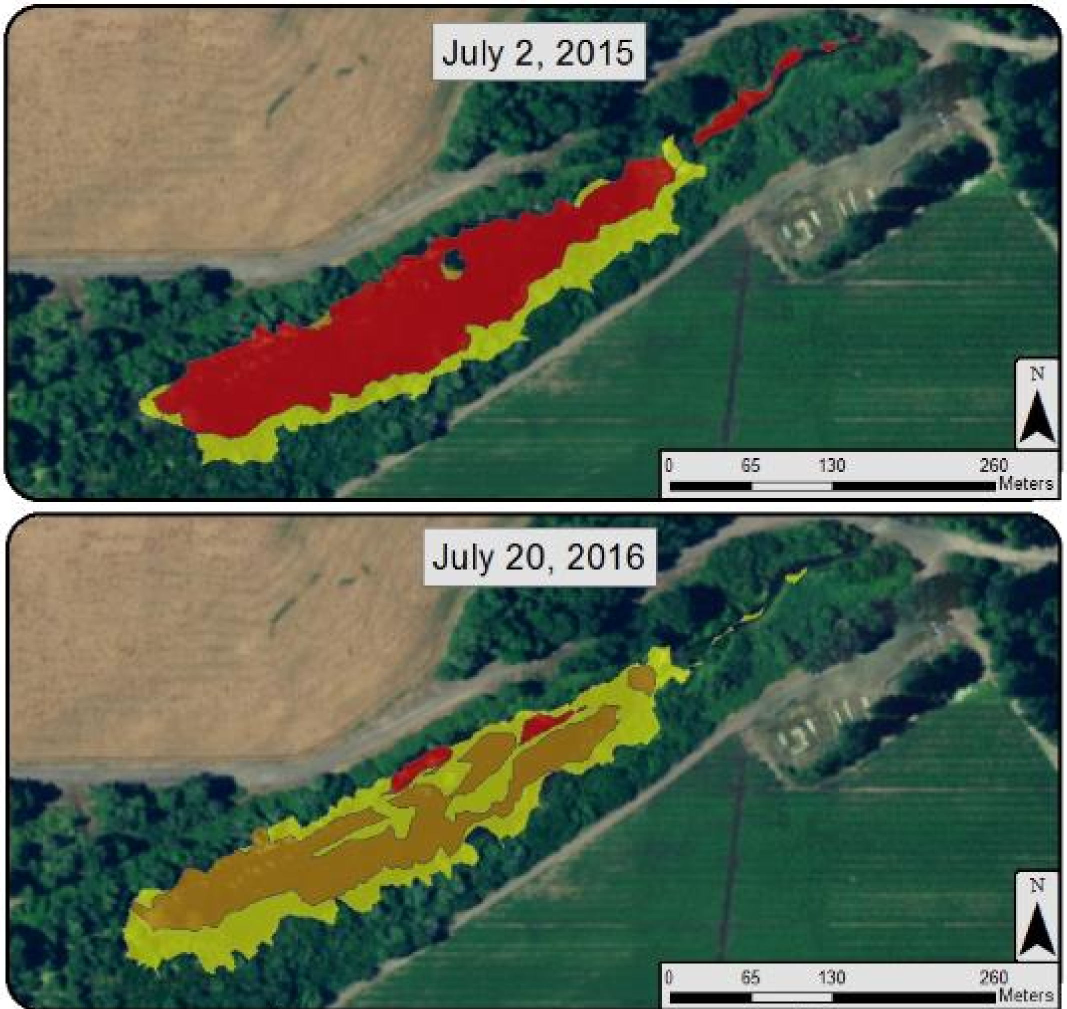


Figure 6. DO comparison in Lower Kiger Pond between surface and 0.5 meter depths in open water and areas previously dominated by Ludwigia. Herbicide application occurred on July 27th, 2016. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green). Error bars represent +/- one standard error. “Ludwigia infested” sampling sites are displayed as “Ludwigia”.

Mean DO within open water surface samples met the non-salmonid threshold of 5 mg/l in July and August, exceeding the cool-water criterion threshold only in July. Mean DO in sites previously occupied by Ludwigia did not exceed either threshold during any sampling date. Of all surface samples collected across all dates, only one discrete measurement in previously infested sample sites exceeded 5 mg/l.

In relation to 2015 mean DO values, areas previously occupied by Ludwigia decreased in all sampling periods except for September from 2015 to 2016 (Appendix A; Appendix B). Open water areas exhibited varied differences between sampling years by month. The highest mean DO values at the surface for 2015 occurred in September, while July of 2016 exhibited the highest mean DO values.

