PLANT METRIC BASED MANAGEMENT STRATEGIES THAT CAN IMPROVE BENEFICIAL USES OF GREAT SALT LAKE IMPOUNDED WETLANDS

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ABSTRACT

Managed impounded wetlands surrounding Great Salt Lake provide habitat resources for millions of migratory and resident waterfowl and shorebirds, yet these wetlands are at risk from habitat loss and water quality degradation, including nutrients and trace metals. We previously developed a multimetric index of biological integrity (MIBI) based on critical vegetative waterfowl food resources and plant health metrics, however, it is not evident that habitat degradation is related entirely to excessive nutrient loads or elevated trace metals associated with surface water and sediment. We examined whether routine management activities limit wetland function, as measured by plant metrics and we categorized several water management practices as possible factors of wetland condition including water and carp management, as well as relative influence of the position of a wetland in the landscape, and its water source. We found strong relationships between plant health metrics and all of these factors, results of which can provide guidance for management and restoration. We then developed a list of recommendations that demonstrate how commonly used management practices can be manipulated to achieve results that align more closely with management objectives and that can improve State of Utah's designated beneficial uses of Great Salt Lake impounded wetlands.

1 INTRODUCTION

Great Salt Lake (GSL), located in northern Utah, U.S.A., a remnant of pluvial Ancient Lake Bonneville is bounded on its eastern border by approximately 75% of the total wetlands found in Utah and provides habitat resources for millions of migratory and resident waterfowl and shorebirds. Freshwater flows from the adjacent Wasatch Range and high mountain desert region located to the east through the most densely populated area of Utah, which is expected to double in populations by 2050. These waters collect urban and agricultural runoff as well as treated municipal waters before draining through wetlands and into GSL (Figure 1.1). Water and sediments become progressively more saline approaching terminal GSL due to evaporative processes. Wetlands composed primarily of emergent plant communities formed naturally along the deltas of surface flow discharge fringing GSL. However, a large proportion of these wetlands have been modified for the creation of waterfowl and shorebird habitat by both public and private entities dating as far back as 1928. Hundreds of miles of earthen berms and dykes were constructed on the lakebed to impound fresh water. Using simplistic to sophisticated control structures, water is conveyed via gravitational flow from source waters through a complex network of impounded wetlands.

Figure 1.1 Impounded wetlands of Great Salt Lake juxtaposed to Utah's densely populated Wasatch Front (Google Earth, 2014).

During the post GSL flood years of the 1990s, thick algal and duckweed surface mats formed in Farmington Bay's impounded wetlands on an annual basis and became a growing concern of managers, scientists and other stakeholders by the turn of the century. Consequently, in 2004, we initiated the development of bioassessment metrics to be incorporated into multimetric indices of biological integrity (MIBI). These metrics were designed to evaluate: a) wetland condition, b) linkages between indicators of potential impairment and nutrients, or other potential stressors, and c) beneficial use support of impounded wetlands. In Utah, impounded wetlands are classified by UDWQ as Class 3d surface waters and have a designated beneficial use for aquatic wildlife that is "protected for waterfowl, shore birds and other water-oriented wildlife … including the necessary aquatic organisms in their food chain" (Utah Admin Code R317-2).

We identified premature die-off of SAV in the Farmington Bay impounded wetlands compared to reference wetlands at Public Shooting Grounds (PSG) in Bear River Bay during 2005 using the metric 'percent cover of submerged aquatic vegetation (SAV)' (Figure 1.2, adapted from Hoven and Miller 2009).

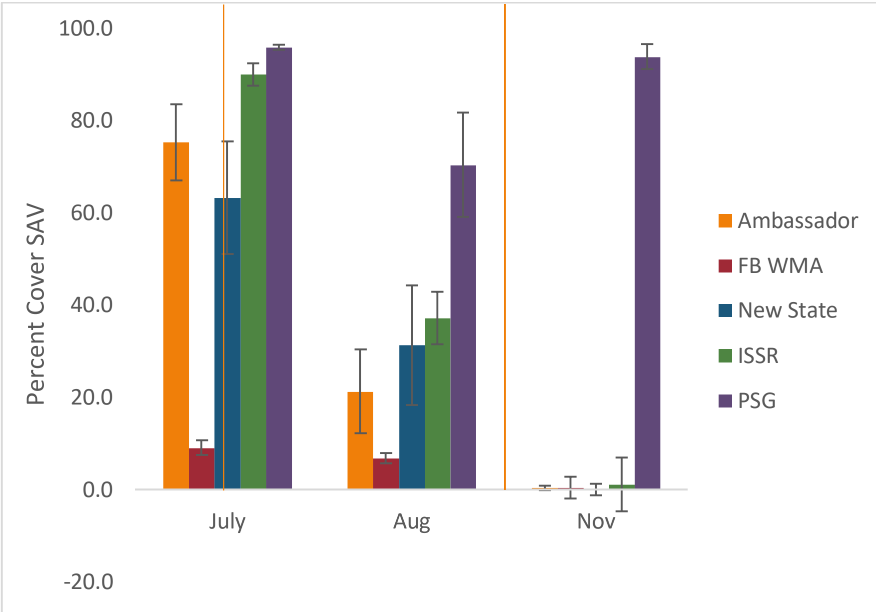


Figure 1.2 Loss in areal cover of SAV (percent cover SAV) at "nutrient-enriched" impoundments by 62 – 84 % ($F_{(df\ 4,8)}$ = 75.5, 13.6; P-value ≤ 0.0001, from Hoven and Miller 2009).

Premature die-off of SAV in first order, impounded wetlands of Farmington Bay (those that receive source waters directly) has repeated annually at ponds F1 and N1 since 2005 compared to reference wetlands as measured by percent cover SAV (Figure 1.3, Table 1.1, $F_{(df\ 8,2)}$ = 8.42, 25.2; P-value < 0.01). The ISSR impoundment was dropped in subsequent years due to budgetary limitations and the Ambassador impoundment was not included because we observed improved conditions after we recommended a modification in their management strategy. Additional summary statistics are presented in Appendix 1.

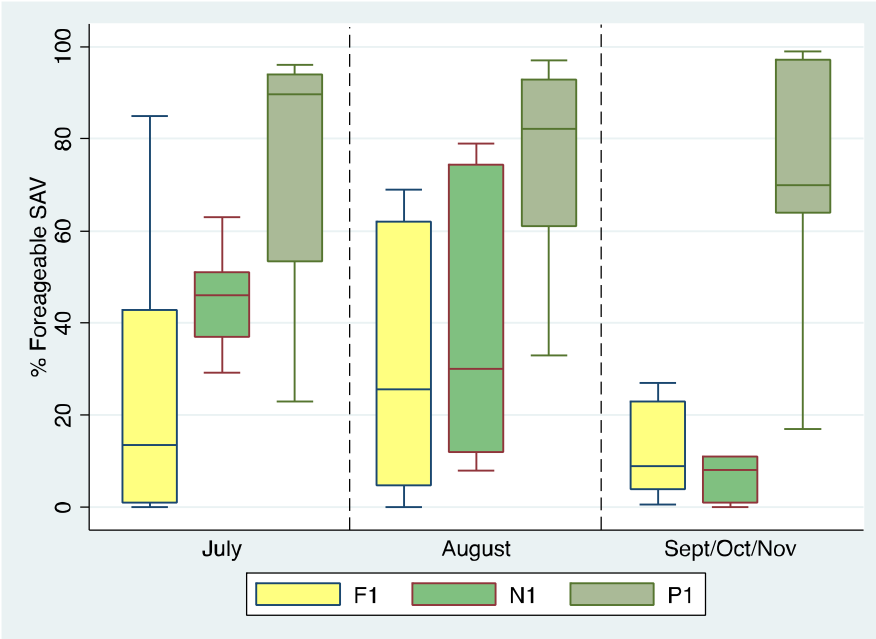


Figure 1.3. Decreased % Forageable SAV and declining seasonal trend of SAV at first order wetlands of FB WMA (F1) and New State Duck Club (N1) compared to reference wetlands at PSG (P1), 2007 – 2014, indicating premature die-off.

Table 1.1 Repeated measures analysis of site by month, all years (2007 – 2014) for percent cover SAV at New State Duck Club (N1) and FB WMA (F1) compared to reference wetlands at PSG (P1).

Number of obs =	69	R-squared =	0.5288
Root MSE =	25.6142	Adj R-squared =	0.4660

Source	Partial SS	df	MS	F	Prob > F
Model	44182.8632	8	5522.85789	8.42	0.0000
site1	33035.5405	2	16517.7702	25.18	0.0000
month2	2962.98474	2	1481.49237	2.26	0.1134
site1#month2	3168.83616	4	792.209041	1.21	0.3171
Residual	39365.1804	60	656.086339		
Total	83548.0435	68	1228.6477		

We then developed and tested a suite of metrics to assess wetland condition, including:

- Percent cover Total SAV
- Percent forageable SAV,
- Percent cover surface mats,
- Percent cover algae on SAV (associated but not attached or epiphytic),
- Percent cover biofilm, diatoms and/or sediment (BDS) on SAV,
- Light penetration through the SAV canopy,
- Light compensation point (P=R),
- SAV Photochemistry (F_v/F_m),
- SAV branch density (# attached, sheathed leaves / m^2), and
- SAV tuber and drupelet biomass.

The most sensitive metrics were used to construct a vegetative MIBI for impounded wetlands (Hoven & Richards 2014), which successfully ranked wetland condition of impounded wetlands of GSL by metric. However, conditions change and all of our metrics significantly varied seasonally, annually and by impoundment (Carling et al. 2013; Hoven and Richards 2015). This variability confounded the determination of any causative effects related to the premature die-off of SAV. We noted several important differences among the impoundments including a variety of water management regimes implemented at different sites (Figure 1.4). Some impoundments were filled and maintained at fairly low water levels, while others were filled and then allowed to draw down throughout the growing season; still others were filled and maintained at fairly deep water levels.

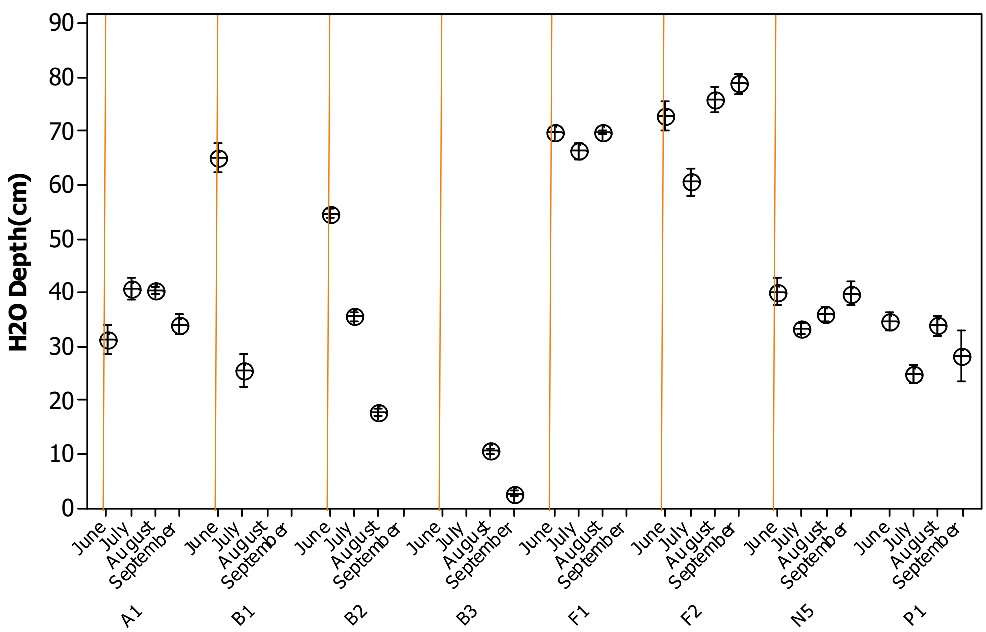


Figure 1.4 2012 water depth measurements at long-term and other study sites illustrating a variety of water management regimes. Mean ± 90% CI. Sites include: A1 = Ambassador 17, B1 = BRMBR Unit 5C, B2 = BRMBR Unit 4C, B3 = BRMBR 3E, F1 = FBWMA Unit 1, F2 = FBWMA Unit 2, N5 = New State Outer Unit, P1 = Pintail Outlet (from Hoven et al. 2014).

We reviewed correlations between plant metrics and sediment trace elements from 2010 – 2012 and used nondimensional multidimensional scaling (NMS) to visually represent co-occurring sediment chemistry samples and plant metric samples to help explain SAV premature die off at certain sites in Farmington Bay, (Figure 1.5, from Hoven et al. 2014). The sites were strongly aligned according to their sediment chemistry and more strongly correlated elements are shaded with blue ellipses using NMS ordination. NMS was also used to visually present co-occurring water chemistry samples and plant metric samples, which had similar results (not shown). While various detrimental effects of excessive algae associated with the SAV (algae on SAV) and sediment metal toxicity may contribute to premature die-off of SAV, no clear stressor-response relationships were evidenced with the selected stressors (Hoven et al. 2014). Thus we concluded that our selected metrics omitted key linkage to other stressors that may be important for understanding premature die-off of SAV and the overall condition of the impoundments.

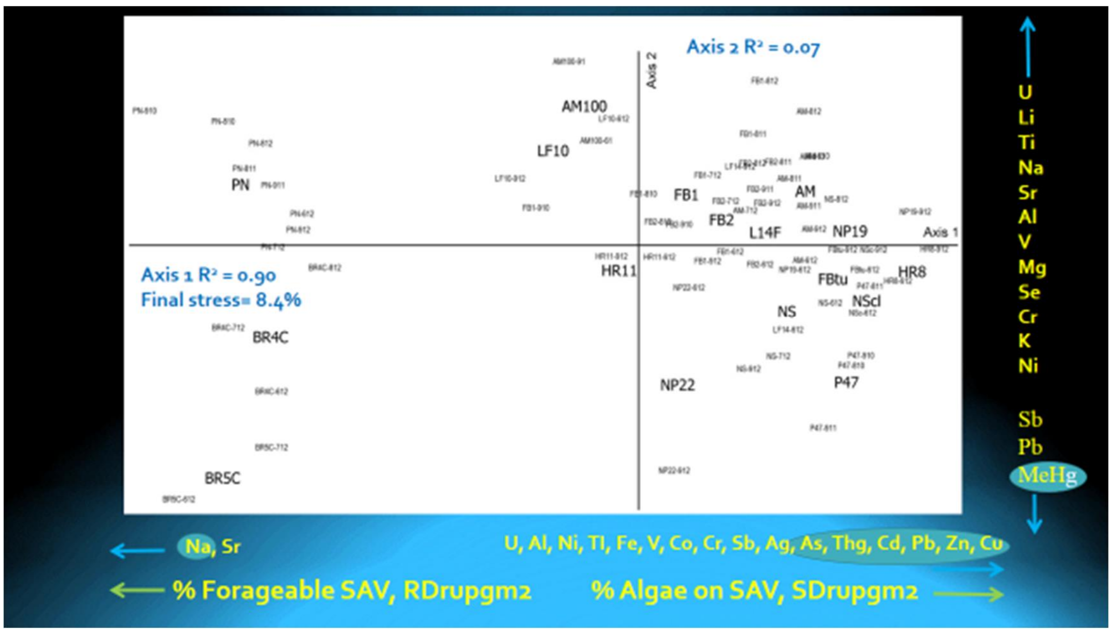


Figure 1.5 NMS ordination using sediment chemistry samples that co-occurred with plant metric samples, 2010 – 2012 combined. Bold black letters represent centroids of sites, PN and BR are sites within the Bear River watershed and all other sites are within the Farmington Bay watershed (from Hoven et al. 2014).

Impounded wetlands of Great Salt Lake are primarily managed for waterfowl habitat and are essentially maintained in an unnatural static, steady-state. Natural wetlands, however are dynamic and provide ecosystem services such as nutrient cycling, filtration of particulates and sediment, flood attenuation, and groundwater recharge (Mitsch and Gosling 2007). Impounded wetlands still provide these services but to a lesser extent. For example, their assimilative capacity may be constrained due to how they are managed and to the proximity of a wetland pond to its water source. The assimilative capacity of wetlands and their ability to provide these services is finite and can be surpassed due to excessive nutrient and sediment loads (Twilley et al. 1985, Kemp et al. 1981; Orth & Moore 1983; Zimmerman et al. 1991; McPherson et al.

1996; Onuf 1996; Short et al. 1996; Chow-Fraser 1998; Fourqurean 2003; Street 2005; Mazzotti et al. 2007) and is often related to their position in the landscape.

Many countries include macrophyte metrics in their assessment programs (e.g., Karr 2006; Brucet et al 2013) including metrics based on landscape setting (eg., Fennessy et al. 2007; CWMW 2012). While these metrics are important in quantifying biological condition and are frequently adequate for the development of MIBI's for natural wetlands (Karr 2006), we argue that in highly managed and modified wetlands, the type and frequency of major management actions need to be included in the overall assessment because biota may be responding to influences outside of, or in addition to typical environmental stressors. Here we provide an alternative approach to help provide guidance toward restoring impounded wetlands that ranked poorly in our vegetative MIBI for Great Salt Lake impounded wetlands (Hoven and Richards, 2015). We specifically ask whether activities related to water and carp management that are commonly applied by managers of Great Salt Lake impounded wetlands to maintain waterfowl habitat favorably enhance a desired outcome or whether in some cases they lead to detrimental effects toward the overall habitat quality since standard environmental stressors failed to explain premature die-off of SAV. If specific management actions show linkage with poor wetland condition, it stands to reason that those very same management actions could be manipulated to test for improved conditions for SAV growth and waterfowl habitat.

Currently, the State of Utah is considering implementation of a beneficial use assessment and 303(d) listing for impounded wetlands of GSL, which would necessitate conducting a total maximum daily load (TMDL) process for each wetland and listed stressor; a process routinely conducted on streams and rivers, but much less so in wetlands. While there is increasing interest in wetland TMDLs, the process provides no connection between listing a site as impaired and restoring it to a healthier state by the currently proposed assessment methodology (UDWQ 2015). Our proposed alternative approach provides guidance towards restoration of poorly functioning wetlands, which have shown good potential for resiliency and positive response to management actions.

2 Methods

2.1 Development of Management Categories

Managers of 29 impounded wetlands were interviewed regarding the timing and frequency of management actions related to water levels and invasive carp control. Water levels are generally managed to maximize the production of sago pondweed (*Stuckenia pectinata*) and related species for waterfowl forage spring through fall. Water levels are frequently drawn down after the waterfowl hunting season ends (during February) to conduct maintenance on water control structures and dykes, and to drop the ice, freeze or poison carp. Water is then re-introduced into the impoundments during the spring once irrigation flows return to the Salt Lake valley; the timing and amount of inundation varies by impoundment.

Since 2004, we have observed infrequent drawdowns at GSL impounded wetlands (intentional draining and evaporative water loss) during the growing season that were used as a management tool to augment the recycling of nutrients from un-decomposed organic sediment and to stimulate productivity of the wetland in subsequent years. Improved conditions were sometimes notable yet short-lived, possibly due to the lack of mimicking a natural hydroperiod in these managed wetlands in addition to other environmental stressors. Currently, one of the greatest challenges in maintaining waterfowl habitat of GSL, is prevention of invasion by the common reed, *Phragmites australis*. Minimizing exposure of moist sediment in managed wetlands reduces the extent of invasion by *Phragmites*. Managers are thus motivated to fill the impoundments and stabilize the water level, incurring a trade-off by reducing the optimum productivity of, for example, SAV and macroinvertebrates (Mitsch and Goselink 2007).

Because management tools related to manipulation of the water level in impounded wetlands are commonly practiced and because they are not at all mimicking a natural hydroperiod, which natural wetlands thrive upon, we developed management categories designed to assess the potential effect management practices have on wetland condition as defined by vegetation metrics described in Hoven and Richards (2015). The management practices are organized into three categories: water management, carp management, and position in the landscape with respect to the level of natural treatment of water quality.

