Plant Metric Refinement for Condition Assessment of Great Salt Lake Impounded Wetlands

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1.0 INTRODUCTION

PROJECT BACKGROUND

Great Salt Lake Utah, U.S.A. (located between 40º and 41º N, 113º and 112º W) is the fourth largest terminal lake in the world and is recognized as a Hemispheric Site within the Western Hemisphere Shorebird Reserve Network. Its status is largely due to extensive wetlands associated along the shores of the Lake. These wetlands annually provide foraging, staging, breeding, and brood-rearing habitat to millions of migratory and resident shorebirds and other waterbirds. Approximately 75% of all wetlands in Utah are found along the freshwater tributaries of Great Salt Lake totaling nearly 182,000 ha. Of these, nearly 61,000 ha are located in the southeast portion of the Lake bordering Farmington Bay. Over half of those wetlands (approximately 35,000 ha) are impounded and managed for waterfowl. Much of the land is owned and managed by Federal and State agencies and private duck clubs as waterfowl habitat. Recently, noticeable algal and duckweed blooms have regularly become established during the summer months in many of the impounded wetlands of Farmington Bay, as well as the Bay itself. This has raised concerns from waterfowl managers, scientists and public interest groups.

Data presented in this report are part of an ongoing study to gain an understanding of relationships between biological responses of impounded wetlands across nutrient and salinity gradients and to develop assessment metrics of wetland condition that could be used to determine whether beneficial uses of waterfowl, shore birds, and other water-oriented wildlife, including their necessary food chain are supported.

One of the most significant findings was that submerged aquatic vegetation (SAV) in some of the same impoundments that tend to develop surface mats of macroalgae and / or duckweed, die-off prematurely just as fall migrant waterfowl arrive (Hoven & Miller 2009; Hoven 2009, Hoven 2010a). SAV is widely recognized as an important food source for many waterfowl as leafy vegetation, drupelets, seeds, tubers, and macroinvertebrates associated with the vegetation provide a variety of nutrients, protein, and fat (Chamberlain 1959; Anderson and Low 1976; Moore 1980; Kantrud 1990; Dennison et al. 1993; Winslow 2003). As such, the question is raised whether ample food is available for the waterfowl when SAV beds die-off prematurely.

STUDY LOCATION

Five impounded wetland sites were identified around or near Farmington and Bear River Bays of Great Salt Lake during the initial study in 2004 (Miller & Hoven 2007) to include nutrient enriched (target) and non-enriched (reference) sites (Figure 1). Ambassador Duck Club, New State Duck Club, and Farmington Bay Wildlife Management Area (FB WMA) all receive inflow from the Jordan River and outflow into a downstream duck club. New State Duck Club passes much of its water on to FB WMA or releases it directly to Farmington Bay. The Inland Sea Shorebird Reserve (ISSR) receives water from the Northpoint Consolidated Canal, a diversion from Jordan River. However, previous studies showed that salinity was more of a determining factor for SAV health than other water quality parameters (Hoven 2010a) and ISSR was discontinued as a primary site. Public Shooting Grounds (PSG), situated at the north end of the lake on Bear River Bay, was selected as a reference site . PSG receives its water from freshwater springs and some irrigation return flows. The Bear River Migratory Bird Refuge (BRBR) was added during 2008 to fill a data gap between nutrient enriched and reference conditions. The “upstream” impoundments (T1) of Ambassador Duck Club, New State Duck Club, Farmington Bay Wildlife Management Area, and the Public Shooting Grounds, as well as B2 of the Bear River Migratory Bird Refuge, were included in the 2010 study.