Stewart Slough #1



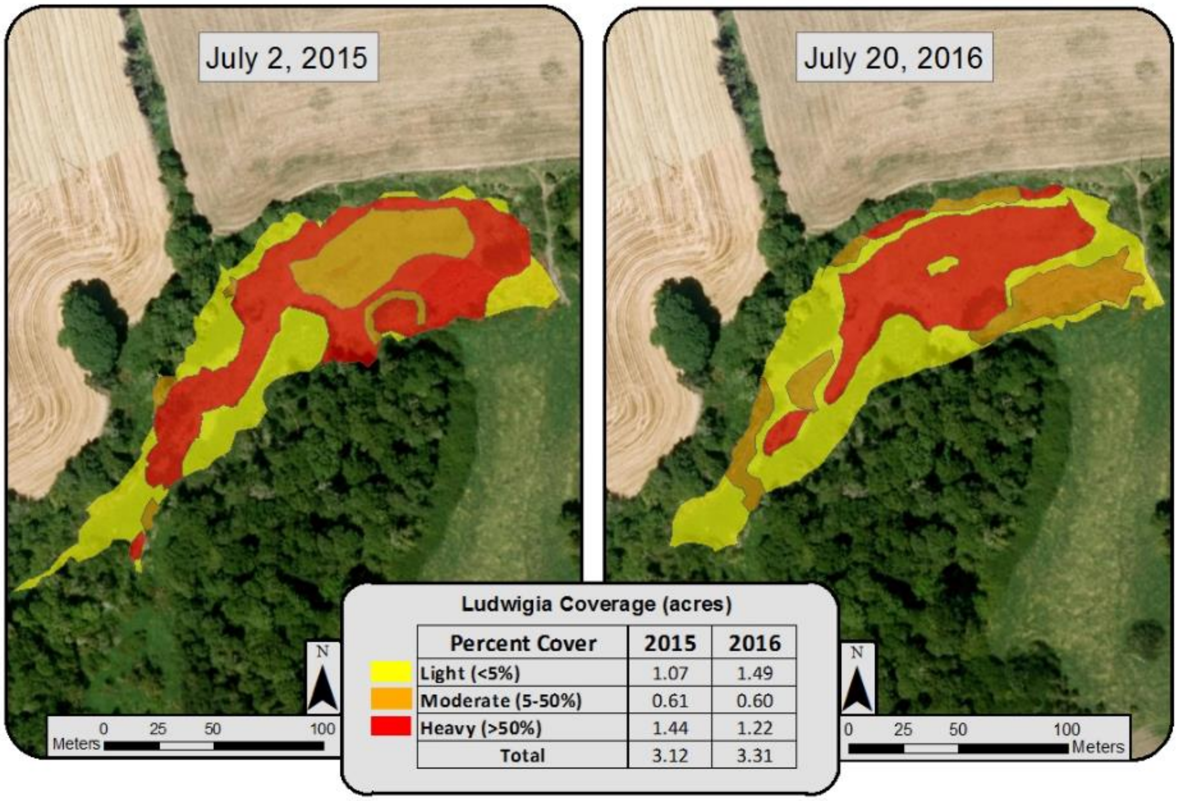
Ludwigia Coverage (acres)

Percent Cover	2015	2016
Light (<5%)	1.19	2.17
Moderate (5-50%)	0.03	2.00
Heavy (>50%)	3.32	0.14
Total	4.52	4.31

Figure 7. Distribution and cover class summary of Ludwigia within Stewart Slough #1 prior to chemical treatment (July 2, 2015) and one year after initial treatment (July 20, 2016).

Ludwigia within the Stewart Slough #1 Site decreased in overall cover from 2015 levels (Figure 7). Previously a monoculture, dense stands of established Ludwigia, depicted by heavy cover in 2015 were reduced by a total of 96% to moderate and light cover classes. Regrowth was observed within these areas resulting in an increase of 1.97 acres of the moderate cover class. Moderate cover was patchy and separated by channels of light cover that was observed being used by nutria and beaver. The eastern portion of the site, which flows into a culvert, experienced a large reduction in the presence of Ludwigia with very few individuals present, compared to dense populations observed on the northern bank in 2015.

Collins Bay



	Percent Cover	2015	2016
	Light (<5%)	1.07	1.49
	Moderate (5-50%)	0.61	0.60
	Heavy (>50%)	1.44	1.22
	Total	3.12	3.31

Figure 8. Distribution and cover class summary of Ludwigia within Collins Bay one year after initial treatment (July 2, 2015) and two years after initial treatment (July 20, 2016).