Water management categories define the conveyance of water into an impounded wetland throughout the growing season (Table 2.1). The categories includes: water depth class (water level); duration of inundation at a measured water level (whether the same water depth is sustained on a monthly basis or whether it changes ± 10 cm or more from the previous month); water availability among different wildlife management areas or duck clubs (discussed below); and two categories describing the frequency of drawdowns. Categories were subcategorized by professional knowledge and observations described in Table 2.1, and assigned ordinal categorical scores. Individual water depths and water depth recorded during the previous month were also evaluated. Sites were visited up to four times per growing season most years from 2004 – 2014 and scored based upon water level measurements and interview responses.

One of the key categories that encapsulates the foundation of the water management regime at each wildlife management area or duck club is water availability as each entity is entitled to a different amount of water rights. Subsequently, water rights likely drive decisions on how each entity meets its wildlife management objectives but how each manger ultimately conveys water to each impoundment determines the availability of water. As such, water availability reflects water rights to a degree but more importantly, it reflects the extent to which the water is used. In some cases, for example, a club or WMA may have access to a large amount of water, but the manager only uses it minimally for a period of time. An impoundment that receives minimal water (regardless of entitlement to water rights), scores a low water availability for the corresponding time period the water is delivered. At a different site or time, provided the land owner is entitled, a large volume of water moves into and through an impoundment and is scored a high water availability for the corresponding time period. Moderate water conveyance receives a moderate water availability score.

Table 2.1 Water Management Categories. Instantaneous Water depths and water depth the previous month were also evaluated.

Water Level	Duration	Water Availability	Drawdown Cycle	Dry Previous Year
1. <25 cm	1. >/= 10 cm decrease	0. None	0. Never, or > 10 yrs	1. Yes
2. 25 – 50 cm	2. no change (< 10 cm)	1. Low	1. Infrequently (>2, <10 yrs)	2. No
3. >50 cm	3. >/= 10 cm increase	2. Moderate	2. Within 2 yrs	
		3. High	3. Annually	

A second primary difference among duck clubs and WMA's was the availability of resources to treat and control carp (*Cyprinus carpio*). The level of available resources determines the level of treatment, but regardless of financial constraints, the actions taken and frequency they are employed can be tracked. Thus carp management categories were organized by how frequently rotenone was applied, where it was applied with respect to the impounded wetland being assessed and whether physical controls to exclude carp were employed (Table 2.2). Examples of physical exclusion of carp are: drawing down impounded wetland to expose carp to air for a prolonged period, use of boards at water control structures to block fish from jumping into the impounded wetlands from the source water channel, deflectors on top of boards such as metal grizzly's and screens, partial draining, which causes fish to move upstream (B. Clements, personal communication, March 11, 2014), and ice drop (draining water from under the ice and letting ice collapse and crush the fish, R. Berger, personal communication, March 11, 2014). The varied and somewhat creative list of controls illustrates the range of resources available to managers as well as the persistence of these invasive fish. Scores for all categories were tallied and those that were greater than 4 were considered a high level of carp control; total scores below 5 were considered low.

Table 2.2 Carp Management Categories

Rotenone Use	Location	Physical Exclusion
0. Never	0. No treatment in pond	0. Never
1. Infrequent = every 7 or more years	1. Spot treatment by hand	1. Occasional, as resources allow
2. Occasional = every 3-6 years	2. Offsite / upstream, with occasional spot treatment	2. Active as needed; persistent annually
3. Frequent = annually / every two years	3. Full Rotenone application directly	

A third management category was designed to differentiate impoundments by water source and to describe the natural level of water treatment relative to the position of the impounded wetland in the landscape and the amount of vegetation at the dispersion point or inflow. The impounded wetlands in our study are located in two sub-basins of GSL: Jordan River and Bear River. Subsequently, wetlands of Farmington Bay and Bear River Bay receive water of varying levels of quality depending on whether it drains through urban areas or through varying types of agricultural land as described in Table 2.3 under water source. Impoundments were assigned a "pond order", which refers to their proximity to source waters or percentage of source water received. For example, first order impoundments receive source water directly; 2nd order impoundments receive source water after at least half of it has flowed through another impoundment; and 3rd order impoundments receive water after it has flowed through a series of two or more impoundments.

The third landscape subcategory addresses the level of natural treatment water receives as it is dispersed into an impoundment. Often, impoundments that are backfilled, that is, filled from the downstream end, have the advantage of filling with slow inflowing water through a well-developed emergent community; however, that was not always true. Therefore, we focused the treatment subcategory on the level of vegetation present (including standing stock from the previous year's growth) as the water was dispersed into the impoundment regardless of the actual location of the distribution point. Wetland vegetation helps improve water quality by filtering particulates and suspended sediment from the water column and by assimilating nutrients and other potential environmental stressors. We assigned scores for the level of treatment inflowing waters received based on the amount of vegetation present at or leading up to the dispersion point. For example, if water flowed through dense stands of emergent or other vegetation at the dispersion point or as it approached the dispersion point, the impoundment was assigned a high level of treatment (3). If water flowed through a long and narrow channel with moderate vegetation at or before the dispersion point, the impoundment was assigned a moderate treatment level (2). If there was minimal vegetation at the inflow or dispersion point, the impoundment was assigned a low treatment level (1).

Table 2.3 Landscape Categories, level of natural water quality treatment

Water Source	Pond Order	Treatment
Jordan River: municipally treated, urban runoff	1. 1st Order: receives source water directly	1. Minimal vegetation at inflow / dispersion point of water.
Bear River: agricultural runoff, irrigation return flows	2. 2nd Order: receives half of its water directly from main water source; other half of its water from an upstream impoundment	2. Long and narrow channel with moderate vegetation at or before dispersion point.
Salt Creek: irrigation return flows, natural springs	3. 3rd Order: receives water that has flowed through at least 2 upstream impoundments	3. Dispersed through dense, extensive stands of emergent or other vegetation.
Farmington Creek: small tributary off the Wasatch, includes agricultural and urban runoff		
Surplus Canal: Stems off the Jordan River		
Ambassador Cut: Surplus Canal water that passes through Ambassador before entering other duck clubs		
State Canal: stems off the Jordan River		

2.2 Statistical Analyses

We developed histograms and kernel density smoothing estimates of the plant metric data (mean values from replicate samples) of July, August, and September data collected from 2004-2014 to determine the most appropriate regression methods. Plant metric data in response to management metrics were modeled as either non-parametric negative binomial and Poisson models or parametric Gaussian General Linear Models (GLM) based on kernel density estimates. The best-fit model was determined using AIC (Akaike Information Criteria) and BIC (Bayesian Information Criteria). Non-parametric models were abandoned if they could not reach convergence and were rerun using parametric GLMs. Branch density data was log + 1 transformed to approximate a Gaussian distribution and analyzed using GLM. Management subcategories and practices that were significantly related to plant metrics ($p < 0.05$) in regression analyses were graphed using box plots for non-Gaussian distributions and mean and 90% confidence intervals (CIs) for approximately Gaussian (normal) distributions. Because much of the plant metric data were often highly skewed or over-dispersed the regression model results should be considered best fit approximations and there may have been more significant relations then we present in this report. All statistical analyses were conducted using STATA 13.1 (StataCorp 2014).

3 Results and Discussion

Our previous work has shown that our best metrics didn't always respond strongly to typical stressors, (after examining box plots, ordered logistic regression and general linear models) and month, year, and site were always a factor (Hoven et al. 2011, Hoven et al. 2014). However, we found significant relationships between plant metrics and the management and the landscape variables.

3.1 Important predictors relative to each plant metric: all months, years and sites

Plant metrics that represent indirect (proportion forageable SAV) and direct (biomass of tubers and drupelets) association with beneficial use for aquatic wildlife and the necessary aquatic organisms in their food chain (and food web) frequently responded to management subcategories and practices. Other biological response shown to have negative effects on the health and condition of SAV in GSL impounded wetlands (e.g., algae on SAV, Hoven and Richards 2015) also responded to several management subcategories and practices. Although total surface mat has not shown predictable negative effects on SAV, we continue to include it in our analyses in case future conditions trigger stronger, problematic responses.

3.1.1 Proportion Forageable SAV

Three management practices were significant predictors of forageable SAV: treatment level, drawdown cycle, and dry previous year (Figure 3.1). Kernel density and histograms of the data are presented in Appendix 2a; the regression matrix is presented in Appendix 2b. Forageable SAV responded strongly to treatment level. Impoundments with 2nd or 3rd levels of treatment had the highest proportion of forageable SAV compared to impoundments with little or no treatment at the point of water dispersion. The effect of drawdown cycle and dry previous year was less clear, possibly due to relatively little data, and sites that were drawn down regularly were often shallow, brackish impoundments that were not necessarily managed for SAV.

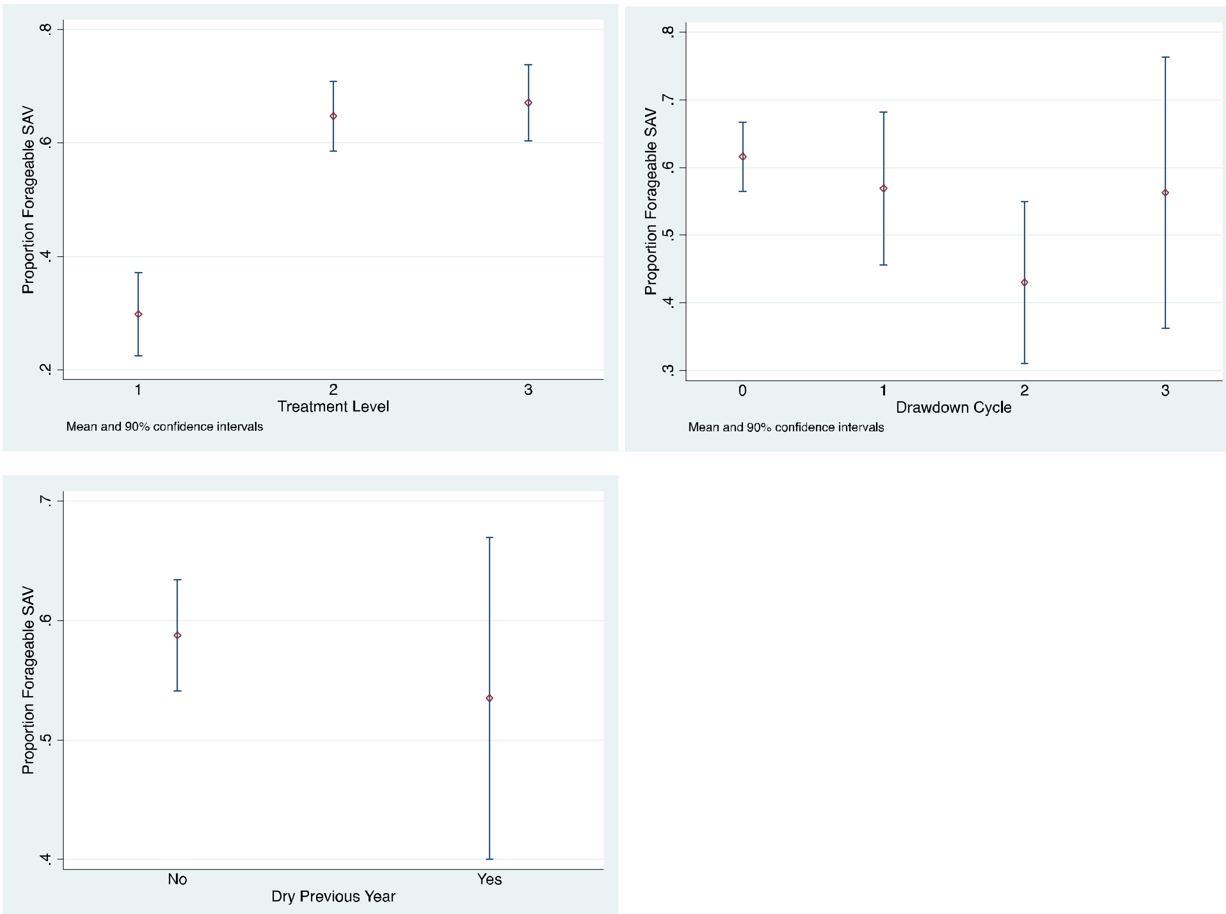


Figure 3.1. Management categories that were significant predictors of forageable SAV were treatment level, drawdown cycle, and dry previous year. Mean ± 90 % confidence interval.

Shallow brackish impounded wetlands are typically managed for shorebirds, exposing moist sediment throughout the summer months to provide ample macroinvertebrate forage. Managers also rely on drawing the shorebird habitat down to retain salt, which inhibits growth of most macrophytes and maintains unvegetated sediment for foraging. As a result, any SAV that develops while the impoundment is inundated eventually dies from exposure to air and / or elevated salinity. Of the other impoundments where there was a drawdown cycle during our study period, we observed different results. The first continued to have low forageable SAV cover for two consecutive years immediately following drawdown (N1). The second had improved forageable SAV cover for two years following drawdown but declined in cover at three + years post drawdown (F2) and scored poorly using our MIBI (Hoven and Richards 2015). Our relatively small data set for pre and post drawdown necessitated pooling all the data, yet it is very likely that differing management objectives for using drawdowns resulted in different results and limited our ability to interpret the effectiveness of drawdowns on improving SAV growth at this point. Additional research is needed to determine the most beneficial drawdown frequency for a range of impounded wetland conditions.

Increased carp control efforts tended to have a positive effect on forageable SAV, however, there was a high level of variability and impoundments with low carp control still had a moderate level of SAV on average.

Although water depth was not a significant predictor of forageable SAV compared to other management practices in the regression models, water depth was analyzed separately. Proportion forageable SAV significantly decreased with increasing depth, particularly so beyond approximately 40 cm depth (Figure 3.2).

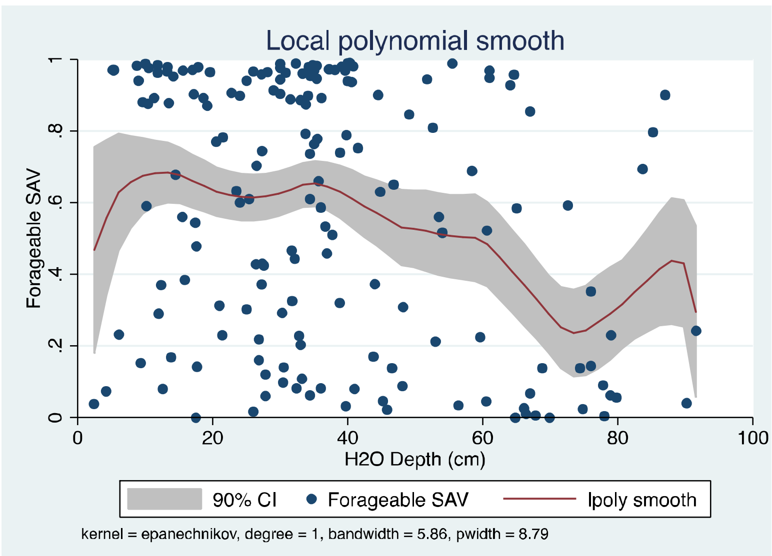


Figure 3.2. Proportion forageable SAV versus water depth.

3.1.2 log Branch Density

Treatment level was the only significant predictor of log branch density (Figure 3.3). Kernel density and histograms of the data are presented in Appendix 3a; the regression matrix is presented in Appendix 3b. The data exhibit higher branch densities as impoundments receive increasing level of treatment.

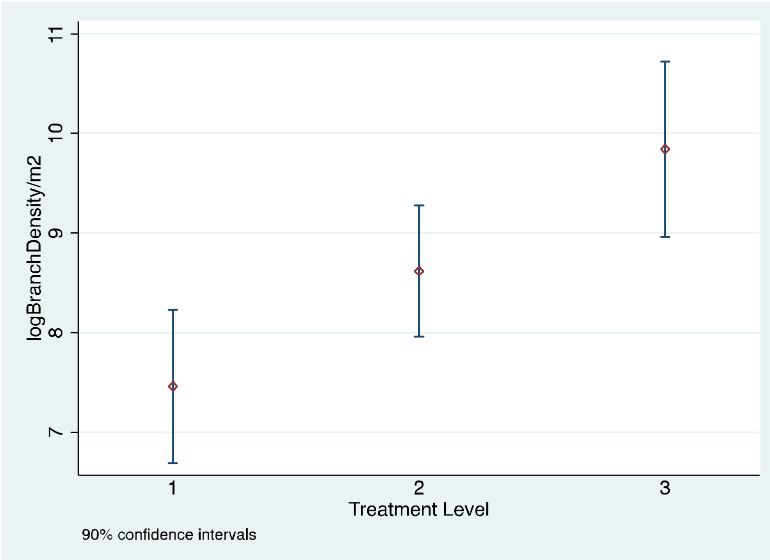
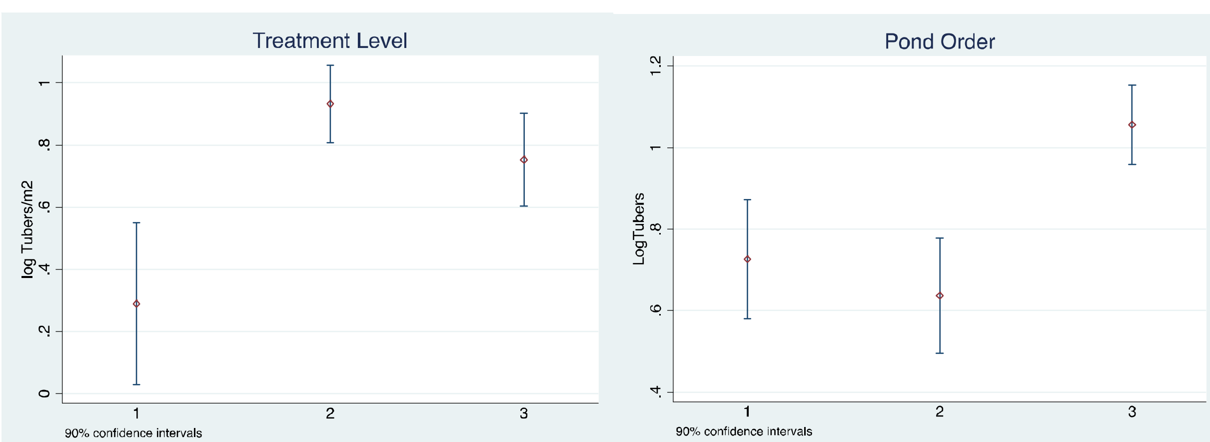


Figure 3.3. Relationship between log branch density/m² and treatment level (mean ± 90% confidence intervals).

3.1.3 Tubers

Three management subcategories and practices were significant predictors of log tubers: treatment level, order of pond in the landscape, and water source (Figure 3.4). Kernel density and histograms of the data are presented in Appendix 4a; the regression matrix is presented in Appendix 4b. Both 2nd and 3rd levels of treatment had and positive effect on tuber biomass as did level of pond order in the landscape. 3rd order impoundments had significantly higher levels of tubers than 1st and 2nd order impoundments. Water source had a significant effect on tuber biomass, where Jordan River and the Surplus Canal were positively correlated and impoundments of Bear River water and the highest log Tubers/m². North Point Consolidated Canal and Salt Creek were negatively correlated. While water source and possibly pond order may not be modified, treatment level can be improved by various management practices as discussed later in this report.



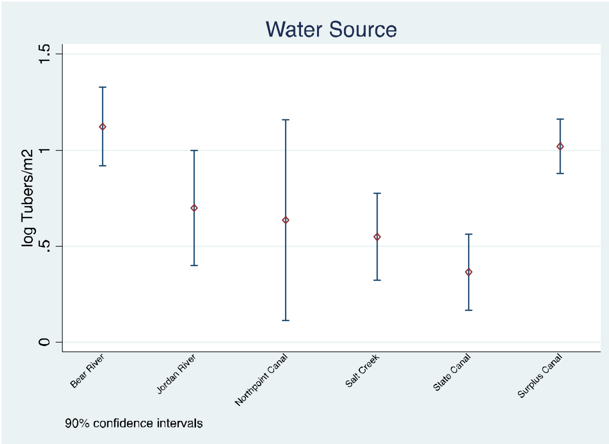


Figure 3.4. Management subcategories and practices that were significant predictors of log branch density were treatment level, order of pond in the landscape, and water source. Mean ± 90% confidence interval.