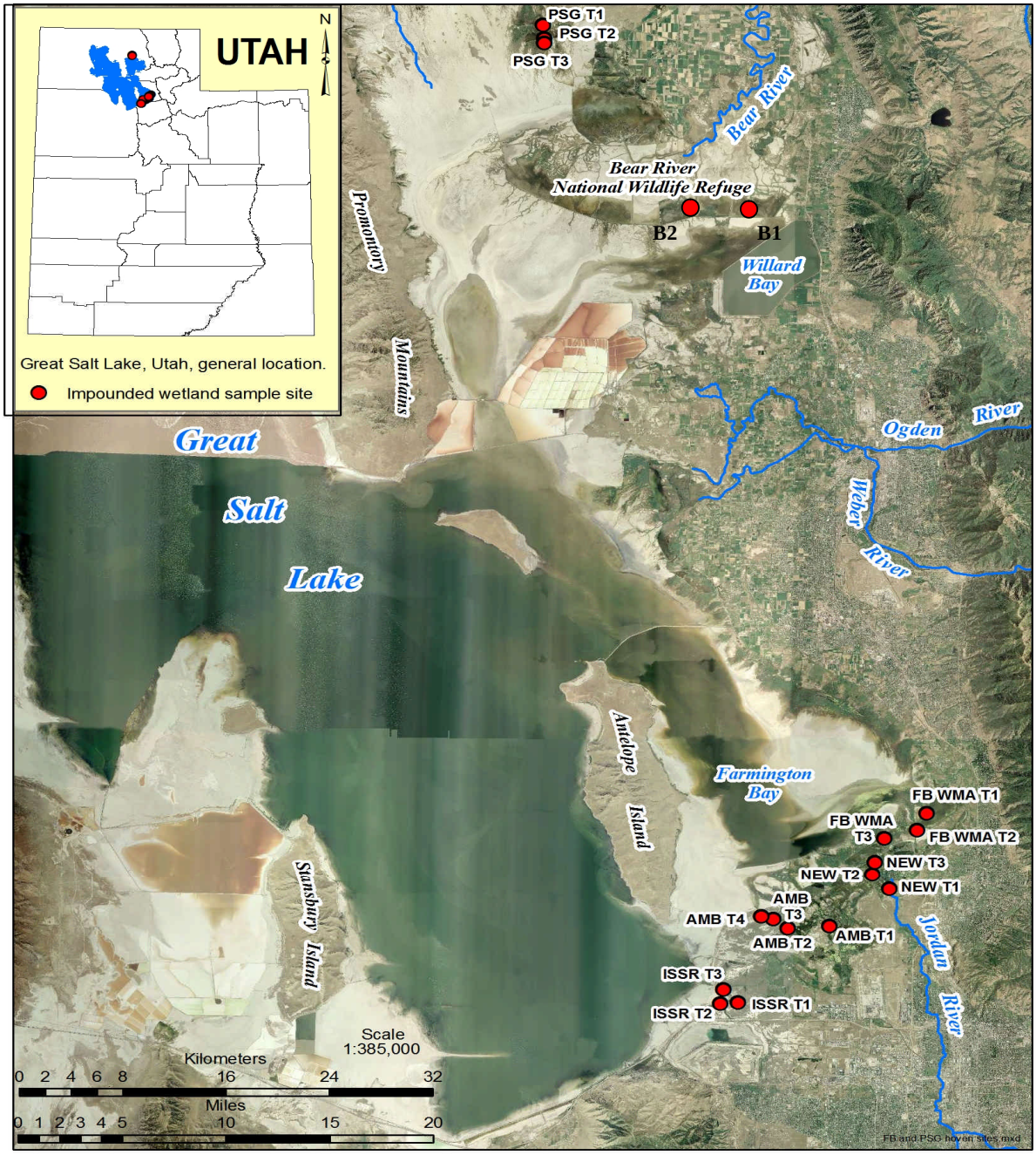


Figure 1.1 Eastern shore of Great Salt Lake, U.S.A. showing original impounded wetland sites of the study on beneficial use assessment of Farmington Bay wetlands. Reference sites are located at the PSG (Public Shooting Grounds) and nutrient-enriched sites are located at FB WMA (Farmington Bay Wildlife Management Area), NEW (New State Duck Club), AMB (Ambassador Duck Club), and ISSR (Inland Sea Shorebird Reserve, discontinued as a target site). Two additional sites along the D-line dyke of Bear River Migratory Bird Refuge (shown as Bear River National Wildlife Refuge, B) were added in 2008 to represent moderate water quality conditions. T with numerals or numerals alone indicate the transect numbers at each location.

The majority of impounded wetlands of this study have sago pondweed (*Stuckenia pectinata*) and western fineleaf pondweed (*S. filiformis* ssp. *occidentalis*) as the dominant SAV. *Stuckenia pectinata* and *S. filiformis* are known to hybridize (Hagstrom 1916; Dandy and Taylor 1946; Harrison 1949; as cited in Best and Boyd 2003) and so no attempt was made to differentiate between the two. Isolated impoundments can have *Ruppia cirrhosa* co-dominant with *Stuckenia* spp. Occasional coon's tail (*Ceratophyllum demersum*), horned pondweed (*Zannichellia palustris*) and curly pondweed (*Potamogeton crispus*) occur, as well (Hoven 2010a).