Prior to initial treatment in 2014, observations from Benton SWCD staff indicated the site was dominated by heavy cover throughout the water body. Collins Bay, did not substantially change in total cover class or distribution after the second year of treatment at the site (Figure 8). Moderate and heavy cover classes decreased by 2% and 16% respectively. Heavy cover decreased within the western arm of the waterbody, but increased within the population center, which was previously represented by moderate cover. Moderate cover in the population center in 2015 was contributed partially to a large mass of dead plant material observed above early season regrowth. By 2016, this area had shifted to heavy cover (Figure 8). Clear boundaries between heavy and light cover classes were present where native species such as yellow spatterdock (*Nuphar polysepela*) were present (Figure 9).

Figure 9. Thick Ludwigia regrowth observed adjacent to *N. polysepela* population at Collins Bay, 7/20/16.

Stewart Slough #2

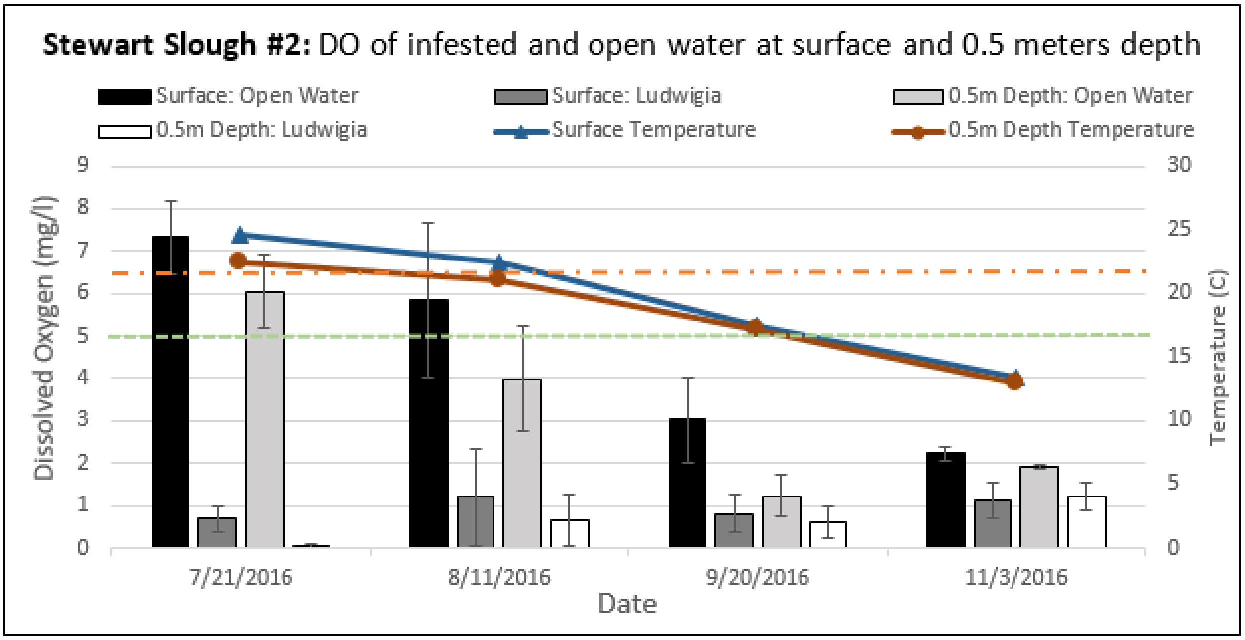


Figure 10. DO comparison in Stewart Slough #2 between surface and 0.5 meter depths in open water and Ludwigia infested waters. Herbicide application occurred on July 27th, 2016. Dashed lines represent cool-water criterion (orange) and moderate impairment for non-salmonid species (green). Error bars represent +/- one standard error. "Ludwigia infested" sampling sites are displayed as "Ludwigia".