3.1.4 *Stuckenia* Drupelets

Five management subcategories and practices were significant predictors of *Stuckenia* drupelet biomass (g/m^2): order of pond in the landscape, treatment level, drawdown cycle, water level, and water source (Figure 3.5). Kernel density and histograms of the data are presented in Appendix 5a; the regression matrix is presented in Appendix 5b. Although water level indicates higher productivity of *Stuckenia* drupelets when all sites, years and months are included, individual analysis shows that there is a limit beyond which increasing water depth is detrimental (see case study 2, section 4.3).

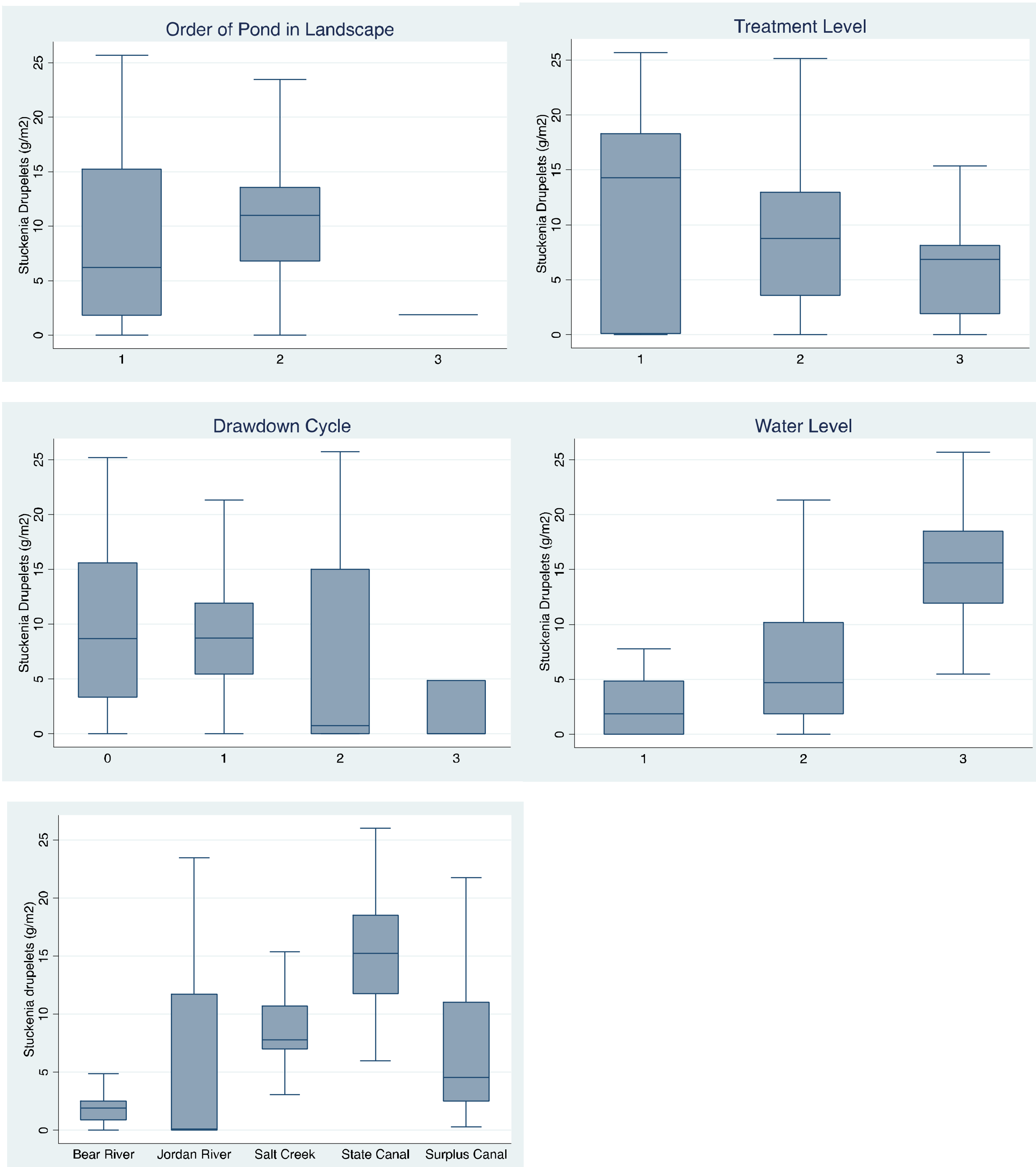


Figure 3.5. Management subcategories and practices that were significant predictors of Stuckenia drupelet biomass (g/m2) were order of pond in the landscape, treatment level, drawdown cycle, water level, and water source. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Drawdown cycle may have a negative effect on *Stuckenia* drupelet biomass, however, there was very high variability for category 2 (drawdown within two years) and as previously mentioned, category 3 (annual drawdown) includes impoundments with different management objectives that may strongly affect the results, thus it is difficult to say conclusively that drawdown cycle negatively effects drupelets. Coordinated research with wetland managers regarding controlled drawdown would be helpful in understanding relationships between SAV productivity (including tuber and drupelet productivity) and drawdown.

Treatment level had a negative effect on *Stuckenia* drupelet biomass. 2nd order impoundments had the highest median drupelet biomass, while 3rd order impoundments had the lowest. Salinity (as specific conductance, SC) may be a covariable explaining lower drupelet biomass at 3rd order (and higher level of treatment) impoundments (x^2 = 23.34, p-value ≤ 0.001; Figure 3.6). *Stuckenia* is not tolerant of higher salinity and is replaced by the more salt tolerant species, *Ruppia cirrhosa*, in brackish to saline impoundments of GSL (Hoven and Richards 2015), which could explain the decreased biomass.

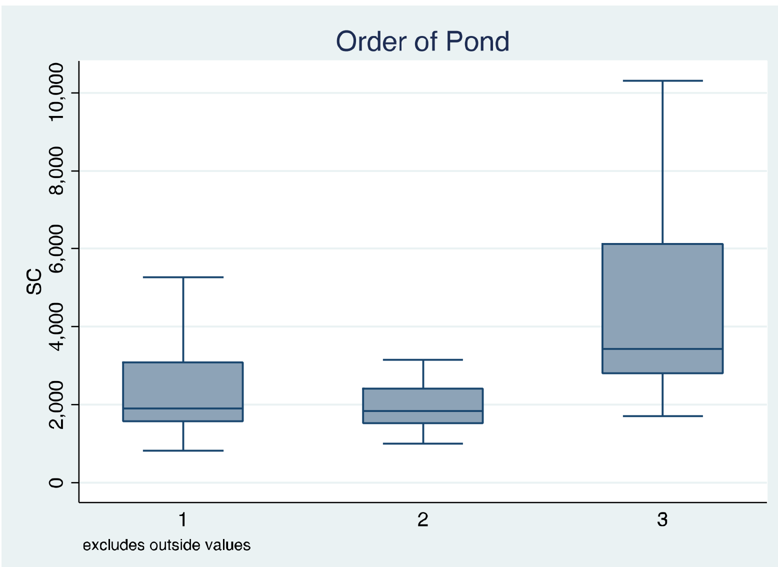


Figure 3.6. Relationship between order of pond in the landscape and specific conductance (SC) as a surrogate for salinity in impounded wetlands of GSL.

3.1.5 *Ruppia* Drupelets

Water source, specifically Salt Creek, was the only management subcategory that was a significant predictor of *Ruppia* drupelet biomass (g/m^2, Figure 3.7). Kernel density and histograms of the data are presented in Appendix 6a; the regression matrix is presented in Appendix 6b. *Ruppia* is tolerant of higher salinities than *Stuckenia* sp. and was more prevalent at our more saline sites as indicated by water source.

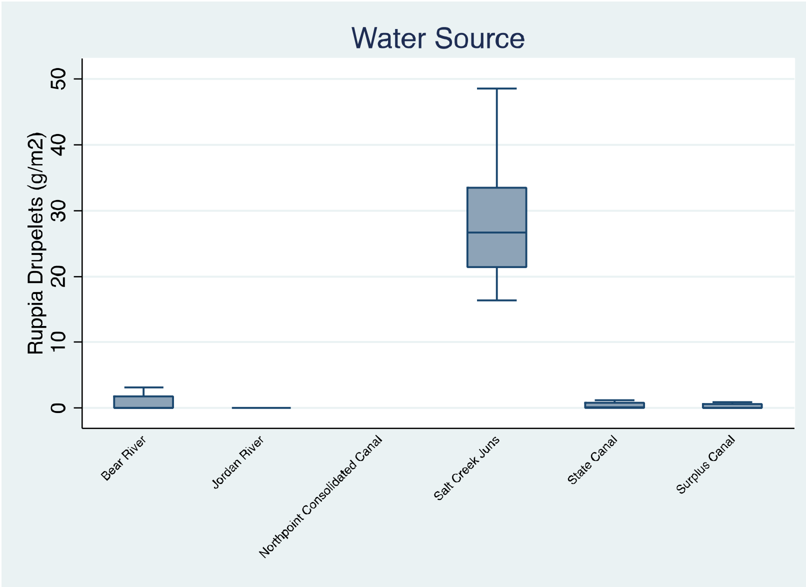


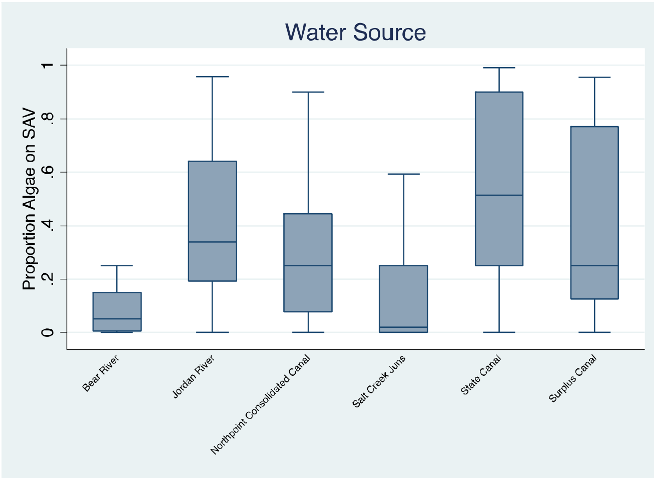
Figure 3.7. Water source was a significant predictor of Ruppia drupelet biomass (g/m2). 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

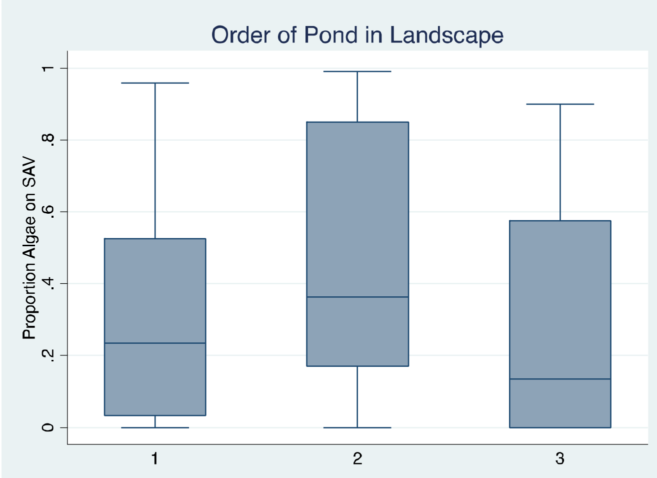
3.1.6 *Stuckenia* and *Ruppia* Drupelets

Significant predictors of *Stuckenia* and *Ruppia* drupelet biomass (g/m^2) closely matched those of *Stuckenia* drupelet biomass (g/m^2) and did not refine any predictive capability. Kernel density and histograms of the data are presented in Appendix 7a; the regression matrix is presented in Appendix 7b.

3.1.7 Proportion Algae on SAV

Four management subcategories and practices were significant predictors of algae on SAV: water source, order of pond in the landscape, carp control, and treatment level (Figure 3.8). Kernel density and histograms of the data are presented in Appendix 8a; the regression matrix is presented in Appendix 8b. Impoundments using Jordan River and three canals that stem off of it had the greatest extent of algae on SAV, making water source the most important factor. While some amount of algae associated with SAV can be quite normal and not detrimental to the SAV, excessive algae on SAV has been negatively correlated with SAV and is a useful metric in determining wetland condition (Hoven et al., 2014; Hoven and Richards 2015). Algae tended to develop on SAV at a greater extent in 2nd order impoundments than 1st and 3rd order impoundments. Level of treatment was also an important factor as SAV growing in impoundments with the highest level of treatment had the least amount of algae. Carp control was an important factor related to algae on SAV, however, it was inconclusive and possibly other unmeasured factors played a role.


Water Source
Proportion Algae on SAV
0
.2
.4
.6
.8
1
Bear River
Jordan River
Northpoint Consolidated Canal
Salt Creek Juns
State Canal
Surplus Canal


Order of Pond in Landscape
Proportion Algae on SAV
0
.2
.4
.6
.8
1
1
2
3

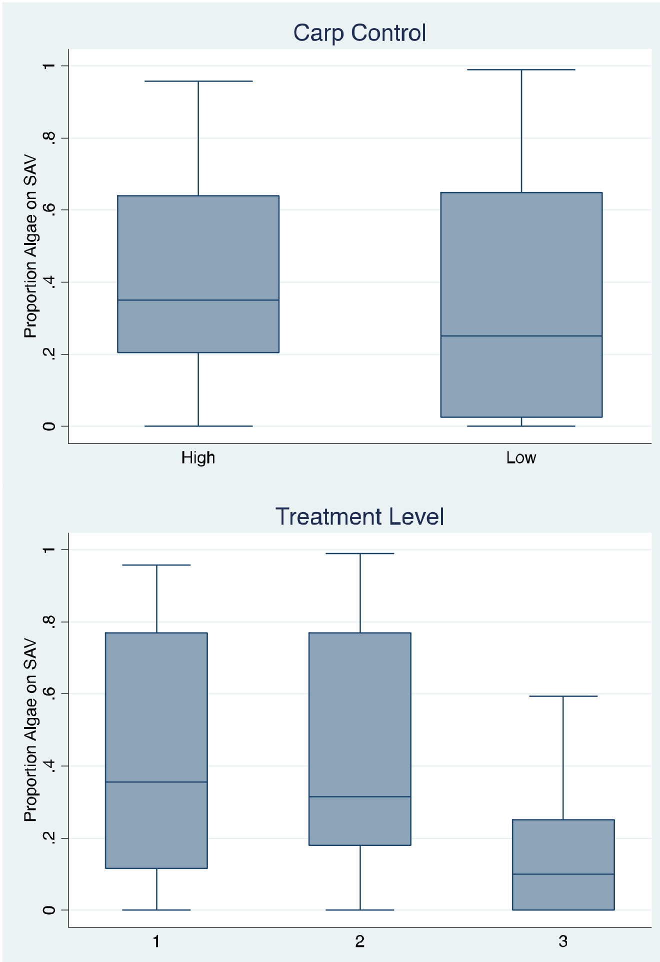


Figure 3.8. Management subcategories and practices that were significant predictors of total mat were water source, order of pond in the landscape, carp control, and treatment level. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from the boxes show the range.

3.1.8 Proportion Total Mat

Currently, total mat measured as total percent cover of duck weed and macroalgae on surface water, has not been linked with negative effects on SAV health and wetland condition in Great Salt Lake impounded wetlands (Hoven et al. 2011, 2014; Hoven and Richards 2015) and consequently none of the statistical models we used showed any predictive capability when data from all months, years and sites were analyzed. Kernel density and histograms of the data are presented in Appendix 9.

3.2 Summation of Predictors Determined from All Months, Years and Sites

We list all the significant management subcategories and practices for each plant metric in Table 3.1. Note that management subcategories and practices are listed in order of importance (shown by regression coefficients in parentheses). Coefficients should not be compared across plant metrics, only within a plant metric column. Treatment, water source and order of pond in the landscape are frequently important when data from all months, years and sites are included. Depending on the management objectives, practices aimed at improving specific biological responses can be developed based on the management practices that are strongly affecting biological response. Before developing general management strategies from Table 3.1 however, we were first interested in seeing whether we could remove some of the variability related to month, year, site and water source to refine our results.

Table 3.1. Management subcategories and practices that were significantly ($p < 0.05$) associated with plant metrics based on parametric and non-parametric regression analyses. Values in parentheses are regression coefficients and management subcategories and practices are listed by importance from top to bottom in columns. Management subcategories and practices with negative coefficients were negatively associated (predictors) with plant metrics. Management subcategories and practices with a range of coefficients in parentheses had more than one level (score) that was significant. Coefficients cannot be compared across metrics.

Proportion Forageable SAV	log Branch Density/m^2	Log Tubers/m^2	Stuckenia Drupelets (g/m^2)	Ruppia Drupelet (g/m^2)	Proportion Algae on SAV
Treatment	Treatment	Treatment	Pond Order	Source	Source
Drawdown Cycle		Pond Order	Treatment		Pond Order
Dry Previous Year		Source	Drawdown Cycle		Carp Control
			Water Level		Treatment
			Source		

3.3 Case Study 1: Farmington Bay Impounded Wetlands, September, 2012

We conducted a case study on southern GSL impounded wetlands based on similar water sources and more nutrients that occur in southern versus northern impoundments (Carling et al. 2013) in order to reduce variability associated with water source. We also used data from the same month and year (September 2012) to remove annual and seasonal variability.

Several management subcategories and practices were good predictors for forageable SAV in the Farmington Bay impounded wetlands. Water availability, carp control, order of pond in the landscape and water depth were all important predictors for percent cover forageable SAV (Figure 3.9; regression matrix presented in Appendix 10). Low water availability, paired with high carp control and water depth of 30 to 40 cm show high percent cover forageable SAV. Additionally, third order ponds are more likely to have higher percent cover forageable SAV then first and second order ponds.

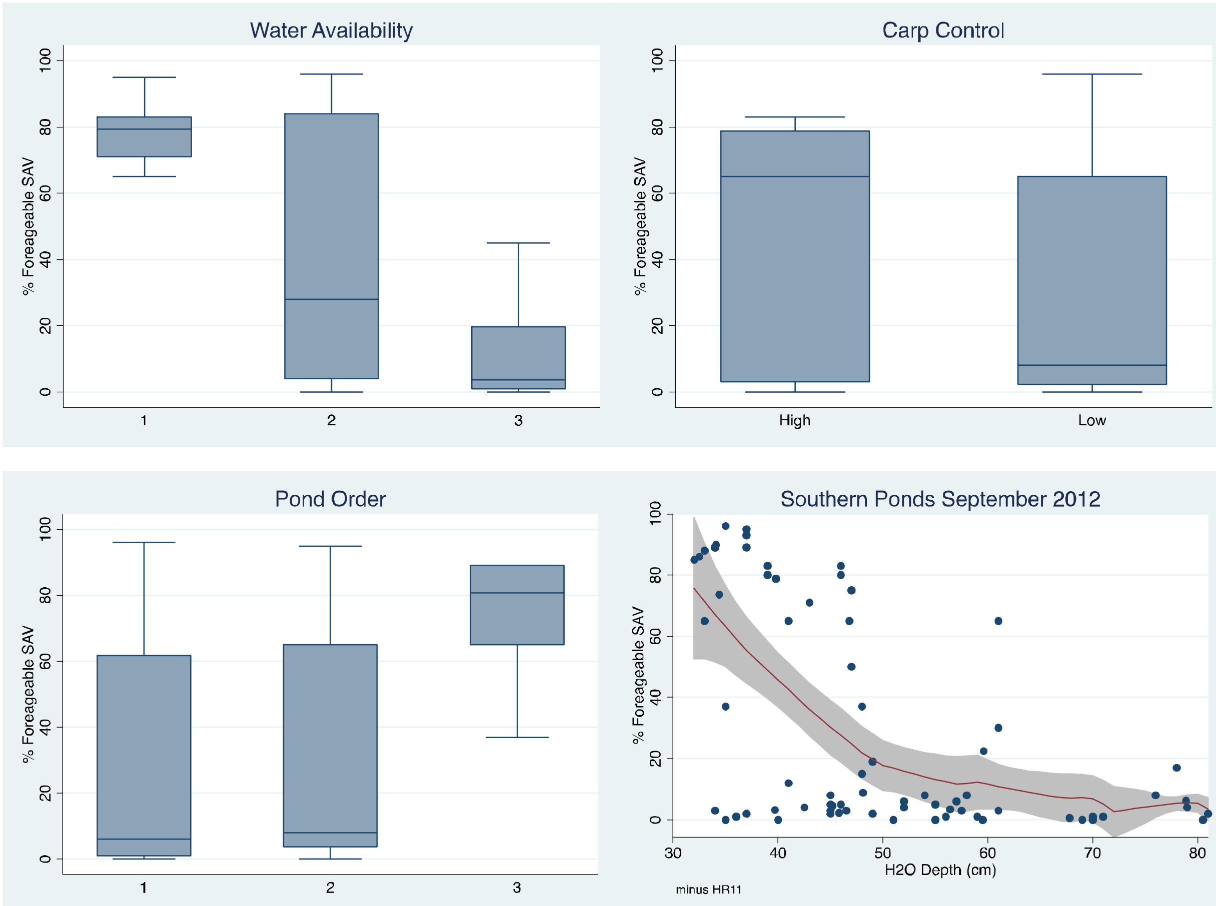


Figure 3.9. Management subcategories and practices that were significant predictors of proportion total mat: water availability, carp control, order of pond in the landscape, and water depth. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Water availability, order of pond in the landscape, carp control, and treatment level were important management subcategories and practices for log branch density (Figure 3.10; regression matrix presented in Appendix 11). There were similar responses in log branch density as there were by percent cover forageable SAV to water availability and order of pond in the landscape. Low water availability and high pond order typically resulted in SAV with high branch density. Additionally, ponds with high treatment level had high branch density. High level of carp control was also related to high levels of branch density but the responses were highly variable.