OBJECTIVES

The underlying objective was to further refine and identify plant metrics that best describe the condition of impounded wetlands and to provide direct linkage between biological response and beneficial use. Previously, a number of macrophyte (plant) metrics were identified as having good potential for assessing the condition of the wetlands (Hoven 2010a). These included: 1) various aspects of SAV areal cover that focus on the establishment and duration of SAV beds throughout the growing season; 2) the establishment and extent of surface mat cover; 3) epiphyte and / or biofilm abundance on SAV; 4) percent surface light and extinction coefficient k_d; 5) the ratio of variable to maximum fluorescence (Fv/Fm) and; 6) net photosynthesis rates (Pn). However, none of these metrics indicated clear relationships between wetland condition and water quality nor did they indicate direct linkage with beneficial use. In 2009, new plant metrics were developed that focused on a linkage with beneficial use: 1) SAV as a component of the waterfowl diet and 2) the capability of an impounded wetland to provide forage for waterfowl during the fall migration season (Hoven 2010b). These and several of the other vegetation-related metrics were also used to capture year-to-year natural variability among and within sites, in 2010. Additionally, emphasis was placed on a wider array of environmental parameters (e.g., surface water, sediment and pore water chemistry) to explore relationships between the plant metrics and the geochemistry of the impoundments.

2.0 METHODS

SAV & SURFACE MAT PERCENT AREAL COVER

Percent cover, species composition, and above ground biomass were determined after EPA Module 10. One square meter quadrats were established at 5 locations along a transect by laying two 2.0 m PVC poles 0.5 m apart and perpendicular to the transect line. Percent cover (to the nearest 1%) was determined by the same person at all sites, as visual areal estimates at mid-canopy of the total SAV and surface cover by macroalgae and / or duckweed. Poles were marked to show area designations (e.g., 1, 5, 10, 25, 30 %), a modification of the Daubenmire frame technique (Daubenmire 1959).

A qualified aquatic botanist recorded observations critical of the seral ecological stage of the SAV and associated biota. Species composition was determined using floristic keys (Prescott 1969, Welsh et al. 1993). Additionally, botanical sample vouchers were collected at each transect to verify plant identification and then discarded.

SAV DRUPELET AND TUBER BIOMASS

Biomass of drupelets and tubers were determined using a 10cm diameter PVC core. Ten biomass core sampling locations were randomly located along the transect and gently pushed

through the SAV canopy to rest on the surface sediment. Cores were moved slowly through the canopy in deep water to avoid pushing plants away. At the sediment – core interface, plant material falling outside of the core were cut with scissors until the core could be easily pushed into the sediment. The core was then pushed firmly through the sediment until the hardpan surface was reached. The core was sealed with a cap and rocked slowly back and forth to dislodge it from the sediment. Samples were rinsed in the field through a mesh-covered basket, most shells, rocks, and macroinvertebrates were discarded, samples were sealed in a pre-labeled plastic bag and returned to the lab. Biomass samples were then sorted by drupelets and tubers, dried for a minimum of 72 hrs at 34 ˚C and weighed.

LIGHT

Light attenuation through the water column and SAV canopy was determined using LI-COR LI-193 (LI-COR Biosciences, Lincoln, Nebraska) underwater spherical quantum sensor. Photon flux density was recorded at 1 cm below the water surface, at the average canopy of the SAV, approximately 3 cm under the canopy and under algal or duck weed surface mats. Recordings were taken on sunny days at three locations along the transects, and depth from surface was recorded for all 2008 measurements. Photon flux density was used to determine percent of surface light reaching the canopy, subcanopy and under the surface mats when present. Subcanopy measurements were taken 3 cm below the SAV canopy when SAV were present and just under the lower surface of the surface mat.

SURFACE WATER, SEDIMENT, AND PORE WATER CHEMISTRY

Surface water, sediment and pore water chemistry methods will be addressed in detail in the Final Report.

STATISTICAL ANALYSIS

We used 90% CIs to compare fluorescence variables. 90% CIs are comparable to statistical hypothesis testing p-value of about alpha = 0.05. If the CIs did not overlap, we concluded that there was strong evidence that they were significantly different. If there was some overlap in CIs and the mean value of one interval was outside of the range of the other variables interval then we suggest there were differences although not statistical given our dataset.