The Stewart Slough #2 site which was not selected for cover and distribution mapping in either monitoring year, represents a waterbody similar to the Stewart Slough #1 site. Prior to treatment in 2015, the site was dominated by a Ludwigia monoculture through nearly the entire extent of the water body. The only large area of open water was at the eastern extent immediately adjacent to the agricultural road for a farm. This area experienced depths exceeding three meters which may contribute to the lack of Ludwigia presence. In 2016, this open area increased substantially in size, but rapid regrowth was observed westward as the site became more shallow. Dense mats of Ludwigia had accumulated large amounts of silt and dirt and acted as floating islands in which technicians were able to walk. Ludwigia regrowth was extensive with 50-100% cover occurring

Mean DO in open water environments was higher than in areas occupied by Ludwigia at both depths (surface and 0.5 m depth), across all sampling dates (Figure 10). Mean DO was highest in open water on 7/21/16. As the year progressed, DO decreased in open water environments. Changes in mean DO of Ludwigia infested samples varied between dates. Temperature decreased substantially from August to September at surface (22.4^{o}C to 13.5 ^{o}C) and 0.5 meter depth (21.1 ^{o}C to 13.0 ^{o}C).

Mean DO within open water surface samples met the non-salmonid threshold of 5 mg/l in July and August, exceeding the cool-water criterion threshold only in July. Mean DO in waters occupied by Ludwigia did not exceed either threshold during any sampling date.

Data Summary and Discussion

Although sampled water bodies possessed varying physical characteristics, hydrologic regimes and different degrees of Ludwigia infestation, seasonal trends have been captured across all three sites sampled for water quality. The 2016 monitoring effort provided information regarding population shifts of Ludwigia in response to one year of treatment and showed how DO may change.

The 2015 control effort was successful at reducing heavy cover of Ludwigia but did not substantially reduce overall distrubution of the target plant at mapped sites. With a 99% and 96% reduction of heavy cover at Lower Kiger Pond and Stewart Slough #1 site, cover shifted to moderate and light classes. Furthermore, populations were no longer erect, but were prostrate and had greatly decreased in overall emergent density and biomass. Ludwigia regrowth was most apparent in muddy, floating masses that represented areas previously inhabited by dense populations.

An unseasonably hot and dry 2015 resulted in the expansion of Ludwigia in typically deeper open water environments. It is well documented that exceptionally low water levels permit macrophyte fragments to root and persist in areas previously unsuitable for macrophyte colonization (Fox and Haller 2000; Lan et al. 2010). Lower Kiger Pond increased in overall distribution of Ludwigia by 0.47 acres before weed control treatments occurred. The expansion was most prominent in the open water habitat. Although systematic water depth data was not collected for the Lower Kiger Pond, unseasonably low water levels were observed in accordance with record high temperatures and lower than average precipitation rates within the Willamette Valley (NOAA 2016).

Mapping and observations within the Scatter Bar Pond exhibited another trend in Ludwigia shifts in response to drought conditions. Without chemical treatment, dead Ludwigia was observed along banks of the waterbody in response to apparent dry conditions from 2015. Drought conditions could have contributed to the large reduction of heavy cover in Lower Kiger Pond, which possessed the majority of the Ludwigia infestation in shallow water and margin environments.

The most prominent regrowth after application occurred within areas of the waterbody in which conditions permitted Ludwigia to form dense floating mats. Stewart Slough #1, Stewart Slough #2, and Collins Bay exhibited moderate to high cover from regrowth occurring on apparent "islands" consisting of dead Ludwigia material and captured silt (Figure 11). These islands varied in size. This was observed in 2015 at Collins Bay, one year after initial treatment. After the second year of treatment at the site,

Figure 11. Floating "island" within Stewart Slough #2 on 11/3/16, exhibiting Ludwigia regrowth on emergent and submerged portions of plant and silt mass.

these areas did not substantially decrease in distribution or cover. It is possible that these "islands" contain a large root biomass, provide silt for seed germination, or are dense enough to shield individuals from chemical application. More research is needed to determine the exact mechanism for the relatively high rates of regrowth. These areas should be taken into consideration when designing plans for the 2017 treatment year.

Ludwigia infested water contained less DO than open water areas within the three sampled sites, which is similar to 2015 monitoring in the project area (Benton SWCD 2015). Only during surface comparisons at Scatter Bar Pond on 11/3/16 was mean DO higher in Ludwigia infested areas than open water. This anomaly could be related to seasonal mixing in relation to the influx of precipitation and run off as seasonal rainfall increases in the Pacific Northwest. In a similar trend, Mean DO values within Lower Kiger Pond and Stewart Slough #2 became more similar to one another between depth and monitoring treatments in November.