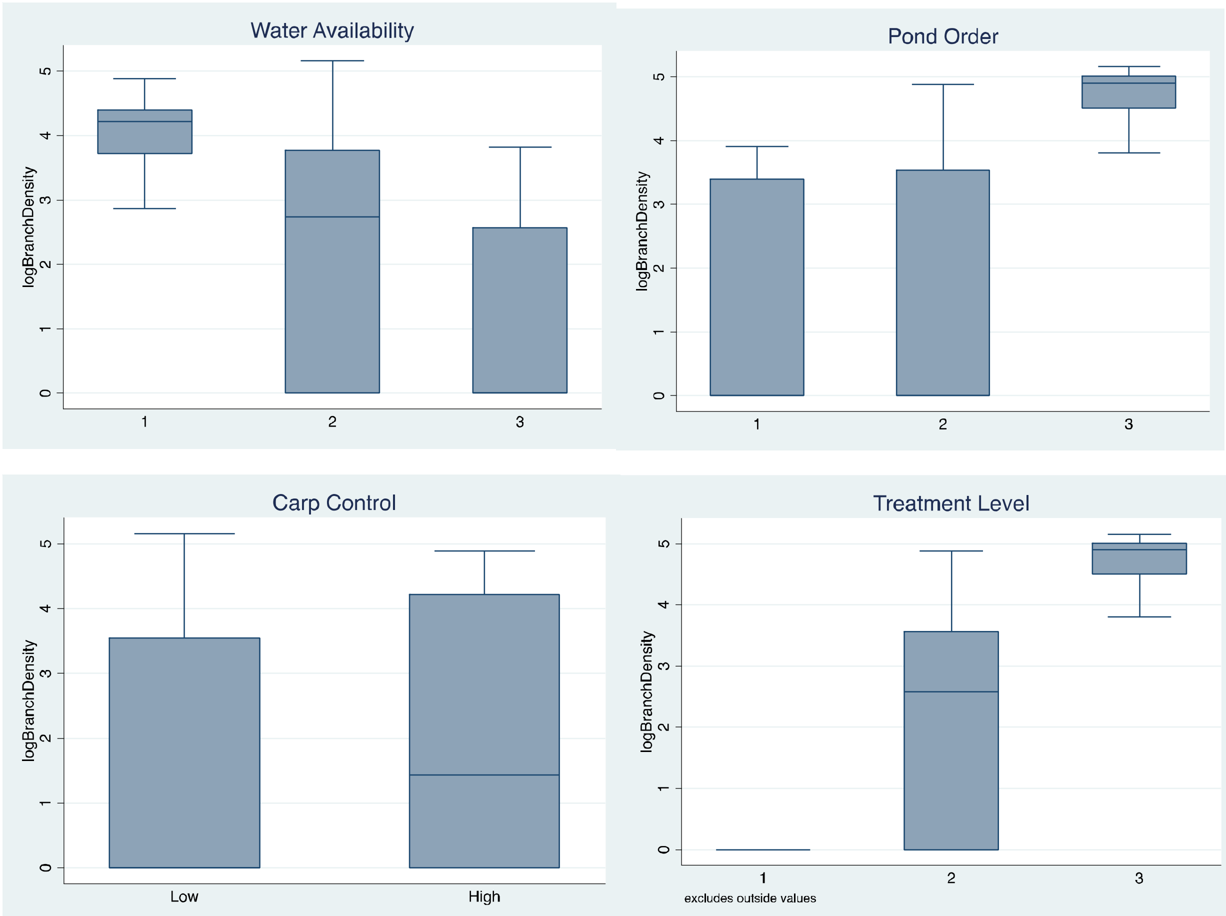


Figure 3.10. Management subcategories and practices that were significant predictors of proportion total mat: water availability, order of pond in the landscape, carp control, and treatment level. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Tuber biomass responded to management subcategories and practices associated with natural treatment. Low water availability, high order of pond in the landscape, and high treatment level were important management subcategories and practices for log tubers (Figure 3.11; regression matrix presented in Appendix 12).

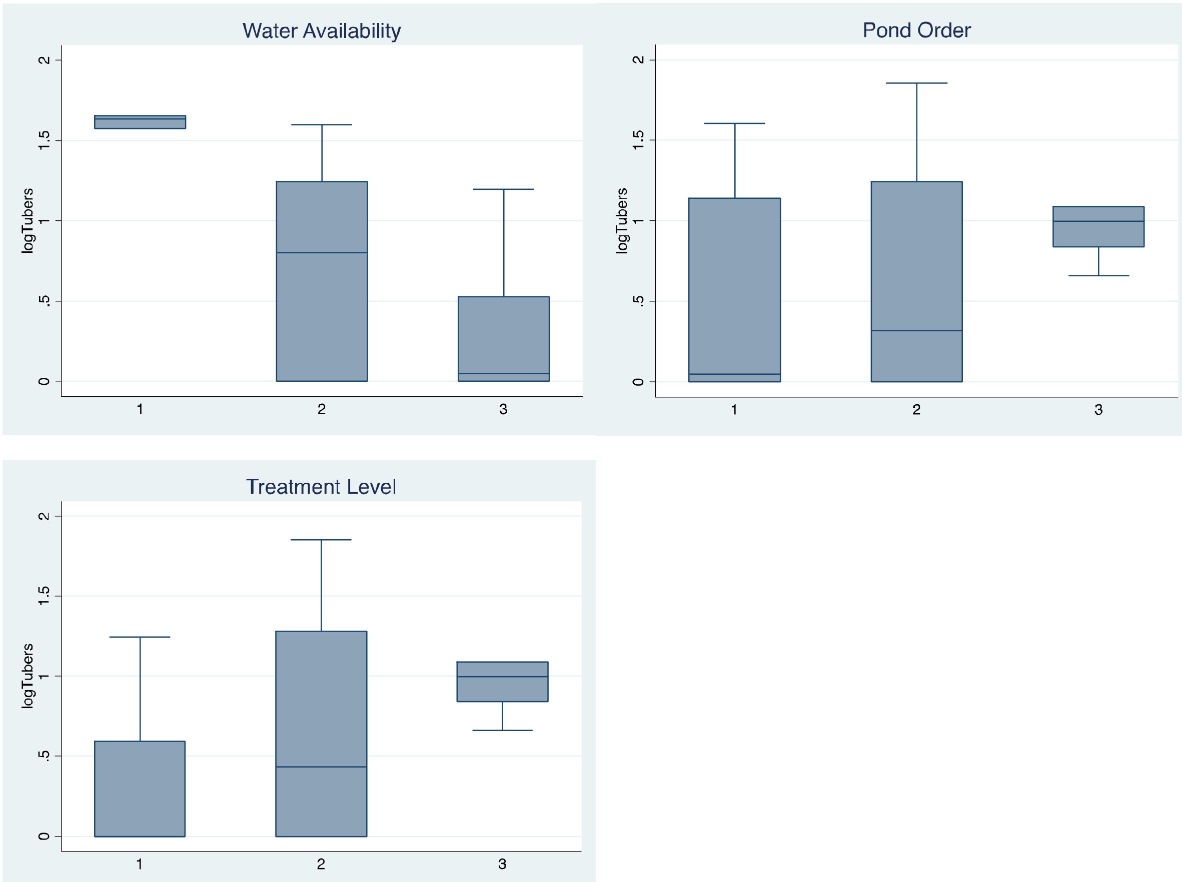


Figure 3.11. Management subcategories and practices that were significant predictors of log tubers (g/m2): water availability, order of pond in the landscape, and treatment level. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Order of pond in the landscape, duration, and carp control were important management subcategories and practices for *Stuckenia* drupelets (g/m^2, Figure 3.12; regression matrix presented in Appendix 13). Higher *Stuckenia* drupelet biomass occurred in first and second order ponds, whereas very low biomass occurred in third order ponds. Salinity could be an important covariable for order of ponds in the landscape as impoundments generally increase in salinity with decreasing distance to the lake and *Stuckenia sp*. is not tolerant of salinity (see Figure 3.6). *Stuckenia* drupelet biomass was higher when water levels remain unchanged during the growing season (duration level 1) as opposed to water levels that rise or fall more than 10 cm (duration level 2). *Stuckenia* drupelet biomass was also higher in impoundments with high carp control versus impoundments with low carp control.

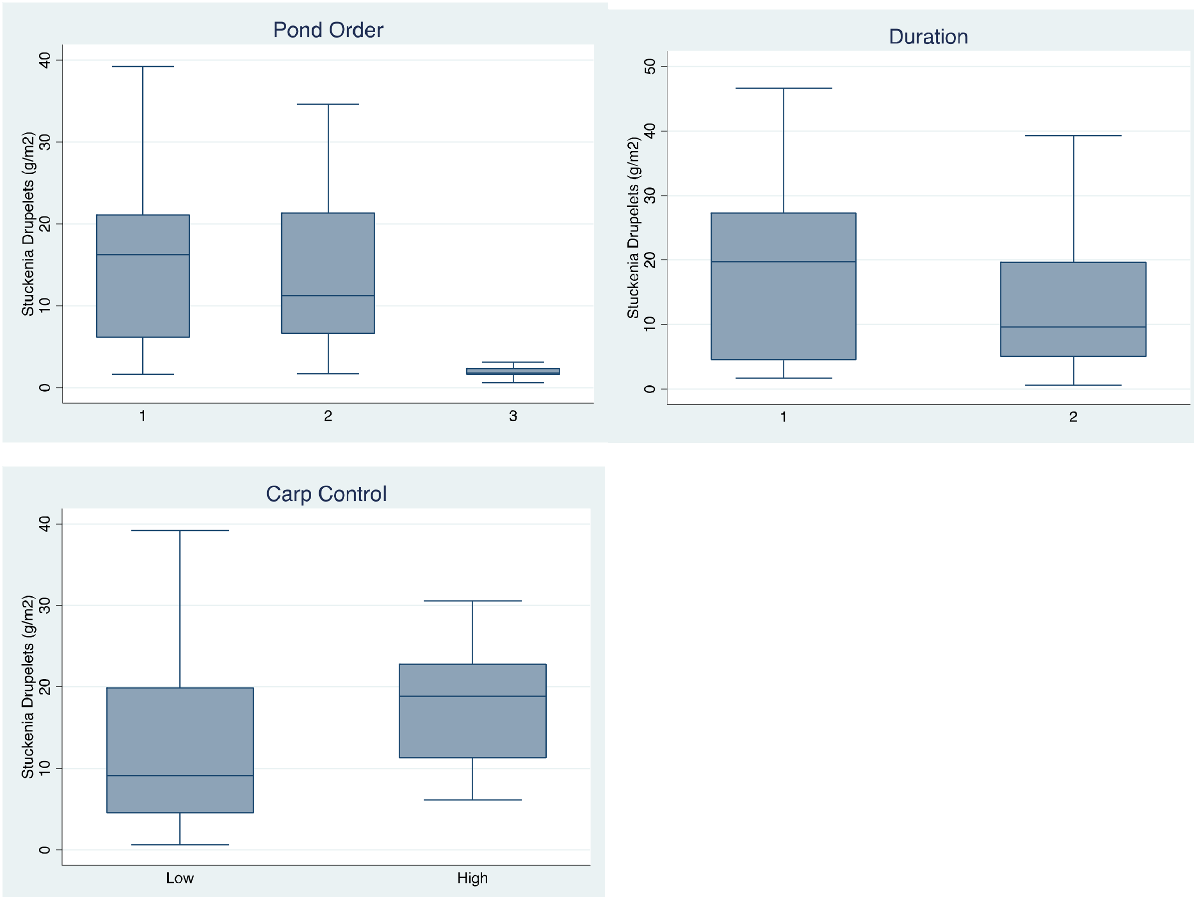


Figure 3.12. Management subcategories and practices that were significant predictors of Stuckenia drupelets (g/m2): water availability, order of pond in the landscape, and treatment level. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Ruppia drupelets (g/m^2) was not a useful metric for the southern impoundments as *Ruppia cirrhosa* was not prevalent in the impoundments studied.

Water availability, order of pond in the landscape, and carp control were important management subcategories and practices for proportion algae on SAV (Figure 3.13; regression matrix presented in Appendix 14). Low water availability and low carp densities resulting from a high level of carp control, are both associated with high proportion of algae on SAV, although the effect of carp control on this plant metric were highly variable. The third order impoundments had the lowest proportion algae on SAV, however salinity could be a covariate in this case. The dominate macroalga associated with the SAV was *Chladophora glomeratus*, which is a freshwater alga.

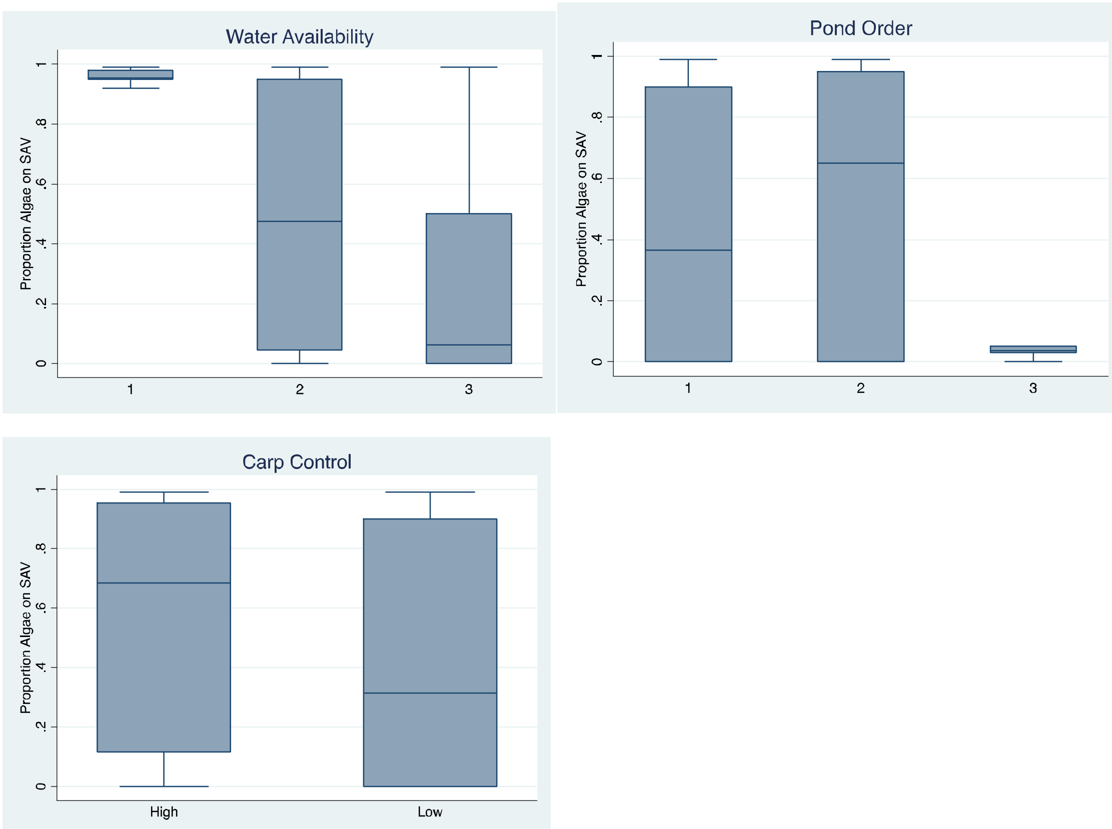


Figure 3.13. Management subcategories and practices that were significant predictors of proportion total mat: water availability, order of pond in the landscape, and carp control. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Combining BDS data with algae on SAV changed the outcome slightly. Order of pond in the landscape was the most important management metric for proportion algae and BDS on SAV, while water availability was somewhat important but less clear due to high variability (Figure 3.14; regression matrix presented in Appendix 15). Highest levels of algae and BDS on SAV were recorded in first and second order ponds, which may be related to higher nutrient availability and assimilation in first and second order impoundments and / or covariance with salinity. Beyond 65 cm, water depth was also important, explaining a 3% decrease in fowling by algae and BDS with increasing depth.

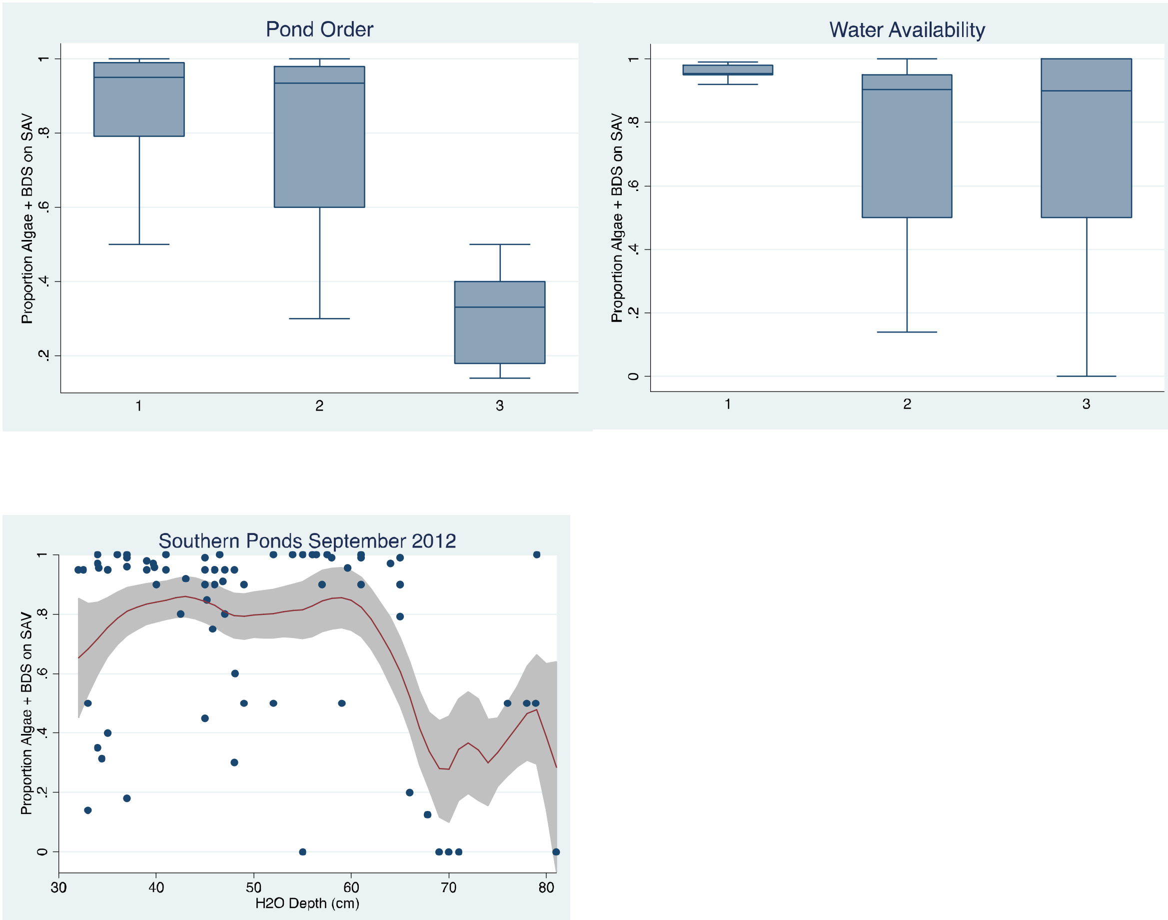


Figure 3.14. Management subcategories and practices that were significant predictors of proportion total mat: order of pond in the landscape, water availability, and water depth. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Order of pond in the landscape, water availability and carp control were important management subcategories and practices for total mat (Figure 3.15; regression matrix presented in Appendix 16). Decreasing proportion total mat with increasing order of pond in the landscape may be associated with increased assimilation of nutrients with a downstream progression as documented at the Ambassador Duck Club (Dicataldo 2008). Salinity may also be a covariable. Increased carp densities with low carp control may be associated with increased localized nutrients and macroalgal response. The effect of water availability on proportion total mat is less clear.