Ordination was used to explore multivariate relationships of ten plant metrics. For exploratory, visual analyses; ordination techniques are often superior for explaining relationships of assemblages and communities than hypothesis testing approaches (McCune and Grace 2002). In general, ordination is the ordering of objects along axes according to their similarities. The main objective of ordination is data reduction and expressing many-dimensional relationships into a small number of easily interpretable dimensions (axes). The strongest correlation structure in the data is extracted (using correlation in the broad sense) and is then used to position objects in ordination space. Objects close in the ordination space are generally more similar than objects distant in the ordination space (McCune and Mefford 2011).

Several types of ordination exist; non-metric multidimensional scaling (NMS) was used for this data. NMS has been shown to be robust for ordination of species composition (e.g., Kenkel and Orloci 1986, Ludwig and Reynolds 1988) and is often more useful than other ordination techniques because, among other things, it avoids the assumption of linear relationships among variables.

We explored several dozen non-metric multidimensional scaling (NMS) scenarios using different distance measures and numbers of axes and then compared these with randomized data Monte Carlo simulations. We then conducted a post hoc analysis of coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space. This provided estimates of the amount of variability in the data explained by each of the ordination axes. We used the computer program PC-Ord (McCune and Mefford 2011) for NMS ordination.

In addition to NMS ordination, we modeled the relationships between plant metrics and chemical surface water, sediment, and pore water variables. We utilized x-y scatterplots, Pearson correlations, and on selected relationships, linear regression.

Pearson correlation coefficients R, were based on log generalized transformations of all chemical variables and Tubers (g m^2), SAV Shoots (# branches m^2), and Drupelets (g m^2). In general, any correlation coefficients with p-values < 0.10 were considered significant and were included in this report. We chose a cut off of significance at 0.10 because of the large inherent variability of ecological relationships, limited number of data points, and the likelihood of non linear relationships. Sediment and pore water chemical and plant metric relationships were based on averaging monthly chemical data to facilitate compatibility.

X- y scatter plots were developed using raw chemical variable data and log generalized transformations of Tubers (g m^2), SAV Shoots (# branches m^2), and Drupelets (g m^2). Many of the x-y scatterplots suggested relationships that may have been other than linear or a power function of the linear relationship. We elected not to attempt to fit specific non linear functions to these relationships because of the limited number of samples, the narrow range of data values, and the gaps in the ranges of data values which would have resulted in over fit models with poor explanatory and predictive value. However, we expect that most of the relationships between plant metrics and chemical variables are power functions of linear relationships or hyperbolic in nature. With the accrual of more data, better models can be developed.

3.0 PLANT METRICS

AREAL EXTENT AS PERCENT SAV AND SAV BRANCH DENSITY

Percent cover and branch density of SAV had similar results among the impoundments and seasonally (Figures 3.1 and 3.2) and are similar to those found in previous years (Hoven and Miller 2009, Hoven 2009, Hoven 2010b). Public Shooting Grounds had the highest percent cover SAV and branch density consistently throughout the growing season (PN). Bear River Migratory Refuge also had high percent cover and density in the early season, but samples were discontinued due to water loss by mid-summer (B2). WD was discontinued due to low water as well. Ambassador (AM) developed a dense bed of SAV by mid-summer but declined by August (Figure 3.2). Farmington Bay Wildlife Management Area (F1 and F2) and New State (N47) all developed low percent cover and density of SAV and showed no improvement or decline by August. Declining trends were apparent before September when the majority of fall migrant waterfowl arrive to forage and rest before continuing their southern migration.

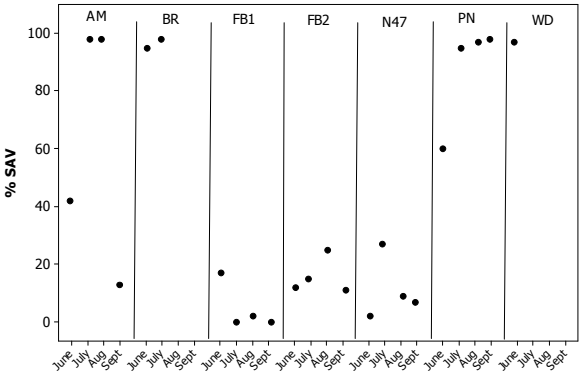


Figure 3.1. Mean (n = 5) percent cover of SAV at seven impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