Prior to seasonal rainfall, the Scatter Bar Pond and Stewart Slough #2 sites possessed anoxic conditions below the 3 mg/l threshold of acute mortality for salmonid, non-salmonid, and aquatic invertebrates (EPA 1986). 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). Mean DO in open water exceeded the cool water criterion of 6.5 mg/l during the month of July in all three waterbodies. Mean DO did not exceed the cool water criterion in any sampled water body during any other sampling date. Interestingly, in Lower Kiger Pond, where large masses of Ludwigia were no longer present, in comparison to 2015, mean DO did not recover and these areas were still lower in mean DO than the open water counterparts. This could be attributed to accumulated litter along the margins, residual decay of the previously treated Ludwigia, or the absence of submerged aquatic species which were observed to be more abundant in deeper, open water environments.

Water quality monitoring in Stewart Slough #2 and Lower Kiger Pond showed a decrease of mean DO in open water areas from July to August, and again from August to September, even as mean temperatures decreased. The inverse relationship of oxygen and temperature (ODFW 2009; USGS 2017) did not appear to be the major factor contributing to the change in DO over sampling dates. The overall decrease of mean DO in open water habitats from early summer to fall could be attributed to the role that submerged aquatic plants contribute to DO within the water bodies of the project area. With abundant populations of *E. densa*, *E. canadensis*, and *C. demersum*, all three sites exhibited the highest mean DO in open water during the month of July when submerged plants are actively growing and photosynthesizing (Coraco & Cole 2002; Coraco et al. 2006; Frodge et al. 1990). It may be the seasonal decrease of DO in open water is closely related to the seasonal decline in photosynthetic rates of submerged aquatic plants. If submerged aquatic plants do play a major role in elevated DO within water bodies of the project area, it is possible that DO recovery within areas previously occupied by Ludwigia could be delayed until the colonization of submerged aquatic plants occur within these areas. More research is needed to investigate these ideas.

Comparisons of the 2015 and 2016 WQ data in the Scatter Bar Pond differed significantly from one another in both open water and Ludwigia infested sampling sites. Such variability was not expected to occur, and may be affected by the difference in Ludwigia control methods between

2015 and 2016, with 2015 sites being chemically treated twice and 2016 sites only able to be treated once. Annual variability could also be a result of changes in sampling methods between years. In 2015 sampling did not contain returnable points or a fixed sample size for each date. However, changes to the study design in 2016 allows for repeatable, permanent collection points to occur after chemical treatment in 2017 and beyond. Comparison of 2015 and 2016 WQ data within the Lower Kiger Pond actually showed that DO decreased in areas previously occupied by Ludwigia. This could indicate that submerged photosynthesis occurred to a degree to elevate DO within the emergent plant beds.

Conclusions

Changes to data collection methods and site selection allowed for WQ monitoring to successfully occur during all sampling dates in 2016. In the previous year, only Lower Kiger Pond underwent WQ monitoring during all four dates. Furthermore, a fixed sample size (n=8) and permanent sampling sites would allow for more in depth discussion regarding annual changes in WQ during future data collection years. Cover class mapping provided valuable insight to shifts in Ludwigia distribution and cover after one year of control treatments. With pre-treatment distribution data now gathered for four distinct waterbodies, progress regarding Ludwigia control efforts can be more closely monitored, and control methods could be compared and adjusted. All findings should be corroborated by further data collection and more comprehensive study. Conclusions build upon and solidify statements made in the previous monitoring year.

<u>Distribution & Cover Mapping Conclusions</u>

1. One year of control efforts resulted in decreased Ludwigia cover, but total distribution was not substantially reduced and in some cases Ludwigia distribution increased.
2. Native plants such as *Sparganium* spp., *Sagittaria* spp. were observed naturally colonizing areas previously occupied by high Ludwigia cover.
3. Ludwigia was not found rooted in water depths >1.9 meters.
4. In some areas with treatments, Ludwigia cover classes shifted from heavy (>50%) to light (<5%) in areas with persisting populations of *N. polysepela* and *Sparganium* species. However, treatment contractors actively avoided and minimized herbicide application to native plants near Ludwigia populations, which may have contributed to the persistence of these native plant populations.
5. Drought conditions of 2015 likely contributed to the expansion of Ludwigia within open water environments and increased mortality along population fringes.
6. Large floating mats of Ludwigia appear to be a major source of Ludwigia regrowth.

<u>Dissolved Oxygen Monitoring Conclusions</u>

1. A “DO crash” related to herbicide treatment of Ludwigia was not observed in the second year of monitoring.
2. Regardless of herbicide application, Ludwigia infested areas possess lower DO than open water environments.

3. Heavy Ludwigia infestations can reduce DO concentrations to levels that would be expected to result in acute mortality to salmonids, non-salmonids and aquatic invertebrates.
4. DO experienced a seasonal trend decreasing from July to September.
5. Submerged macrophytes may contribute to elevated DO levels in summer months. Future monitoring should consider including submerged aquatic plant monitoring.
6. Areas previously inhabited by Ludwigia did not immediately see a rise in DO in the year following initial control efforts.