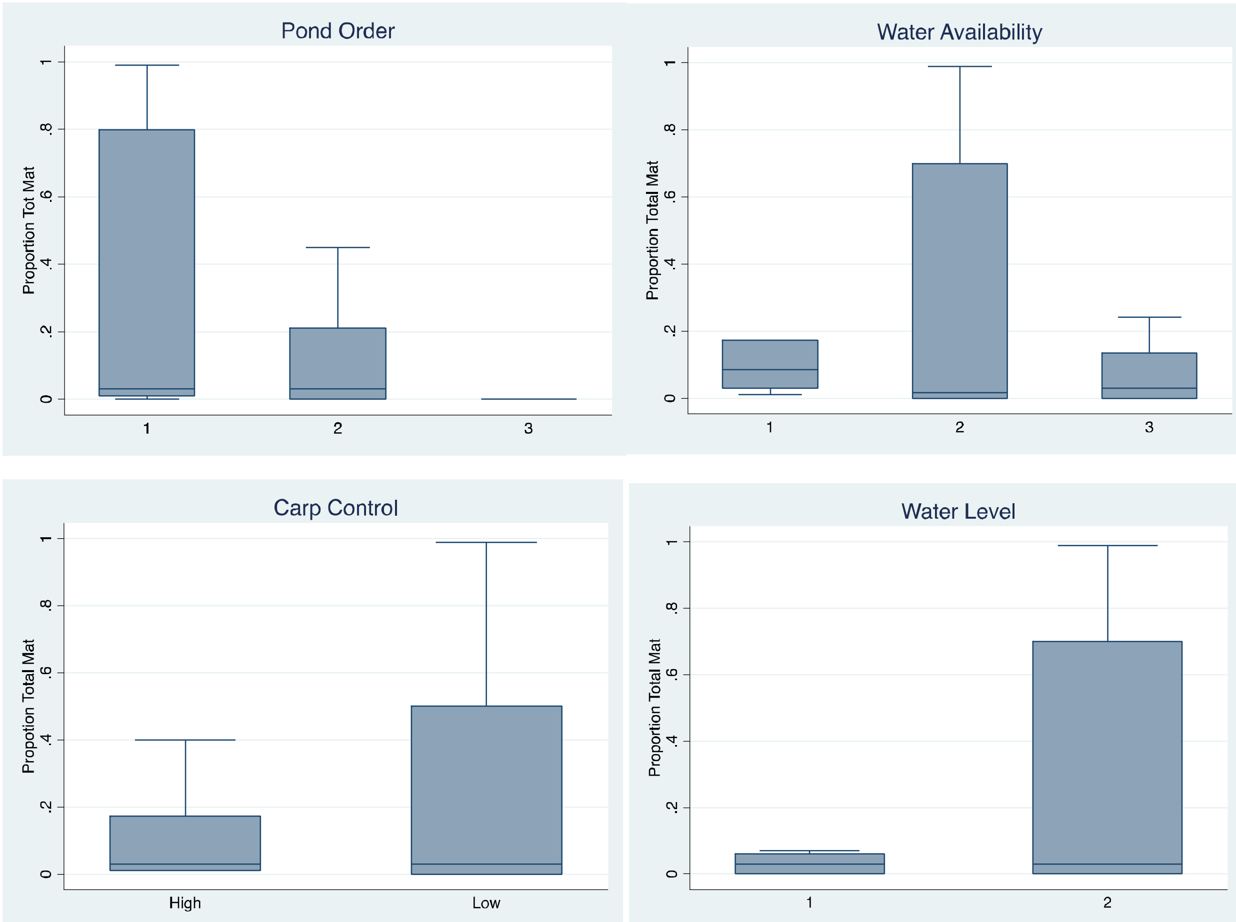


Figure 3.15. Management subcategories and practices that were significant predictors of proportion total mat: order of pond in the landscape, water availability, and carp control. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range.

Management subcategories and practices that were significantly associated with plant metrics at Farmington Bay impounded wetlands (southern impoundments) were arranged by level of importance in Table 3.2. Order of pond in the landscape and water availability were commonly the most important management categories with respect to individual to plant metrics. Other management categories that were of secondary importance were carp control, water level or water depth, treatment level, and duration.

Table 3.2. Management subcategories and practices that were significantly ($p < 0.05$) associated with plant metrics based on parametric and non-parametric regression analyses of Farmington Bay impounded wetlands during September, 2012. Values in parentheses are regression coefficients and management subcategories and practices are listed by importance from top to bottom. Management subcategories and practices with negative coefficients were negatively associated (predictors) with plant metrics. Management subcategories and practices with a range of coefficients in parentheses had more than one level (score) that was significant.

Proportion Forageable SAV	log Branch Density/m²	Log Tubers(g/m²)	Stuckenia Drupelets (g/m²)	Proportion Algae on SAV	Proportion Algae + BSD on SAV	Proportion Total Mat
Availability	Availability	Availability	Pond Order	Availability	Pond Order	Pond Order
Carp Control	Pond Order	Pond Order	Carp Control	Pond Order	Availability	Availability
Pond Order	Carp Control	Treatment	Duration	Carp Control	Water Depth	Carp Control
Water Depth	Treatment					Water Level

3.4 Case Study 2: Farmington Bay WMA, September, 2012

We conducted a second case study of September 2012 data from Farmington Bay units 1, 2, and Turpin Unit (F1, F2 and Fbtu) to remove, annual, seasonal, site, and water source variability and to identify site specific responses from the management subcategories and practices. There were only three management subcategories and practices that differed among the three sites: drawdown cycle, order of pond in the landscape, and treatment level. All three ponds were managed similarly for the remaining management practices. Therefore the other pratices had no influence on differences in plant metric responses. Management regimes were similar at F1 and F2 but applied differently at Fbtu, which precluded our ability to differentiate further among the three management subcategories and practices. We used Kruskal-Wallis tests based on replicate data to determine significant relationships between the three management subcategories and practices and several plant metric responses.

There was a significant affect/relationship on percent cover forageable SAV and the three management subcategories and practices (Figure 3.16, $x^2 = 4.79$, $p < 0.05$, Appendix 17). Percent cover ranges were low at all three impoundments compared to other more productive impounded wetlands (Hoven et al. 2014), however, modifying the drawdown cycle and level of treatment are both potentially feasible and could prove to be useful toward improving productivity of SAV, which is consistent with the literature (Mitsch and Gosselink 2007). Level of treatment was frequently an important metric when all data from all months, years and sites were analyzed above and had a positive response for forageable SAV, which means that improving treatment at the FB WMA sites may have a favorable response. Although we can't differentiate the differences in affects from the three subcategories or practices, they provide the basis for initiating management modifications. Further, changes in management actions and associated biological response can now be monitored.

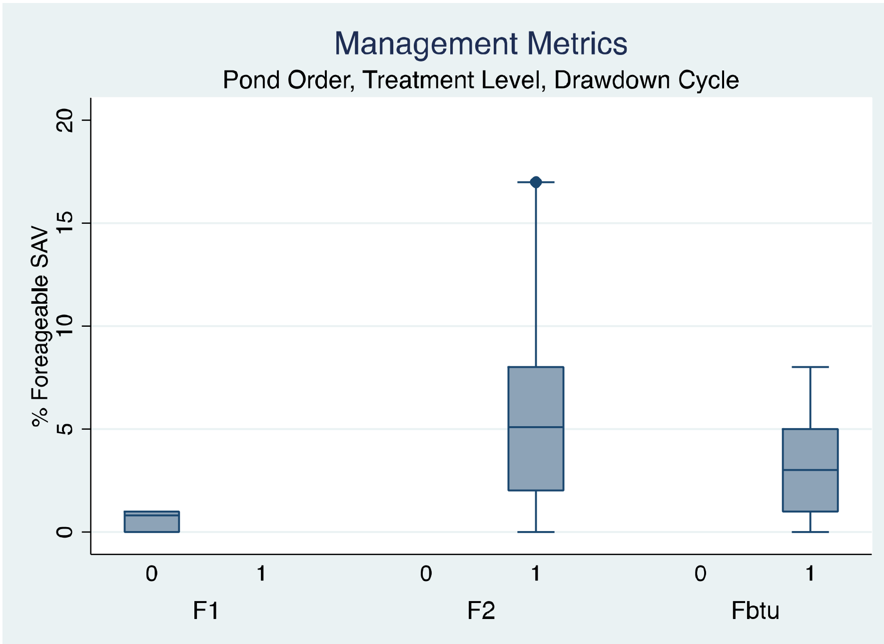


Figure 3.16. Management subcategories and practices that were significantly related to percent cover forageable SAV at FB WMA F1, F2 and Fbtu during September 2012; (x2 with ties = 4.79, $p < 0.05$). Zero represents 1st pond order, minimal treatment, and no drawdown within 10 years; 1 represents 2nd pond order, moderate treatment and drawdown within 10 years. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range, dots are outliers.

There was also a significant effect on tubers (g/m^2) at FB WMA F1, F2 and Fbtu during September 2012 (Figure 3.17, $x^2 = 6.83$, $p < 0.01$, Appendix 18). An increase in forage for waterfowl provides a direct linkage to beneficial use support and shows that managers are meeting their management objectives in providing good waterfowl habitat. Treatment was the most important metric for tuber biomass when all months, years and sites were analyzed, showing a positive response, and may be an important factor at the FB WMA impoundments as well. Analysis of drawdown cycle all months, years and sites had a slightly negative effect on tuber biomass, but the data were highly variable and sparse to draw strong conclusions. Manipulating management practices and monitoring resultant biological response will show whether productivity (as measured by tuber biomass) can be improved.

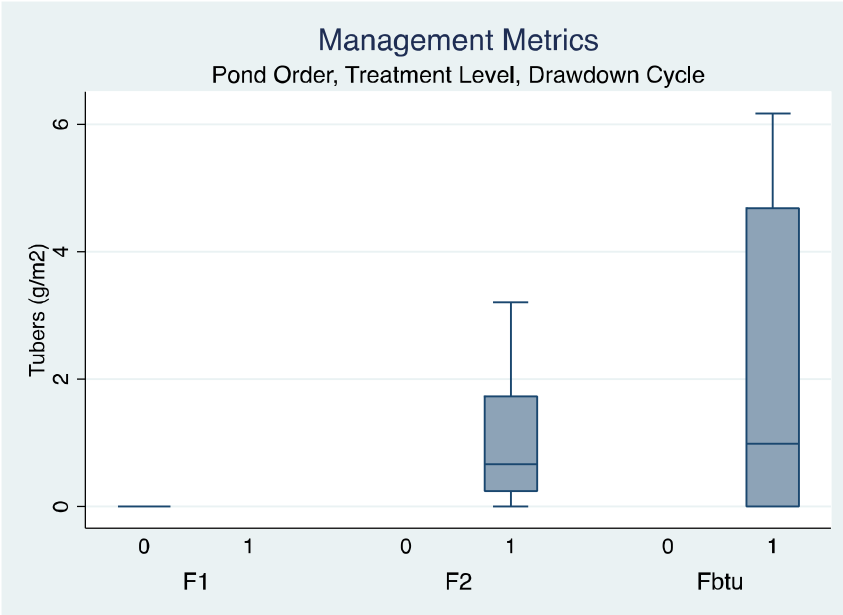


Figure 3.17. Three management subcategories and practices, order of pond in the landscape, treatment level, and drawdown cycle, had a significant affect on tubers (g/m2) at FB WMA F1, F2 and Fbtu during September 2012; (x2 with ties = 6.83, p < 0.05). Zero represents 1st pond order, minimal treatment, and no drawdown within 10 years; 1 represents 2nd pond order, moderate treatment and drawdown within 10 years. 25th to 75th percentiles, horizontal lines across boxes are medians, vertical lines extending from boxes show the range, dots are outliers.

Another significant affect in the Farmington Bay impoundments that has important relevance to beneficial use support was that *Stuckenia* drupelets were negatively correlated with water depth at FB WMA F1, F2 and Fbtu during September 2012 (Figure 3.18, r = -0.43, p <0.01, Appendix 19). Depths of moderate range (approaching 60 cm) showed good drupelet biomass levels compared to other sites we have been monitoring (Hoven et al. 2014) and at depths of > 75 cm drupelet biomass decreased by 50%. This implies that conditions beyond 60 cm change and become unfavorable for drupelet production.

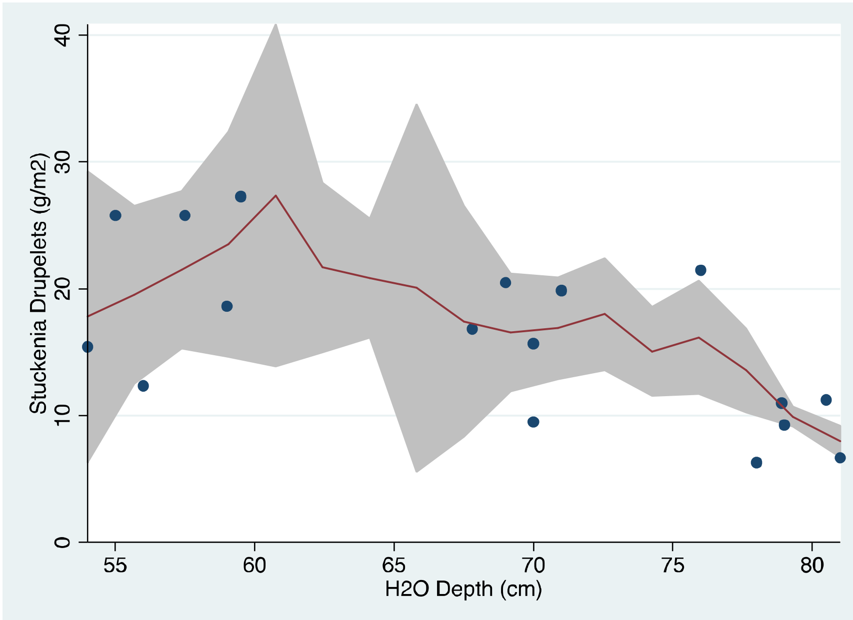


Figure 3.18 Stuckenia drupelets (g/m2) were negatively correlated with water depth at FB WMA F1, F2 and Fbtu during September 2012; (r = -0.43, p <0.01, shaded area is 95% confidence interval).

3.5 Biological Response to Drawdown at Farmington Bay WMA

While there were relatively few drawdown events at impoundments we have been following since 2004 and that have been managed for waterfowl, F1 was drawn down partially in 2008 and completely in 2013. The objective of the partial drawdown was to dry shoreline Phragmites for a late summer burn treatment, with no secondary intension of improving growing conditions for the submerged wetlands. The complete drawdown was intended for improving SAV growth.

We found improved biological response in every SAV metric except drupelet biomass during years immediately following both partial and complete drawdown (Figures 3.19 – 3.21, note branch density was not implemented prior to 2010). Regardless of the intended objectives, we found positive responses when F1 was partially drawn down, implying there may be alternatives to the frequency, duration, and extent of drawdown that may stimulate equivalent or better responses by SAV.

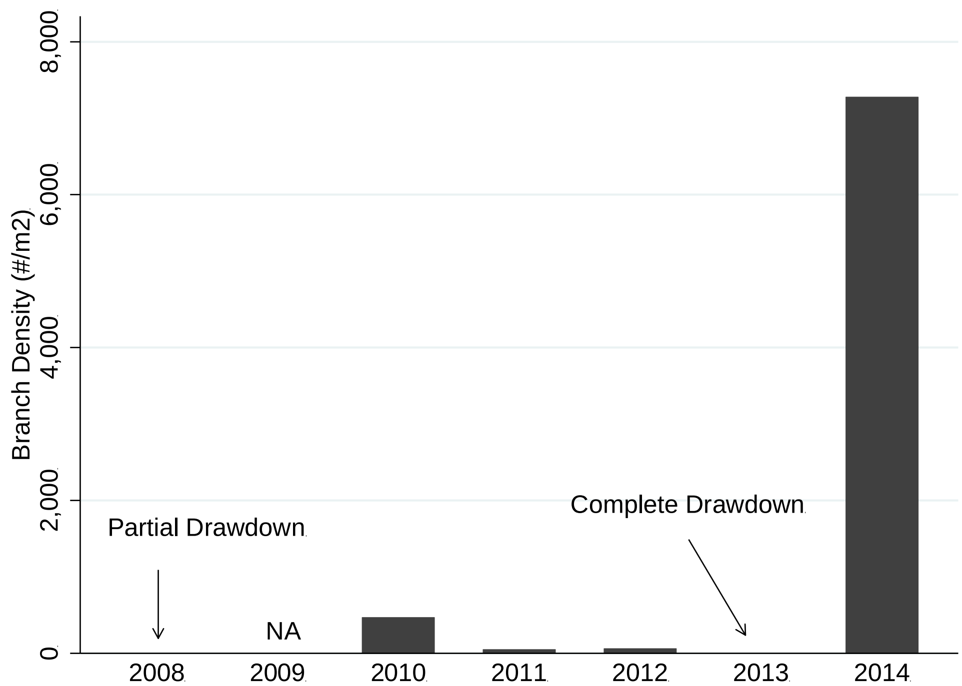


Figure 3.19. Branch density (# attached sheathed leaves / m2) response to drawdown at F1 (metric was not implemented prior to 2010).

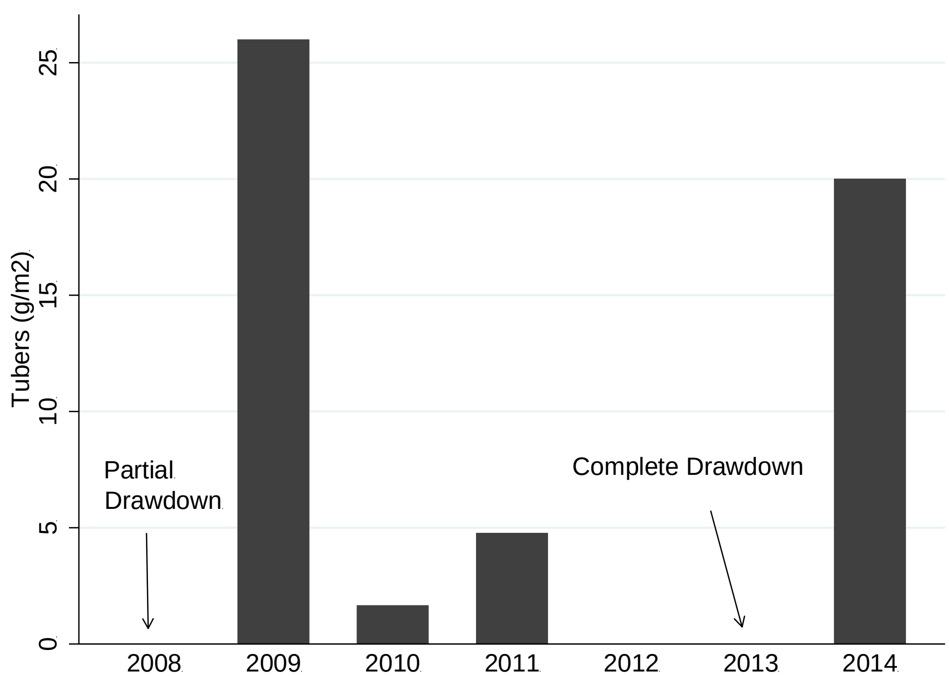


Figure 3.20. Tuber biomass response (g / m2) resulting from drawdown at FI.