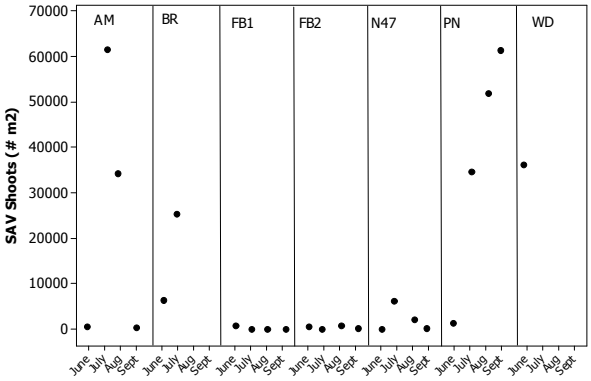


Figure 3.2. Mean (n = 5) density (as number of branches m2) of SAV at seven impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

Branch density provides a quantitative measure for what is observed and may be more sensitive to declining SAV trends before it becomes evident in the canopy as percent cover. Only FB1 and N47 reflect decline by August in the percent cover data whereas AM, FB1, FB2, and N47 all show decline by or before August in the density data. Recording a biological response prior to the arrival of migrant waterfowl that graze and potentially reduce the canopy structure is important. Here is a metric that provides such timing.

Branch density may also provide insight to the differences in SAV canopy structure at sites that are managed with deep water versus those managed as shallow ponds. SAV that grows in deep water tends to be long with more interstitial space between the leaves (e.g., B2, F2) than plants that grow densely in shallow impoundments (e.g., PSG). There may be implications for habitat niches for various macroinvertebrates provided by the SAV and its associated macroalgal and periphyton assemblages if water column depth and epiphyte abundance are incorporated into an SAV branch density metric (Tessier et al. 2004; Rennie & Jackson, 2005). As noted in Kantrud (1990), sago can host a diverse community of epiphytes, small plants and animals.

SURFACE MAT

Impoundments that developed surface mats were Ambassador (AM), FB WMA (F1 and F2) and New State (N47) (Figure 3.3). Surface mats at AM and N47 were primarily composed of *Lemna minor* (duckweed) (Appendix A, Figure A1), while those of F1 and F2 were composed primarily of macroalgae (Figure A2). One of the difficulties in using surface mats as a predictive biological response is that the algae-dominated mats tend to sink at some point during the summer. This point was illustrated during our July sampling period when percent cover of surface mat at F1 and F2 was reported at near 100 % (pers. comm. Hanson 2010) until a weekend storm knocked it into the water column. This weather event occurred 2 days before our sample event and no surface mat remained. The impoundments that developed surface mats are the same ones that have developed them in previous years (Hoven 2009, 2010a and b).

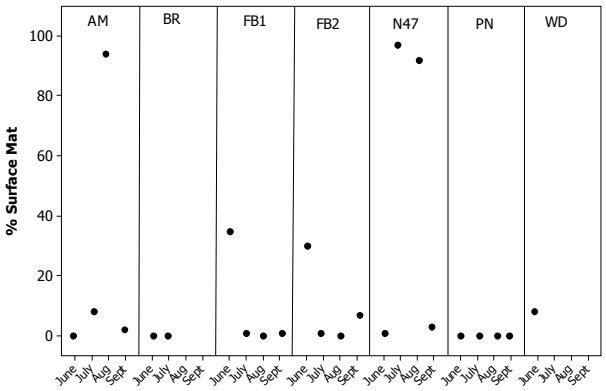


Figure 3.3. Mean (n = 5) percent cover of SAV at seven impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

PERCENT SURFACE LIGHT, SUBCANOPY

Percent surface light in the SAV subcanopy is the most informative location for measuring photosynthetically active radiation (PAR) available to the plants (Hoven 2010a). At this location, localized shading effects from surface mats are somewhat “softened” as scattered light levels are frequently higher within the canopy than that directly under the surface mat. Percent surface light in the SAV subcanopy is lowest in one of the most dense SAV beds that had no surface mat (PN) indicating self shading and that the SAV are tolerant of low light conditions. This point is particularly important in understanding the relevance of surface mats as a metric for impounded wetland condition. The original hypothesis that surface mats may cause shade stress that contributes to SAV die-off may be refuted here as the plants that do the best are also enduring highly shaded conditions. This relationship has been documented in the 2008 and 2009 data as well (Hoven 2009, 2010a and b).