Management Considerations

In relation to management decisions, to substantially reduce overall distribution of Ludwigia, numerous management techniques should be carried out in conjunction with herbicide application. Hand removal can be effective in areas that have been reduced to light cover (City of Eugene 2012; Thiebaut 2007). This strategy can be most directly applied to Lower Kiger Pond, or similar water bodies that experience distribution expansion due to drought conditions. Due to the natural regrowth and competition of native plants observed at Collins Bay and Lower Kiger Pond, seeding of native species may be beneficial within areas that exhibit natural recruitment. If persistent regrowth continues to occur in areas exhibiting floating Ludwigia and silt mats, serious consideration should be made in the mechanical removal of these sources of regrowth. Open water should be preserved and maintained to act as refugia for aquatic species.

Monitoring Improvements

In order to adequately capture any “DO crash” that may occur, continuous monitoring devices should be installed in upcoming years. Such devices would be able to capture DO at specific time intervals sensitive enough to identify large scale reduction in DO from diurnal fluctuations or isolated events.

Although DEQ standardized methods were applied to the 2016 monitoring techniques, standards utilized by USGS should be considered for future monitoring years (USGS 2015). Other local projects related to Ludwigia have recently begun working with USGS in regards to WQ monitoring. By standardizing the methods applied to monitoring in the project area, Benton SWCD can share data and build upon local work being carried out by USGS.

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Appendix A: 2016 Water Quality Data Summary by Site

Dissolved oxygen percentage (DO%), specific conductivity (SPC), pH, and oxidation reduction potential (ORP), were collected at the same time as DO and temperature and summarized below. "Top" refers to a depth of 0.5 meters, "Bottom" refers to 0.5 meters from the bottom of the waterbody, and "surface" refers to a full emersion of the probe which is 0.13 meters. Percent Cover category was separated into treatments of "Open" (<15% Ludwigia Cover) and "Ludwigia" (>50% Ludwigia Cover).

a. Lower Kiger Pond

				Temp (C)		DO%		DO (mg/l)		SPC (uS/cm)		pH		ORP (mV)	
Date	Percent Cover	Depth	Sample Size (n)	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
7/21/2016	Open	Surface	8	22.9	0.161	74.1	9.185	6.96	0.513	174.2	5.837	8.34	0.290	-124.9	7.859
7/21/2016	Open	Top	8	22.0	0.068	65.6	8.107	5.78	0.721	180.7	2.781	8.32	0.209	8.3	0.209
7/21/2016	Open	Bottom	7	20.2	0.281	4.2	1.941	0.51	0.203	195.4	7.501	7.33	0.157	-166.0	8.503
7/21/2016	Ludwigia	Surface	8	22.3	0.574	23.2	2.968	2.21	0.270	173.4	13.902	7.90	0.168	-110.0	14.820
7/21/2016	Ludwigia	Top	8	22.0	0.592	6.5	2.532	0.85	0.257	188.7	1.868	7.49	0.085	-139.3	12.998
7/21/2016	Ludwigia	Bottom	0												
8/11/2016	Open	Surface	8	21.6	0.107	69.6	10.833	6.26	1.175	182.7	23.285	7.83	0.256	39.8	13.202
8/11/2016	Open	Top	8	21.6	0.760	36.8	4.881	3.30	0.440	210.6	1.058	7.73	0.248	33.5	12.816
8/11/2016	Open	Bottom	7	20.5	0.991	6.2	4.949	0.56	0.449	226.7	8.011	7.06	0.134	-25.7	9.058
8/11/2016	Ludwigia	Surface	8	24.3	1.028	21.8	2.999	1.93	0.236	204.9	3.950	7.42	0.164	-71.2	13.662
8/11/2016	Ludwigia	Top	8	21.2	0.776	5.6	1.606	0.50	0.144	203.6	7.792	7.26	0.126	-64.6	8.224
8/11/2016	Ludwigia	Bottom	0												
9/20/2016	Open	Surface	8	17.2	0.087	44.0	5.772	4.32	0.608	225.3	0.609	7.43	0.128	85.7	14.721
9/20/2016	Open	Top	8	17.1	0.074	42.4	7.962	4.05	0.756	225.6	0.656	7.43	0.104	96.5	10.157
9/20/2016	Open	Bottom	6	16.9	0.037	13.0	3.242	1.23	0.320	237.8	8.370	7.13	0.105	43.0	26.924
9/20/2016	Ludwigia	Surface	8	16.3	0.313	25.3	5.525	2.50	0.569	221.7	3.437	7.41	0.159	104.4	11.933
9/20/2016	Ludwigia	Top	8	16.3	0.305	17.1	4.805	1.65	0.484	223.7	3.405	7.44	0.166	93.9	16.860
9/20/2016	Ludwigia	Bottom	0												
11/3/2016	Open	Surface	8	13.2	0.019	45.5	3.285	4.33	0.257	158.9	4.881	6.88	0.062	301.1	120.901
11/3/2016	Open	Top	8	13.2	0.042	32.4	2.594	3.32	0.241	157.5	4.766	6.81	0.069	176.3	5.146
11/3/2016	Open	Bottom	8	13.1	0.161	10.1	3.177	1.06	0.331	161.2	5.476	6.77	0.075	156.0	13.152
11/3/2016	Ludwigia	Surface	8	13.2	0.122	25.1	2.714	3.52	0.145	158.9	3.345	6.77	0.058	196.3	9.001
11/3/2016	Ludwigia	Top	8	13.1	0.081	25.5	2.413	2.61	0.188	159.5	3.832	6.68	0.108	196.3	6.246
11/3/2016	Ludwigia	Bottom	8	13.0	0.060	25.6	2.456	2.76	0.296	156.8	4.746	6.80	0.053	195.8	5.780