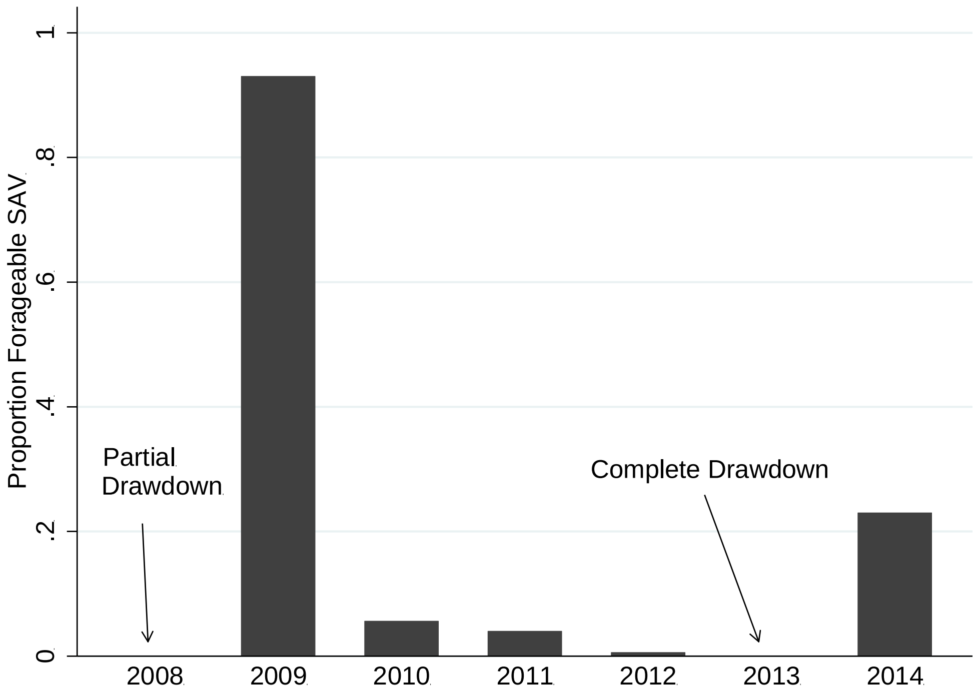


Figure 3.21. Proportion forageable SAV response to drawdown at F1.

4 SUMMARY

We document significant relationships between management subcategories and practices and the plant metrics notwithstanding the influence of seasonality, annual variability, and other non-modeled variables such as solar radiation, wind, precipitation, and water or sediment chemistry that certainly contribute to the variability of the plant metrics. We also show which management practices most likely effect each of the plant metrics and provide the foundation upon which restoration guidance can be implemented.

The plant metrics used in these analyses were developed to assess beneficial use support of impounded wetlands, which are specifically managed for aquatic wildlife and necessary aquatic organisms in their food web. Our results are a valuable tool that can be used to advise mangers on how to improve the condition of wetlands that they are responsible for. We previously have not been able to provide strong scientific guidance on which aspects of a management regime to modify with respect to improving the measured biological responses until these analyses. Our MIBI (Hoven and Richards 2015) indicates the relative condition of an impoundment and how those conditions change through time but does not provide the important linkage between management regimes and the measured biological responses, which is central toward identifying restoration opportunities. The linkages we have identified between management practices and biological response illustrates that managed impounded wetlands that do not appear to be functioning well can potentially be restored and conditions improved by altering specific management actions.

Managers can now make informed decisions by identifying the most important management practices associated with each plant metric. Although there may not be alternatives, for example, to source water remediation or altering the order of pond in the landscape, efforts can focus on the next most important practices. By improving biological response, managers are more likely to achieve their desired response and attain their overall management objectives.

This approach provides an important alternative for 303d assessment by the regulatory community. We suggest that this approach is much more pragmatic, well timed, cost effective, and informative as opposed to implementing the currently proposed TMDL process. Wetlands including highly managed wetlands, are dynamic, not static. All wetlands are driven by biological and biogeochemical processes that vary spatially and temporally (e.g., Public Shooting Grounds, our best available condition reference site (Hoven and Richards 2015)). These management practices and the following recommended strategies to implement them effectively will serve as a framework of tools to remedy poor wetland condition and have direct application for both the wetland management and regulatory communities.

4.1 RECOMMENDED MANAGEMENT STRATEGIES

The following strategies can be used to improve the effectiveness of management practices typically employed at impounded wetlands of GSL. The list is not intended to be exhaustive and may inspire ideas related to the included concepts. Mangers can use these or related strategies to adjust a management regime to target desired biological response(s) based on most important predictors (in order of importance from Tables 3.1 and 3.2) such as:

TREATMENT LEVEL → AND WATER AVAILABILITY	Redirect dispersion point through vegetated areas. Fill slowly to encourage emergent vegetation near dispersion point and to reduce siltation. Sustain low water availability to stimulate tuber production.	If designating an impoundment for pre-treatment is not feasible, consider slower fills and increased residence time when impoundments are first inundated in the spring and alter conveyance patterns to maximize the number of managed units through which water is conveyed
	Designate a pre-treatment wetland to improve water quality prior to being conveyed to down-gradient impoundments. Increase residence time within pre-treatment wetland.	

WATER LEVEL →

Manipulate water levels to improve forageable SAV cover and drupelet production: avoid depths beyond 60cm; avoid ± changes in water depths greater than 10 cm once desired level is attained.

DRAWDOWN CYCLE →

Consider implementing drawdown cycle studies to: mimic a natural wetland hydroperiod more closely; test for most beneficial drawdown frequency, duration and extent with respect to increasing SAV forage; test efficacy of rotational drawdowns.

CARP MANAGEMENT →

Conduct most effective carp management as resources allow; pool resources with other managers using same water source.

4.2 CONFLICTING MANAGEMENT OBJECTIVES TO CONSIDER

a) *Phragmites* control (or other invasive macrophytes). Recently, a review of *Phragmites* management methods and related research identified several opportunities for managers to modify their techniques (including timing of chemical applications and mowing) whereby better efficacy of control efforts might be attained (Hazelton et al. 2014). Once *Phragmites* control is better understood, conflicting management objectives may be resolved. Currently, drawing down an impoundment to mimic a more natural hydroperiod and stimulate nutrient cycling and productivity is typically not an option due to the aggressive nature of *Phragmites.* Mangers fear the loss of important wetland habitat to *Phragmites* and choose to stabilize water levels at the risk of compromising SAV and associated macroinvertebrate productivity.

b) Avian botulism. It is believed that changing water levels during the late summer may be a high risk because of a suspected link between exposing recently anoxic sediment and disease outbreak in waterbirds that forage in the newly exposed sediment (B. Clements, personal communication, August 2014). Until the transport mechanisms and linkages between habitat and disease outbreak are better understood, managers of waterfowl habitat are not likely to alter impounded wetland hydrology in a way that may risk lives of the birds.

4.3 RELEVANCE FOR AGENCIES

Å Agencies can save time and resources:

- Å Combined results of our vegetative MIBI and management strategies provide an essential link between wetland condition, beneficial use support and restoration opportunities not addressed by either the State's MMI assessment framework for impounded wetlands (CH2M HILL 2014) or the TMDL process.
- Å Modification of management practices based on our vegetative MIBI and recommended management strategies is testable and adaptable and can be monitored for restoration of improved wetland condition on a site by site basis.
- Å Combined results of our vegetative MIBI and management strategies could circumvent the need for 303d listing of impaired wetlands and the TMDL process altogether.

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6 APPENDICES

Appendix 1. Summary statistics of percent cover forageable SAV by month for three first order impounded wetland sites, F1, N1, and P1

-> site1 = F1

Summary for variables: foreageablesav
by categories of: month2 (Month)

month2	mean	p50	N	sd	p25	p75
July	25.96667	13.5	6	33.23021	1	42.8
August	31.725	25.6	8	29.389	4.8	62
Sept/Oct/Nov	19.44444	9	9	29.02151	4	23
Total	25.41739	9.8	23	29.3462	3	42.8

-> site1 = N1

Summary for variables: foreageablesav
by categories of: month2 (Month)

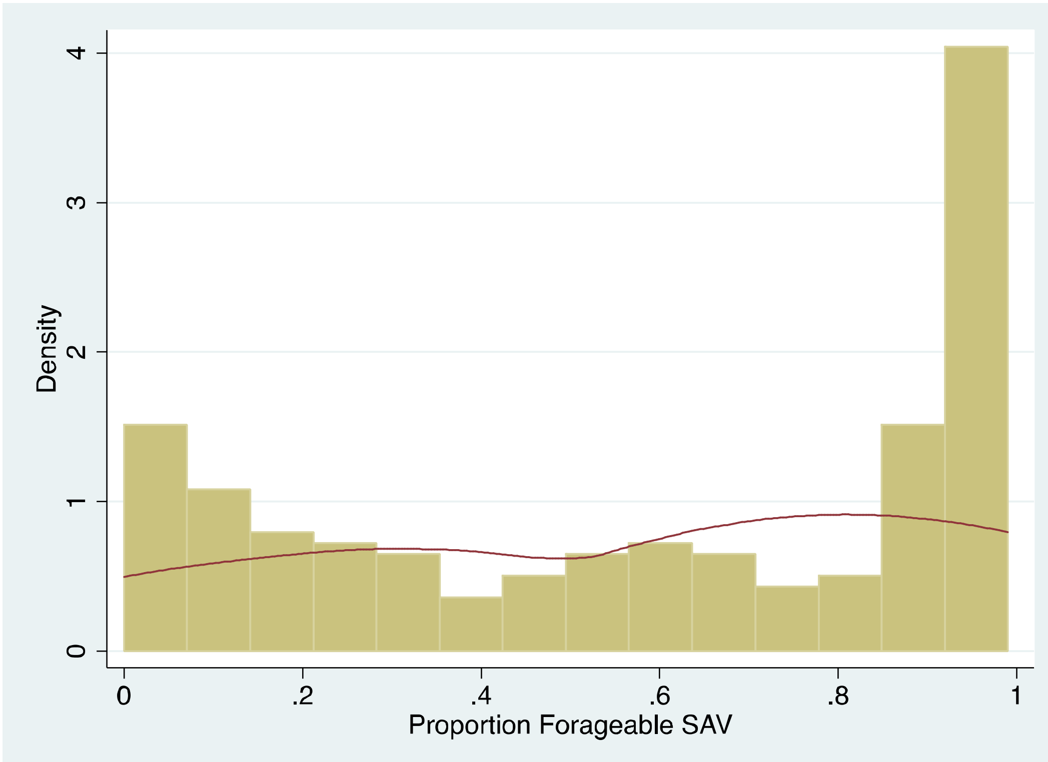
month2	mean	p50	N	sd	p25	p75
July	45.24	46	5	12.98414	37	51
August	38.9	30	6	31.92836	12	74.4
Sept/Oct/Nov	10.72	8.1	10	11.66693	1	11
Total	26.99048	16	21	24.65769	8	44

-> site1 = P1

Summary for variables: foreageablesav
by categories of: month2 (Month)

month2	mean	p50	N	sd	p25	p75
July	74.27778	89.66667	6	29.69206	53.33333	94
August	75.25	82.2	8	22.23196	61	92.8
Sept/Oct/Nov	75.69091	70	11	24.89086	64	97.2
Total	75.21067	87.4	25	24.21366	63	96

Appendix 2a. Kernel density and histograms of proportion forageable SAV data from 2004 – 2014 at 27 impounded wetlands of GSL

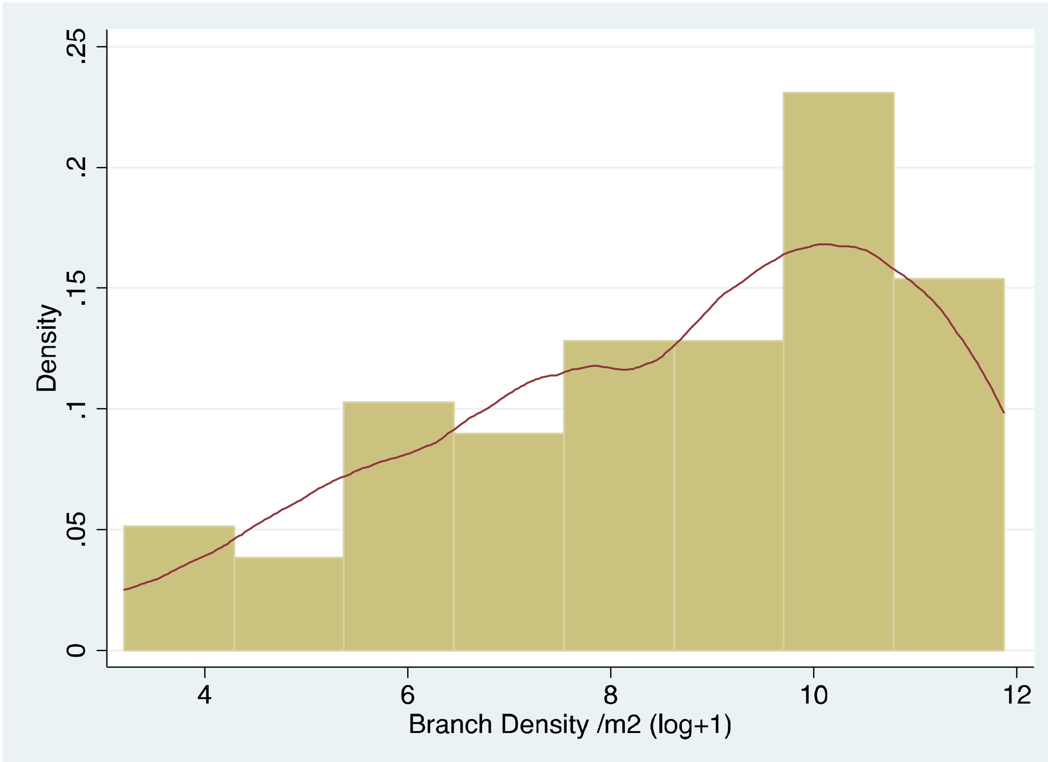


Appendix 2b. Generalized linear model regression of proportion forageable SAV versus management subcategories and practices

```
Generalized linear models                          No. of obs      =        124
Optimization     : ML                              Residual df     =        107
                                                   Scale parameter =          1
Deviance         =   60.2550168                    (1/df) Deviance =    .563131
Pearson          =  59.63544454                    (1/df) Pearson  =   .5573406

Variance function: V(u) = u*(1-u/1)                [Binomial]
Link function    : g(u) = ln(u/(1-u))              [Logit]

                                                   AIC             =   1.200961
Log pseudolikelihood = -57.45955906                BIC             =  -455.5151
```

proportionforageablesav	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
carpcontrolscore1						
Low	-.2846489	1.236073	-0.23	0.818	-2.707308	2.13801
watersource1						
Jordan River	1.389973	2.091233	0.66	0.506	-2.708768	5.488714
Northpoint Consolidated Canal	-2.331831	1.461709	-1.60	0.111	-5.196728	.5330666
Salt Creek	-.8185391	1.023596	-0.80	0.424	-2.824751	1.187673
State Canal	1.724818	2.162615	0.80	0.425	-2.513829	5.963466
Surplus Canal	.8454651	1.733286	0.49	0.626	-2.551714	4.242644
drypreviousyear2						
Yes	2.8832	.9015497	3.20	0.001	1.116195	4.650205
orderofpond2						
2	-.6636543	.8217717	-0.81	0.419	-2.274297	.9469887
3	-1.961857	1.966005	-1.00	0.318	-5.815156	1.891441
treatmentlevel2						
2	2.75345	.9777445	2.82	0.005	.8371056	4.669794
3	5.123461	2.379554	2.15	0.031	.4596205	9.787301
drawdowncycle2						
1	-1.545196	.5756634	-2.68	0.007	-2.673476	-.4169167
2	-2.04378	.5372774	-3.80	0.000	-3.096824	-.9907354
3	-3.544499	1.701948	-2.08	0.037	-6.880255	-.2087433
previousdepthcm	.0108942	.0145991	0.75	0.456	-.0177195	.039508
waterdepthcm	-.0177913	.0146432	-1.21	0.224	-.0464914	.0109088
_cons	-2.186078	2.184177	-1.00	0.317	-6.466987	2.094831

Appendix 3a. Kernel density and histograms of log branch density data from 2004 – 2014 at 27 impounded wetlands of GSL

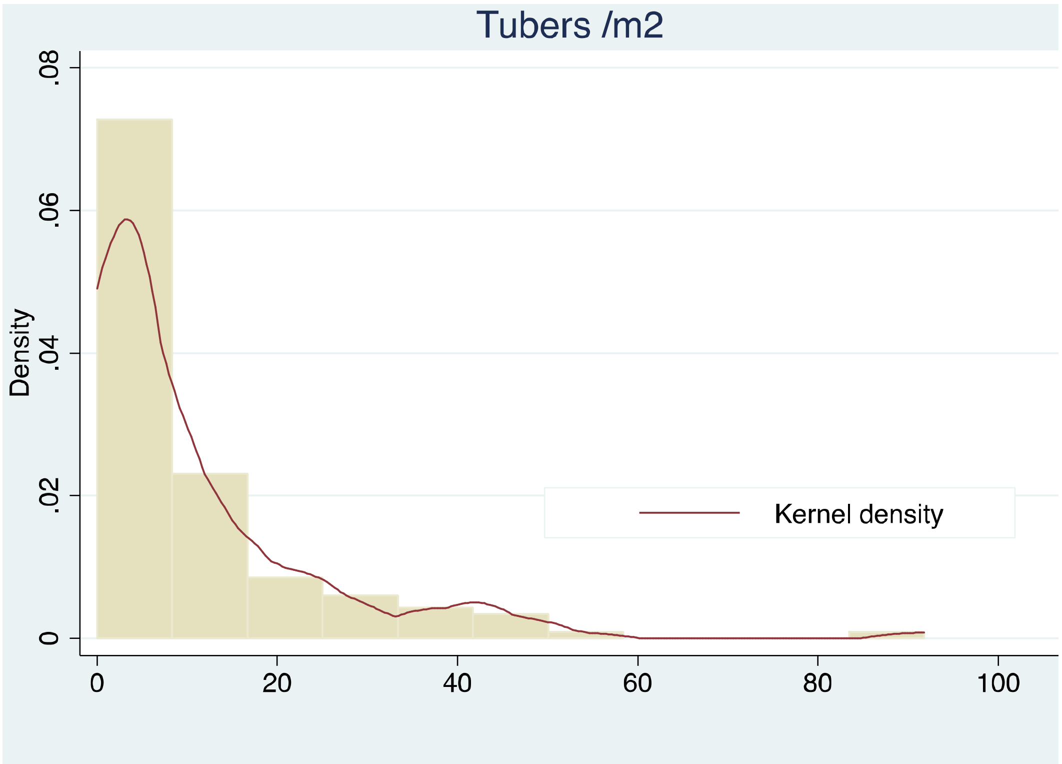


Appendix 3b. General linear model regression of log branch density versus management subcategories and practices

```
Generalized linear models                          No. of obs      =         70
Optimization     : ML                              Residual df     =         55
                                                   Scale parameter =   1.854251
Deviance         =  98.27531698                    (1/df) Deviance =   1.786824
Pearson          =  98.27531698                    (1/df) Pearson  =   1.786824

Variance function: V(u) = 1                        [Gaussian]
Link function    : g(u) = u                        [Identity]

                                                   AIC             =   3.605726
Log pseudolikelihood = -111.2004152                BIC             = -135.3919
```

logbranchdensity	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
carpcontrolscore1						
Low	-.1477049	.7854939	-0.19	0.851	-1.687245	1.391835
watersource1						
Jordan River	1.873813	2.210902	0.85	0.397	-2.459474	6.207101
Salt Creek	1.790679	1.32186	1.35	0.176	-.8001189	4.381477
State Canal	1.708654	1.713099	1.00	0.319	-1.648959	5.066267
Surplus Canal	1.430684	1.823829	0.78	0.433	-2.143954	5.005323
drypreviousyear2						
Yes	1.634749	1.451221	1.13	0.260	-1.209592	4.479091
orderofpond2						
2	-.3262295	.8841202	-0.37	0.712	-2.059073	1.406614
3	.3677837	1.664913	0.22	0.825	-2.895386	3.630954
waterlevel						
2	.5192149	.689727	0.75	0.452	-.8326251	1.871055
3	-.3005041	1.401241	-0.21	0.830	-3.046885	2.445877
treatmentlevel2						
2	1.813509	.6926757	2.62	0.009	.4558895	3.171128
3	2.652251	1.781698	1.49	0.137	-.8398127	6.144315
drawdowncycle2						
1	-.5853148	.8670523	-0.68	0.500	-2.284706	1.114077
2	-.6724469	1.137757	-0.59	0.555	-2.902409	1.557515
3	0	(omitted)				
previousdepthcm	.0171612	.021289	0.81	0.420	-.0245645	.058887
waterdepthcm	.0057303	.0226977	0.25	0.801	-.0387563	.0502169
_cons	-.6553154	2.359745	-0.28	0.781	-5.280331	3.9697