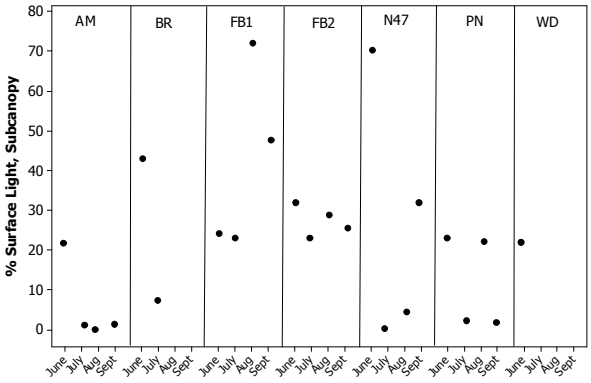


Figure 3.4. Mean (n = 5) percent surface light in the SAV subcanopy at seven impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

TUBER BIOMASS

SAV utilize two methods of reproduction, sexual and vegetative. Tubers are the underground vegetative reproductive structure that stores protein and carbohydrates as energy reserves (Anderson and Low 1976) and can over-winter to produce new shoots in the spring or during the same growing season (Kantrud 1990). SAV at Public Shooting Grounds increase tuber production during the mid-summer and reach the highest levels during the sampling period in September (Figure 3.5). No SAV from any other site compares to that of PN and those of FB1, FB2, and N47 are lowest by the time the waterfowl arrive in the fall, providing little food for foraging. High production of tubers at Public Shooting Grounds mirrored that of its branch density and although branch density is initially high at Ambassador, the subsequent decline in SAV rendered moderately low tuber biomass.

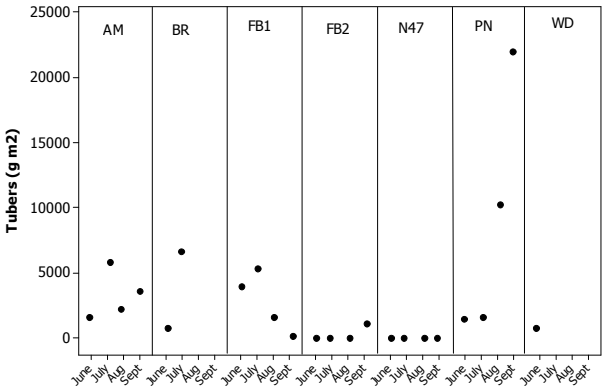


Figure 3.5. Mean (n = 5) tubers (g m2) of produced by SAV at seven impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

DRUPELET BIOMASS

Drupelets are the fruiting bodies that are produced by sexual reproduction of SAV. They are a highly prized food item by many herbivorous and omnivorous waterfowl due to high levels of fat compared to other parts of the plant (Anderson and Low 1976). SAV at Public Shooting Grounds produce the highest amount of drupelets, while those at Ambassador, Bear River Migratory Bird Refuge and New State produce the lowest (Figure 3.6). SAV at FB WMA produce moderately low levels of drupelets and are frequently less than half that recorded at Public Shooting Grounds.

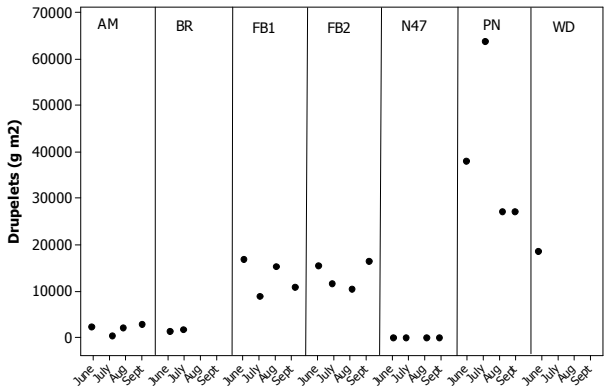


Figure 3.6. Mean (n = 5) drupelets (g m2) produced by SAV at seven impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

One potential complication is that there isn't a true reference condition for comparison in these highly managed impoundments. At our reference site, water is managed differently than that at the other sites. Alternating deep flooding on one side of the main dike during alternate years changes the hydrology, salinity and plant species distribution there. Stewart and Kantrud (1972) documented temporary changes in species composition during times of dilution where extensive beds of *P. pectinatus* and *Chara* spp. replaced *R. maritima* and vise versa during times of lower water and increased salinity. A similar shift has been documented during 2008, 2009 (Hoven 2010a and b; and 2010 (data not shown)). In our reference site, *Stuckenia* sp. maintains a moderate distribution with *R. cirrhosa* during low water years such as 2010, and although the salinity and possibly high temperature exposure caused *Stuckenia* sp. to senesce early, drupelet production was still higher than that at other impoundments.