b. Stewart Slough #2

				Temp (C)		DO%		DO (mg/l)		SPC (uS/cm)		pH		ORP (mV)	
Date	Percent Cover	Depth	Sample Size (n)	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
7/21/2016	Open	Surface	8	23.7	0.468	88.8	11.232	7.32	0.866	300.7	2.086	7.38	0.114	-71.3	12.638
7/21/2016	Open	Top	8	21.9	0.141	69.3	0.141	6.05	0.863	301.4	4.199	7.23	0.131	-77.0	13.256
7/21/2016	Open	Bottom	4	17.8	0.857	2.5	1.377	0.12	0.024	371.3	27.562	6.55	0.087	-135.2	34.017
7/21/2016	Ludwigia	Surface	8	25.4	0.468	7.9	3.352	0.69	0.287	277.9	8.959	6.66	0.095	-112.9	18.979
7/21/2016	Ludwigia	Top	8	23.0	0.452	0.6	0.681	0.05	0.051	280.1	11.603	6.49	0.095	-141.2	26.303
7/21/2016	Ludwigia	Bottom	0												
8/11/2016	Open	Surface	8	22.0	0.514	67.5	21.441	5.84	1.836	374.2	41.929	7.23	0.224	33.7	21.553
8/11/2016	Open	Top	7	20.9	0.403	41.0	14.564	3.99	1.310	344.9	26.614	7.00	0.146	27.9	25.512
8/11/2016	Open	Bottom	4	18.2	0.566	0.7	0.119	0.05	0.018	403.5	34.429	6.32	0.075	-39.9	7.391
8/11/2016	Ludwigia	Surface	8	22.8	0.673	14.0	13.180	1.20	1.131	319.1	68.330	6.68	0.146	-30.5	19.255
8/11/2016	Ludwigia	Top	8	21.2	0.642	7.3	6.895	0.64	0.602	381.5	20.117	6.52	0.114	-30.4	20.160
8/11/2016	Ludwigia	Bottom	0												
9/20/2016	Open	Surface	8	17.3	0.219	21.8	5.547	3.02	1.003	349.7	9.890	6.83	0.069	42.1	22.474
9/20/2016	Open	Top	8	16.9	0.234	12.7	5.132	1.23	13.306	361.9	13.306	6.79	0.066	30.4	27.209
9/20/2016	Open	Bottom	4	16.6	0.000	0.9	0.041	0.08	0.013	338.4	2.431	6.84	0.030	5.0	11.658
9/20/2016	Ludwigia	Surface	8	17.6	0.460	10.3	5.966	0.82	0.440	394.9	17.259	6.61	0.092	4.0	22.277
9/20/2016	Ludwigia	Top	8	17.6	0.440	6.8	4.119	0.62	0.378	397.2	24.202	6.55	0.088	-7.0	21.812
9/20/2016	Ludwigia	Bottom	0												
11/3/2016	Open	Surface	8	13.1	0.067	20.7	0.948	2.23	0.147	128.1	0.680	6.60	1.209	135.3	9.851
11/3/2016	Open	Top	8	12.7	0.122	17.7	0.708	1.92	0.036	129.2	0.100	6.52	1.194	147.3	8.434
11/3/2016	Open	Bottom	8	12.5	0.062	16.2	1.266	2.90	1.206	129.0	0.620	6.41	1.212	134.9	7.935
11/3/2016	Ludwigia	Surface	8	13.8	0.315	10.9	3.921	1.13	0.408	155.2	14.964	6.57	0.824	115.4	18.615
11/3/2016	Ludwigia	Top	8	13.2	0.151	11.6	3.389	1.21	0.355	176.2	44.199	6.47	0.810	6.5	0.810
11/3/2016	Ludwigia	Bottom	1	13.5	0.000	16.8	0.000	1.80	0.000	129.6	0.000	6.45	0.000	135.3	0.000