Appendix 4a. Kernel density and histograms of SAV tubers data from 2004 – 2014 at 27 impounded wetlands of GSL

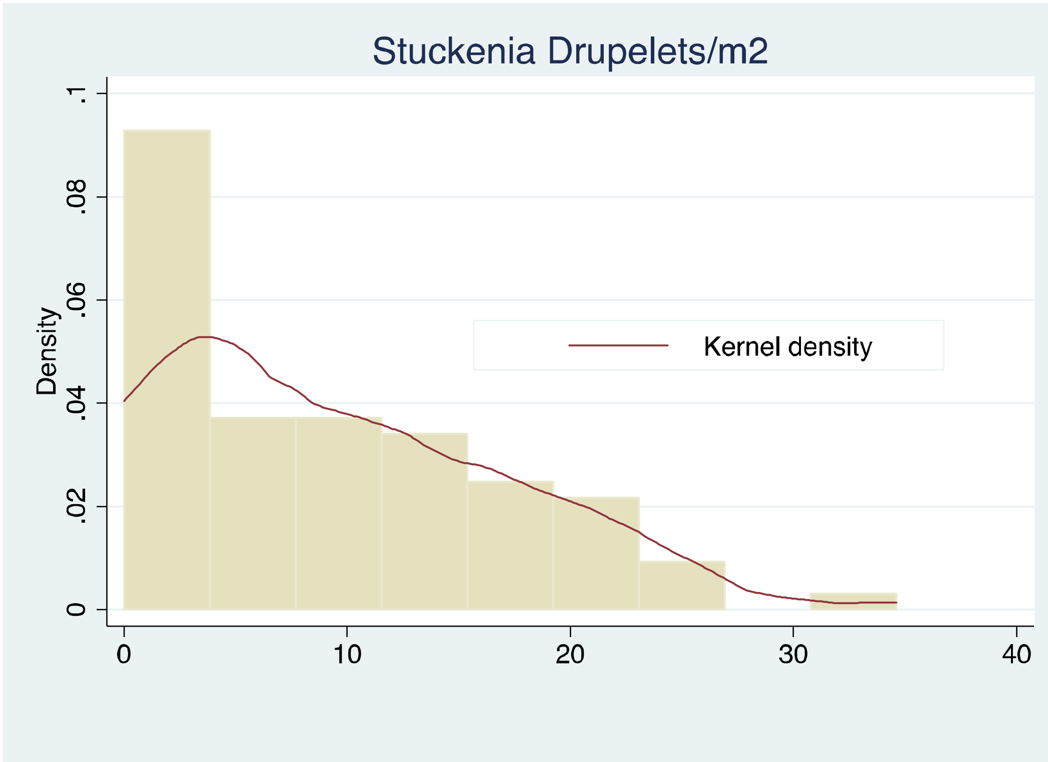


Appendix 4b. Generalized linear model regression of SAV tubers versus management subcategories and practices

```
Generalized linear models                          No. of obs      =        98
Optimization     : ML                              Residual df     =        80
                                                   Scale parameter =    .187604
Deviance         =  14.82071705                    (1/df) Deviance =    .185259
Pearson          =  14.82071705                    (1/df) Pearson  =    .185259

Variance function: V(u) = 1                        [Gaussian]
Link function    : g(u) = u                        [Identity]

                                                   AIC             =  1.316283
Log pseudolikelihood = -46.49784392                BIC             = -351.9767
```

logtubers	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
carpcontrolscore1						
Low	.3023093	.3112834	0.97	0.331	-.3077949	.9124135
watersource1						
Jordan River	1.237075	.4170322	2.97	0.003	.4197066	2.054443
Northpoint Consolidated Canal	-1.494614	.2524763	-5.92	0.000	-1.989458	-.9997698
Salt Creek	-1.0167	.3059096	-3.32	0.001	-1.616272	-.417128
State Canal	.6217742	.4646171	1.34	0.181	-.2888585	1.532407
Surplus Canal	.7574734	.3820318	1.98	0.047	.0087048	1.506242
drypreviousyear2						
Yes	.2832034	.3106383	0.91	0.362	-.3256365	.8920434
orderofpond2						
2	-.053723	.1981573	-0.27	0.786	-.4421041	.3346582
3	-1.535936	.418063	-3.67	0.000	-2.355324	-.7165474
waterlevel						
2	.2677758	.1780155	1.50	0.133	-.0811282	.6166798
3	.5076467	.4257611	1.19	0.233	-.3268297	1.342123
treatmentlevel2						
2	.602808	.1996553	3.02	0.003	.2114908	.9941252
3	2.275338	.5212967	4.36	0.000	1.253616	3.297061
drawdowncycle2						
1	-.5025845	.2207461	-2.28	0.023	-.9352388	-.0699301
2	-.0488027	.236086	-0.21	0.836	-.5115227	.4139174
3	-.094319	.4255893	-0.22	0.825	-.9284587	.7398207
previousdepthcm	-.0032042	.0046264	-0.69	0.489	-.0122718	.0058635
waterdepthcm	.0001026	.0074012	0.01	0.989	-.0144034	.0146087
_cons	-.7385825	.4124075	-1.79	0.073	-1.546886	.0697213

Appendix 5a. Kernel density and histograms of *Stuckenia* drupelets data from 2004 – 2014 at 27 impounded wetlands of GSL

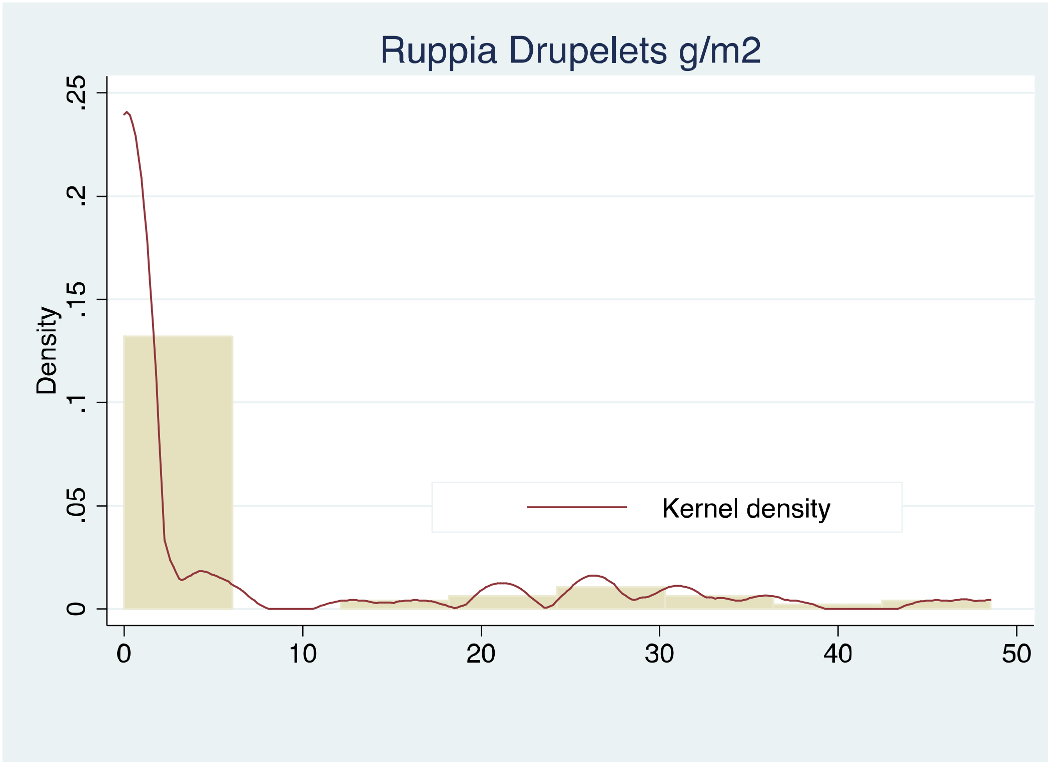


Appendix 5b. Generalized linear model regression of *Stuckenia* drupelets versus management subcategories and practices

```
.  glm stuckeniadrupeletsgm2 i.carpcontrolscore1 i.watersource1 i.drypreviousyear2 i.orderof
> m waterdepthcm,  robust
note: 4.drawdowncycle2 omitted because of collinearity

Iteration 0:   log pseudolikelihood = -223.73712

Generalized linear models                         No. of obs      =         72
Optimization     : ML                             Residual df     =         56
                                                  Scale parameter =   38.33548
Deviance         =  2108.451671                   (1/df) Deviance =   37.65092
Pearson          =  2108.451671                   (1/df) Pearson  =   37.65092

Variance function: V(u) = 1                       [Gaussian]
Link function    : g(u) = u                       [Identity]

                                                  AIC             =   6.659365
Log pseudolikelihood = -223.7371236               BIC             =   1868.958
```

stuckeniadrupeletsgm2	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
carpcontrolscore1						
Low	-3.619794	4.005959	-0.90	0.366	-11.47133	4.231743
watersource1						
Jordan River	1.511543	5.235599	0.29	0.773	-8.750041	11.77313
Salt Creek	-11.24529	5.548968	-2.03	0.043	-22.12107	-.3695148
State Canal	13.42906	5.17257	2.60	0.009	3.291008	23.56711
Surplus Canal	7.760214	3.566073	2.18	0.030	.770839	14.74959
drypreviousyear2						
Yes	3.075744	2.276663	1.35	0.177	-1.386434	7.537922
orderofpond2						
2	12.03683	5.228783	2.30	0.021	1.7886	22.28505
3	-26.03177	5.231375	-4.98	0.000	-36.28508	-15.77846
treatmentlevel2						
2	-.2412081	3.51211	-0.07	0.945	-7.124817	6.6424
3	21.45648	6.222337	3.45	0.001	9.260927	33.65204
waterlevel						
2	3.922473	2.230544	1.76	0.079	-.4493134	8.294259
3	15.11605	6.220869	2.43	0.015	2.923375	27.30873
drawdowncycle2						
1	-17.52769	4.475857	-3.92	0.000	-26.3002	-8.755166
2	-3.901653	3.400405	-1.15	0.251	-10.56632	2.763018
3	0	(omitted)				
previousdepthcm	.0171678	.0731593	0.23	0.814	-.1262217	.1605574
waterdepthcm	-.1329292	.0980631	-1.36	0.175	-.3251294	.0592709
_cons	2.453558	4.183475	0.59	0.558	-5.745903	10.65302

Appendix 6a. Kernel density and histograms of *Ruppia* drupelets data from 2004 – 2014 at 27 impounded wetlands of GSL

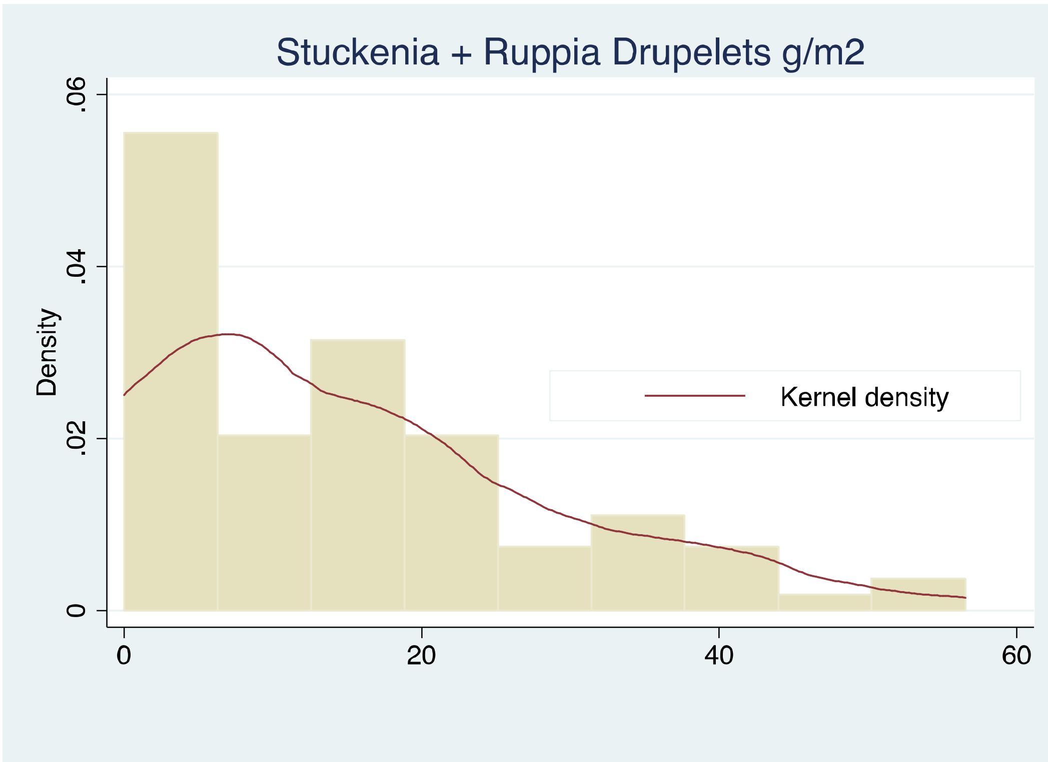


Appendix 6b. General linear model regression of *Ruppia* drupelets versus management subcategories and practices

```
Generalized linear models                          No. of obs      =         70
Optimization     : ML                              Residual df     =         54
                                                   Scale parameter =   12.43856
Deviance         =  659.2437596                    (1/df) Deviance =   12.20822
Pearson          =  659.2437596                    (1/df) Pearson  =   12.20822

Variance function: V(u) = 1                        [Gaussian]
Link function    : g(u) = u                        [Identity]

                                                   AIC             =   5.537618
Log pseudolikelihood = -177.8166314                BIC             =    429.825
```

ruppiadrupeletsgm2	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
carpcontrolscore1						
Low	-6.76095	2.866173	-2.36	0.018	-12.37855	-1.143354
watersource1						
Jordan River	-5.38796	2.956492	-1.82	0.068	-11.18258	.4066574
Salt Creek	28.69877	2.203912	13.02	0.000	24.37918	33.01836
State Canal	1.03374	1.456646	0.71	0.478	-1.821233	3.888714
Surplus Canal	1.46765	1.417741	1.04	0.301	-1.311071	4.24637
drypreviousyear2						
Yes	.274985	.3864111	0.71	0.477	-.4823668	1.032337
orderofpond2						
2	.9340213	.5551116	1.68	0.092	-.1539774	2.02202
3	.4389357	1.806044	0.24	0.808	-3.100845	3.978716
treatmentlevel2						
2	.8132251	.7418274	1.10	0.273	-.6407298	2.26718
3	-.0696747	2.347263	-0.03	0.976	-4.670226	4.530877
waterlevel						
2	-.2481911	2.355424	-0.11	0.916	-4.864738	4.368355
3	2.611437	3.561574	0.73	0.463	-4.36912	9.591994
drawdowncycle2						
1	-.0443631	1.263087	-0.04	0.972	-2.519969	2.431243
2	.3096169	.3956371	0.78	0.434	-.4658176	1.085051
3	0	(omitted)				
previousdepthcm	.0355389	.0472004	0.75	0.451	-.0569722	.1280499
waterdepthcm	-.0933824	.0549395	-1.70	0.089	-.2010618	.014297
_cons	7.336189	4.70191	1.56	0.119	-1.879385	16.55176

Appendix 7a. Kernel density and histograms of *Stuckenia* and *Ruppia* drupelets data from 2004 – 2014 at 27 impounded wetlands of GSL

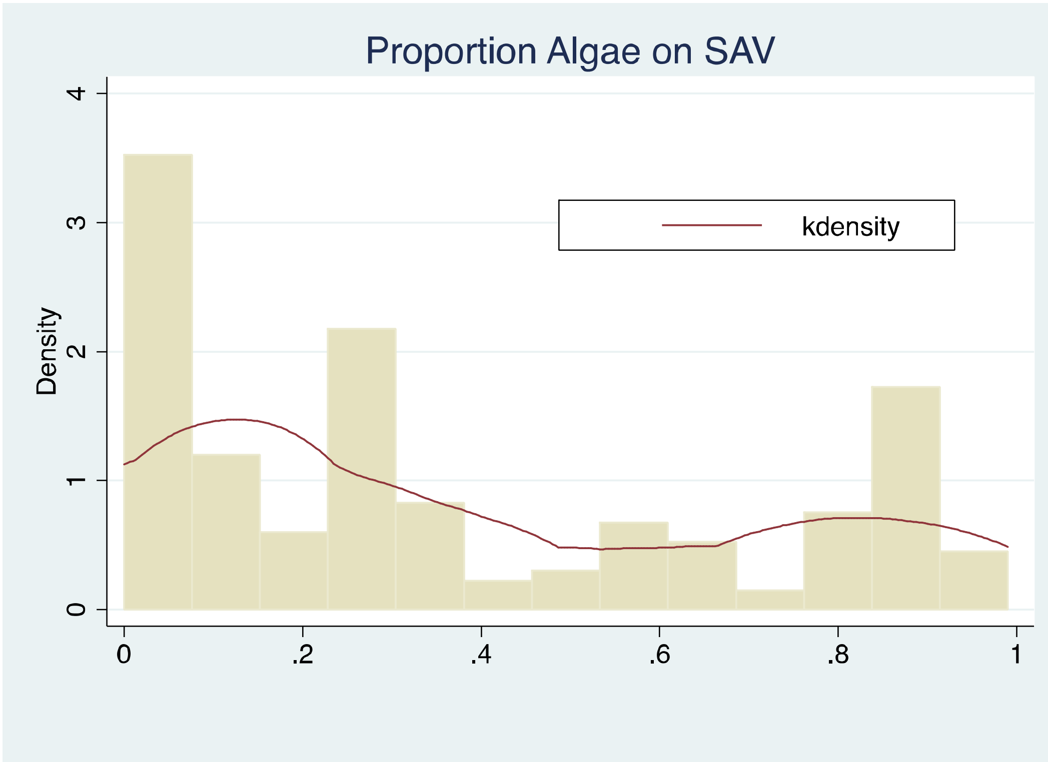


Appendix 7b. General Linear Model regression of *Stuckenia* and *Ruppia* drupelets versus management subcategories and practices

```
Generalized linear models                         No. of obs      =         74
Optimization     : ML                             Residual df     =         55
                                                  Scale parameter =   32.06717
Deviance         =  1667.492826                   (1/df) Deviance =   30.31805
Pearson          =  1667.492826                   (1/df) Pearson  =   30.31805

Variance function: V(u) = 1                       [Gaussian]
Link function    : g(u) = u                       [Identity]

                                                  AIC             =   6.466402
Log pseudolikelihood = -220.2568726               BIC             =   1430.769
```