Reference conditions at Public Shooting grounds contain the most productive SAV of all the sites in this study based on branch density, percent cover estimates, drupelet and tuber biomass. Conditions at FB WMA (Units 1 and 2) and Ambassador (Pond W1) are moderate to low and those at New State (Pond 47) are poor based on those same parameters.

CHLOROPHYLL FLUORESCENCE

Chlorophyll fluorescence of PSII has been widely used as diagnostic tool to assess plant response to ecophysiological stresses (Bolhàr-Nordenkampf et al. 1989, Baker 2008). During photosynthesis, the electronic configuration of the chlorophyll molecule reaches an excited state as it absorbs light energy. The excited state is quickly (typically < 10^{-8} sec) dissipated by a) photochemical processes (electron is donated to an acceptor molecule, which transfers the energy necessary for carbon fixation), and b) non-photochemical processes (energy is re-emitted in the form of heat and red/far-red radiation, known as chlorophyll fluorescence). Due to

competition between these processes for absorbed light energy, the means of dissipation are inversely related such that an increase in one (eg., by photochemical processes) will cause a decrease in the other (eg., non-photochemical processes) and vise versa. Measurement of changes in fluorescence emission can be used to infer information about changes in the efficiency of light use for photochemistry (Krause & Weis 1991; Baker 2008).

Fv/Fm, or photosynthtetic efficiency, is indicative of plant stress such that the greater the fluorescence per unit of light, the higher the photosynthetic efficiency. As a plant endures physiological stress, Fv/Fm decreases (Krause & Weis 1991; Baker 2008). Fv/Fm of terrestrial plants ranges from 0.75 – 0.85 (Bolhàr-Nordenkampf et al. 1989) and the accepted average is 0.83 (Björkman & Demmig 1987). Fv/Fm of some SAV has been analyzed for its utility as a diagnostic tool and ranges from 0.71 (*Z. marina*, Hoven 1998), to 0.73 (*Halophila ovalis*, Ralph & Burchett 1995), to 0.77 (*R. cirrhosa* and *Zostera capensis*, Adams & Bate 1994).

Using Fv/Fm as a condition assessment metric for impounded wetlands that are managed to grow SAV is still in the development stage; however, there are some interesting points worth noting. *Stuckenia* was only available during August at the Public Shooting Grounds and was not bright green. There was minimal water coverage at that time and most of the *Stuckenia* was showing signs of premature senescence. By September, presumably due to exposure to high light and / or temperature and increased salinity levels outside of its tolerance range, all the *Stuckenia* was bleached out and no green leaf tissue was found. This response has been observed elsewhere for the same reasons (Kantrud 1990). Thus, measurements derived from PSG *Stuckenia* may only represent plants growing in sub-optimal, stressed condition and may not be a suitable reference for comparison with data from SAV at other sites during 2010 (Figure 3.7).