c. Scatter Bar Pond

				Temp (C)		DO%		DO (mg/l)		SPC (uS/cm)		pH		ORP (mV)	
Date	Percent Cover	Depth	Sample Size (n)	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
7/21/2016	Open	Surface	8	21.3	1.201	93.8	18.817	10.13	1.622	264.9	11.237	7.13	0.082	-49.9	23.141
7/21/2016	Open	Top	8	19.1	0.939	58.8	13.075	5.52	1.204	277.1	14.655	6.76	0.090	-64.3	23.706
7/21/2016	Open	Bottom	5	14.0	0.237	8.6	2.509	1.49	1.236	359.3	17.610	6.63	0.096	-82.3	16.983
7/21/2016	Ludwigia	Surface	8	19.2	0.743	11.1	4.051	0.97	0.230	156.2	15.250	6.59	0.064	-99.1	14.581
7/21/2016	Ludwigia	Top	8	18.0	0.422	6.5	2.458	0.68	0.306	176.7	18.889	6.31	0.084	-117.8	15.397
7/21/2016	Ludwigia	Bottom	0												
8/11/2016	Open	Surface	8	22.1	1.166	20.4	5.248	1.79	0.441	114.2	8.578	6.56	0.055	64.5	15.374
8/11/2016	Open	Top	8	17.7	0.694	5.8	1.918	0.60	0.154	136.2	18.133	6.43	0.051	55.0	22.898
8/11/2016	Open	Bottom	7	15.9	0.532	0.8	0.151	0.07	0.014	213.0	46.613	6.11	0.065	76.9	15.802
8/11/2016	Ludwigia	Surface	8	19.5	0.403	2.9	0.550	0.23	0.057	117.6	3.418	6.14	0.085	41.4	23.000
8/11/2016	Ludwigia	Top	8	18.1	0.167	1.4	0.779	0.06	0.005	129.3	38.881	6.00	0.095	14.9	9.359
8/11/2016	Ludwigia	Bottom	0												
9/20/2016	Open	Surface	8	16.6	0.394	63.7	9.841	6.12	0.970	354.3	12.890	6.71	0.055	90.1	8.728
9/20/2016	Open	Top	8	15.1	0.387	43.9	9.610	4.47	0.997	351.8	12.717	6.74	0.024	122.5	26.071
9/20/2016	Open	Bottom	7	14.4	0.339	14.2	5.569	1.44	0.564	397.4	30.956	6.56	0.036	60.6	24.378
9/20/2016	Ludwigia	Surface	8	15.0	0.138	4.5	2.561	0.45	0.258	338.3	11.797	6.44	0.069	19.7	8.002
9/20/2016	Ludwigia	Top	8	14.6	0.105	1.5	0.618	0.15	0.063	341.1	14.576	6.23	0.053	11.1	6.448
9/20/2016	Ludwigia	Bottom	0												
11/3/2016	Open	Surface	8	14.5	0.310	27.9	7.427	2.85	0.653	219.1	1.854	6.54	1.198	66.5	20.380
11/3/2016	Open	Top	8	13.2	0.095	11.4	2.017	1.53	0.142	226.1	7.817	6.68	1.225	69.8	19.873
11/3/2016	Open	Bottom	7	12.6	0.057	-1.3	1.016	0.03	0.032	316.3	14.575	6.59	1.333	16.3	12.718
11/3/2016	Ludwigia	Surface	8	14.8	0.603	31.5	2.528	3.29	0.295	185.3	25.835	6.55	1.240	69.6	0.140
11/3/2016	Ludwigia	Top	8	13.2	0.158	6.3	1.467	0.77	0.214	199.5	28.958	6.59	1.248	37.6	14.040
11/3/2016	Ludwigia	Bottom	0												