StuckeniaRuppiaDrupelets	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
PondOrder1						
2	10.44441	3.505285	2.98	0.003	3.57418	17.31464
TreatmentLevel1						
2	3.91719	2.653237	1.48	0.140	-1.283059	9.117439
3	8.324879	6.000827	1.39	0.165	-3.436525	20.08628
PreviousDepth	-.1659627	.0898123	-1.85	0.065	-.3419917	.0100662
WaterDepth	-.0378675	.1273608	-0.30	0.766	-.28749	.211755
WaterLevel1						
1	-6.635041	4.212725	-1.57	0.115	-14.89183	1.621748
2	2.146592	2.888181	0.74	0.457	-3.514139	7.807323
3	22.25008	4.168093	5.34	0.000	14.08077	30.41939
Duration1						
1	12.51603	5.744855	2.18	0.029	1.256318	23.77573
2	.4276125	2.477393	0.17	0.863	-4.427988	5.283213
3	0	(omitted)				
DrawDownCycle1						
1	-15.42542	4.325025	-3.57	0.000	-23.90232	-6.948531
2	-.5720722	1.839421	-0.31	0.756	-4.177271	3.033126
3	-12.79495	5.136489	-2.49	0.013	-22.86228	-2.727614
Availability1						
1	33.26027	4.040535	8.23	0.000	25.34096	41.17957
2	27.10751	4.669592	5.81	0.000	17.95528	36.25974
3	26.28834	4.657504	5.64	0.000	17.1598	35.41688
WaterSource1						
Jordan River	21.10766	3.348198	6.30	0.000	14.54531	27.67
Salt Creek Juns	24.5728	4.678741	5.25	0.000	15.40263	33.74296
State Canal	2.514599	2.695455	0.93	0.351	-2.768397	7.797594
Surplus Canal	0	(omitted)				
DryPreviousYear1						
Yes	3.011368	2.382348	1.26	0.206	-1.657949	7.680685
CarpControlMetric1						
Low	22.36368	2.132363	10.49	0.000	18.18432	26.54303
_cons	-43.18086	3.722271	-11.60	0.000	-50.47638	-35.88534

Appendix 8a. Kernel density and histograms of proportion algae on SAV data from 2004 – 2014 at 27 impounded wetlands of GSL

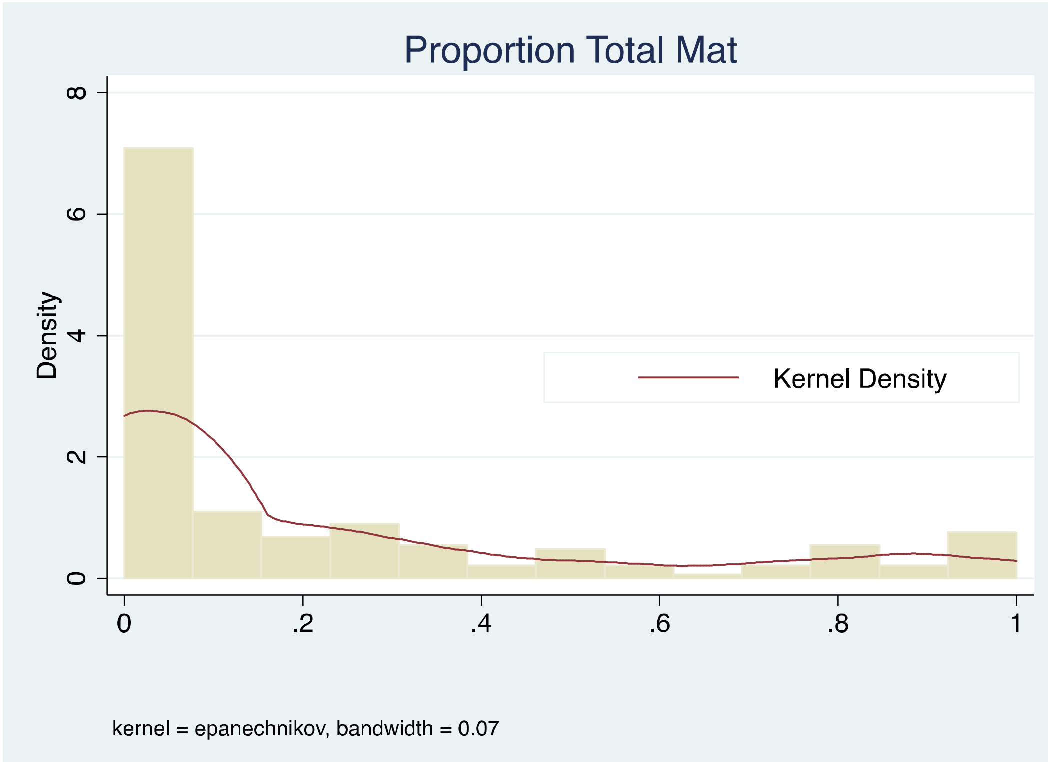


Appendix 8b. Generalized linear model regression of proportion algae on SAV versus management subcategories and practices

```
Generalized linear models                          No. of obs      =        114
Optimization     : ML                              Residual df     =         97
                                                   Scale parameter =          1
Deviance         =  52.72283043                    (1/df) Deviance =   .5435343
Pearson          =   47.6732816                    (1/df) Pearson  =   .4914771

Variance function: V(u) = u*(1-u/1)                [Binomial]
Link function    : g(u) = ln(u/(1-u))              [Logit]

                                                   AIC             =   1.219056
Log pseudolikelihood = -52.48619286                BIC             =  -406.6884
```

proportionalgaeonsav	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
carpcontrolscore1						
Low	3.480731	1.150426	3.03	0.002	1.225937	5.735524
watersource1						
Jordan River	6.489762	1.931753	3.36	0.001	2.703596	10.27593
Northpoint Consolidated Canal	1.189759	.8530294	1.39	0.163	-.4821478	2.861666
Salt Creek	.0749665	.9403139	0.08	0.936	-1.768015	1.917948
State Canal	3.153961	1.769988	1.78	0.075	-.3151511	6.623074
Surplus Canal	3.889158	1.648808	2.36	0.018	.6575528	7.120762
drypreviousyear2						
Yes	.3070668	1.307835	0.23	0.814	-2.256242	2.870376
orderofpond2						
2	1.514272	.4802132	3.15	0.002	.5730715	2.455473
3	-4.264718	1.854745	-2.30	0.021	-7.899952	-.6294837
treatmentlevel2						
2	-1.564262	.5048122	-3.10	0.002	-2.553676	-.5748482
3	1.079748	1.868796	0.58	0.563	-2.583025	4.742521
drawdowncycle2						
1	1.045455	.6916332	1.51	0.131	-.3101209	2.401031
2	-1.401268	1.097651	-1.28	0.202	-3.552626	.7500889
3	-2.152114	1.733297	-1.24	0.214	-5.549314	1.245086
previousdepthcm	-.0004401	.0181925	-0.02	0.981	-.0360968	.0352165
waterdepthcm	-.0160649	.0166144	-0.97	0.334	-.0486286	.0164987
_cons	-6.008715	1.902518	-3.16	0.002	-9.737583	-2.279847

Appendix 9. Kernel density and histograms of proportion total mat data from 2004 – 2014 at 27 impounded wetlands of GSL



Appendix 10. Negative binomial regression of proportion foreagable SAV versus management subcategories and practices

Negative binomial regression		Number of obs =	**78**
Dispersion =	**mean**	Wald chi2(**9**) =	**181.80**
Log pseudolikelihood =	**-312.63678**	Prob > chi2 =	**0.0000**

foreageablesav	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	**-1.81158**	**.3395121**	**-5.34**	**0.000**	**-2.477011**	**-1.146148**
3	**-.3082568**	**.3332458**	**-0.93**	**0.355**	**-.9614067**	**.344893**
treatmentlevel						
2	**-.2082142**	**.3489094**	**-0.60**	**0.551**	**-.892064**	**.4756356**
3	**0**	(omitted)				
h2odepthcm	**.0523039**	**.0239414**	**2.18**	**0.029**	**.0053797**	**.0992281**
2.waterlevel	**-.1274107**	**1.120626**	**-0.11**	**0.909**	**-2.323798**	**2.068976**
2.duration	**.4255438**	**.3848299**	**1.11**	**0.269**	**-.3287089**	**1.179796**
availabilty						
2	**-5.295365**	**.7993538**	**-6.62**	**0.000**	**-6.862069**	**-3.72866**
3	**-8.170436**	**1.151104**	**-7.10**	**0.000**	**-10.42656**	**-5.914313**
CarpControl2	**-3.785715**	**.6218965**	**-6.09**	**0.000**	**-5.004609**	**-2.56682**
_cons	**7.807181**	**1.982277**	**3.94**	**0.000**	**3.92199**	**11.69237**
/lnalpha	**.1185487**	**.1907158**			**-.2552474**	**.4923448**
alpha	**1.125862**	**.2147196**			**.7747248**	**1.636148**

Appendix 11. Generalized linear model regression of log branch density versus management subcategories and practices

```
Generalized linear models                          No. of obs      =         77
Optimization     : ML                              Residual df     =         67
                                                   Scale parameter =   1.867735
Deviance         =  125.1382334                    (1/df) Deviance =   1.867735
Pearson          =  125.1382334                    (1/df) Pearson  =   1.867735

Variance function: V(u) = 1                        [Gaussian]
Link function    : g(u) = u                        [Identity]

                                                   AIC             =   3.583231
Log pseudolikelihood = -127.9543896                BIC             =  -165.8967
```

logBranchDensity	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	-1.342689	.521927	-2.57	0.010	-2.365647	-.3197311
3	2.721963	.4997802	5.45	0.000	1.742412	3.701514
treatmentlevel						
2	1.220469	.435405	2.80	0.005	.3670907	2.073847
3	0	(omitted)				
h2odepthcm	.0267348	.0249779	1.07	0.284	-.022221	.0756905
2.waterlevel	-.3020404	1.073116	-0.28	0.778	-2.405308	1.801228
2.duration	.6463967	.5878888	1.10	0.272	-.5058441	1.798637
DryPreviousYear						
No	0	(omitted)				
availabilty						
2	-4.172466	.6321713	-6.60	0.000	-5.411499	-2.933433
3	-6.41669	1.066325	-6.02	0.000	-8.506649	-4.326731
CarpControl2	2.134343	.4551282	4.69	0.000	1.242308	3.026378
_cons	.6323975	1.748083	0.36	0.718	-2.793783	4.058578

Appendix 12. Generalized linear model regression of log tubers (g/m^2) versus management subcategories and practices

```
Generalized linear models                          No. of obs      =         71
Optimization     : ML                              Residual df     =         61
                                                   Scale parameter =   .2475711
Deviance         =  15.10183591                    (1/df) Deviance =   .2475711
Pearson          =  15.10183591                    (1/df) Pearson  =   .2475711

Variance function: V(u) = 1                        [Gaussian]
Link function    : g(u) = u                        [Identity]

                                                   AIC             =   1.571704
Log pseudolikelihood = -45.79547957                BIC             =  -244.9216
```

logTubers	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	-.3693855	.1774382	-2.08	0.037	-.7171579	-.0216131
3	.4076637	.2007019	2.03	0.042	.0142952	.8010322
treatmentlevel						
2	.3392817	.1574109	2.16	0.031	.030762	.6478015
3	0	(omitted)				
h2odepthcm	.0030051	.0081461	0.37	0.712	-.0129609	.0189712
2.waterlevel	-.1267395	.3825285	-0.33	0.740	-.8764816	.6230027
2.duration	.0257005	.2125991	0.12	0.904	-.3909861	.4423871
DryPreviousYear						
No	0	(omitted)				
availabilty						
2	-1.144204	.2665176	-4.29	0.000	-1.666568	-.6218387
3	-1.726444	.4364649	-3.96	0.000	-2.581899	-.8709884
CarpControl2	.1244901	.271078	0.46	0.646	-.406813	.6557932
_cons	1.496017	.6783712	2.21	0.027	.1664339	2.8256

Appendix 13. Negative binomial regression of log *Stuckenia* drupelets (g/m^2) versus management subcategories and practices

Negative binomial regression		Number of obs	= **71**
Dispersion	= **mean**	Wald chi2(**9**)	= **247.47**
Log pseudolikelihood	= **-229.38874**	Prob > chi2	= **0.0000**

stuckeniadrupeletsgm2	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	**.0961006**	**.184712**	**0.52**	**0.603**	**-.2659282**	**.4581295**
3	**-1.479021**	**.2365044**	**-6.25**	**0.000**	**-1.942561**	**-1.015481**
treatmentlevel						
2	**-.3059042**	**.1821234**	**-1.68**	**0.093**	**-.6628596**	**.0510512**
3	**0**	(omitted)				
h2odepthcm	**.0084568**	**.0120639**	**0.70**	**0.483**	**-.015188**	**.0321016**
2.waterlevel	**-.196911**	**1.080483**	**-0.18**	**0.855**	**-2.314619**	**1.920798**
2.duration	**-.7461489**	**.2363777**	**-3.16**	**0.002**	**-1.209441**	**-.282857**
availabilty						
2	**.214255**	**.26258**	**0.82**	**0.415**	**-.3003923**	**.7289024**
3	**.4720592**	**.993342**	**0.48**	**0.635**	**-1.474855**	**2.418974**
CarpControl2	**.9026114**	**.2195243**	**4.11**	**0.000**	**.4723517**	**1.332871**
_cons	**2.544672**	**1.460715**	**1.74**	**0.081**	**-.3182766**	**5.40762**
/lnalpha	**-1.354498**	**.2417313**			**-1.828283**	**-.8807133**
alpha	**.2580768**	**.0623853**			**.1606893**	**.4144872**

Appendix 14. Negative binomial regression of proportion algae on SAV versus management subcategories and practices

Negative binomial regression		Number of obs =	**74**
Dispersion =	**mean**	Wald chi2(**9**) =	**293.78**
Log pseudolikelihood =	**-49.076929**	Prob > chi2 =	**0.0000**

palgaeonsav	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	**-1.214004**	**.33066**	**-3.67**	**0.000**	**-1.862085**	**-.5659221**
3	**-3.548565**	**.3565512**	**-9.95**	**0.000**	**-4.247392**	**-2.849737**
treatmentlevel						
2	**-.1833308**	**.2992112**	**-0.61**	**0.540**	**-.769774**	**.4031124**
3	**0**	(omitted)				
h2odepthcm	**.0439465**	**.0222291**	**1.98**	**0.048**	**.0003784**	**.0875147**
2.waterlevel	**.7712765**	**.7580124**	**1.02**	**0.309**	**-.7144005**	**2.256954**
2.duration	**-.3666524**	**.3115618**	**-1.18**	**0.239**	**-.9773024**	**.2439976**
availabilty						
2	**-3.075306**	**.6951487**	**-4.42**	**0.000**	**-4.437773**	**-1.71284**
3	**-4.664134**	**.965063**	**-4.83**	**0.000**	**-6.555623**	**-2.772646**
CarpControl2	**-2.126903**	**.5414938**	**-3.93**	**0.000**	**-3.188211**	**-1.065594**
_cons	**1.32426**	**1.66271**	**0.80**	**0.426**	**-1.934592**	**4.583112**
/lnalpha	**-20.91085**	**.**			**.**	**.**
alpha	**8.29e-10**	**.**			**.**	**.**

Appendix 15. Negative binomial regression of proportion algae and BDS on SAV versus management subcategories and practices

Negative binomial regression		Number of obs =	74
Dispersion = mean		Wald chi2(9) =	75.16
Log pseudolikelihood = -66.070012		Prob > chi2 =	0.0000

AlgaeBDSonSAV	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	.2602367	.1167633	2.23	0.026	.0313849	.4890886
3	-1.088685	.2020866	-5.39	0.000	-1.484767	-.6926025
treatmentlevel						
2	-.0326994	.1332697	-0.25	0.806	-.2939032	.2285043
3	0	(omitted)				
h2odepthcm	-.030805	.0094734	-3.25	0.001	-.0493726	-.0122375
2.waterlevel	-.1993074	.2103613	-0.95	0.343	-.6116081	.2129932
2.duration	.0427088	.1370383	0.31	0.755	-.2258814	.3112989
availabilty						
2	.2320491	.1939026	1.20	0.231	-.1479931	.6120912
3	.5059923	.2259136	2.24	0.025	.0632099	.9487748
CarpControl2	.1968694	.1246553	1.58	0.114	-.0474505	.4411892
_cons	.9136896	.6963442	1.31	0.189	-.4511199	2.278499
/lnalpha	-23.73064	.			.	.
alpha	4.94e-11	.			.	.

Appendix 16. Negative binomial regression of proportion total mat versus management subcategories and practices

```
Negative binomial regression                    Number of obs     =         78
Dispersion           = mean                     Wald chi2(9)      =    1435.12
Log pseudolikelihood = -35.82301                Prob > chi2       =     0.0000
```

ptotmat	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
pondorder						
2	-1.767826	.5505607	-3.21	0.001	-2.846905	-.6887468
3	-15.73487	.5737527	-27.42	0.000	-16.85941	-14.61034
treatmentlevel						
2	.1993186	.4233434	0.47	0.638	-.6304193	1.029057
3	0	(omitted)				
h2odepthcm	.0729375	.0269488	2.71	0.007	.0201187	.1257562
2.waterlevel	2.738495	.7502672	3.65	0.000	1.267999	4.208992
2.duration	.3869409	.6640158	0.58	0.560	-.9145061	1.688388
availabilty						
2	-3.646144	.8206251	-4.44	0.000	-5.25454	-2.037749
3	-4.152038	.9258783	-4.48	0.000	-5.966726	-2.33735
CarpControl2	-3.928828	.4566605	-8.60	0.000	-4.823866	-3.03379
_cons	-2.300632	1.865667	-1.23	0.218	-5.957272	1.356009
/lnalpha	-36.79626	.			.	.
alpha	1.05e-16	.			.	.

Appendix 17. Kruskal-Wallis, foreageble SAV and three management subcategories and practices that differed among F1, F2 and Fbtu at Farmington Bay WMA, September, 2012

```
. kwallis foreageablesav, by(DrawDownCycle)

Kruskal-Wallis equality-of-populations rank test
```

DrawDo~e	Obs	Rank Sum
0	6	32.50
1	11	120.50

```
chi-squared =     4.669 with 1 d.f.
probability =     0.0307

chi-squared with ties =     4.793 with 1 d.f.
probability =     0.0286
```

Appendix 18. Krukal-Wallis of tubers (g/m^2) and three management subcategories and practices that differed among F1, F2 and Fbtu at Farmington Bay WMA, September, 2012

```
. kwallis tubersgm2, by(DrawDownCycle)

Kruskal-Wallis equality-of-populations rank test
```

DrawDo~e	Obs	Rank Sum
0	6	30.00
1	11	123.00

```
chi-squared =     5.818 with 1 d.f.
probability =     0.0159

chi-squared with ties =     6.831 with 1 d.f.
probability =     0.0090
```

Appendix 19. Generalized linear model of *Stuckenia* drupelets (g/m^2) and water depth at F1, F2 and Fbtu at Farmington Bay WMA, September, 2012

```
. glm stuckeniadrupeletsgm2 h2odepthcm, robust

Iteration 0:   log pseudolikelihood = -51.689082

Generalized linear models                         No. of obs      =         17
Optimization     : ML                             Residual df     =         15
                                                  Scale parameter =   29.03072
Deviance         =    435.46081                   (1/df) Deviance =   29.03072
Pearson          =    435.46081                   (1/df) Pearson  =   29.03072

Variance function: V(u) = 1                       [Gaussian]
Link function    : g(u) = u                       [Identity]

                                                  AIC             =   6.316363
Log pseudolikelihood = -51.68908247               BIC             =   392.9626
```

stuckeniadrupeletsgm2	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
h2odepthcm	-.434174	.1413079	-3.07	0.002	-.7111325	-.1572155
_cons	45.76351	10.14352	4.51	0.000	25.88257	65.64444