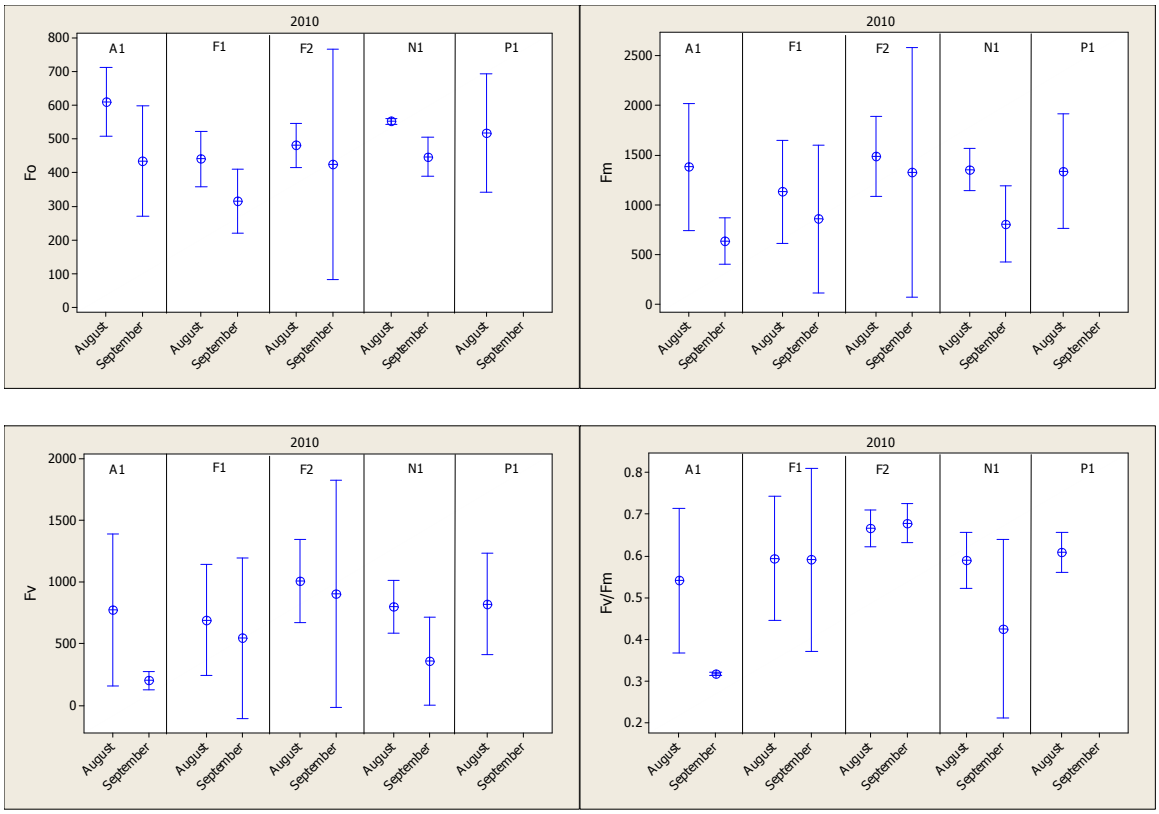


Figure 3.7 Characterization of chlorophyll fluorescence of Stuckenia sp. at five impounded wetlands of Great Salt Lake (mean ± 95% CI, n = 3). Fo = the initial rise in fluorescence, Fm = maximum fluorescence, Fv = variable fluorescence, and Fv/Fm = the ratio of Fv to Fm. A1 = Ambassador W1, F1 = FB WMA Unit 1, F2 = FB WMA Unit 2, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond outlet.

There were a few significant differences (non overlap of CIs) within and among sites for some chlorophyll fluorescence variables for *Stuckenia*: Fo of F1 was lower than Fo at N1 during September; Fo of N1 was lower during September than during August; Fv/Fm of A1 was lower during September than during August; Fv/Fm of A1 was also lower than Fv/Fm of F1 and F2 during September. Fv/Fm was very low in SAV from A1 and N1 during September.

Although most 90% CIs overlapped, there is an obvious downward trend in fluorescence variables from August and September (Figure 3.7). Most CIs had wide intervals due to the variability in the data. The large variability was probably due to low sample size (n = 3), different condition of individual plants within sites, and possibly due to a lack of good reference material. There were often new shoots coming in later in the season after many had died making it difficult to get true replicates of same aged plants. It also is important to note that there were no early season data of young, healthy plants, which would provide a necessary benchmark for comparisons with plants enduring stress.

While maximum plant biomass was found to be most sensitive to change in photosynthetic activity at light saturation but not to change in light use efficiency (Best & Boyd 2003), our data suggest otherwise. Additional work will be necessary to establish averages for these measures, but the physiological implications are that SAV is enduring stress at A1, F1 and N1 and succumbing to it by September.

EXPLORING RELATIONSHIPS AMONG PLANT METRICS AND STUDY SITES USING NMS ORDINATION

Our best NMS model had a 2-dimensional solution using a Sorenson's distance measure. This model resulted in a final stress of 8.97 and final instability of 0.00 at 60 iterations. McCune and Grace (2002) suggested that most ecological assemblage data sets will have NMS solutions with stress between 10 and 20 and that values in the lower half of this range are quite satisfactory. Final stress between 5 and 10 is considered to be "a good ordination with no real risk of drawing false inferences" [Clarke's (1993) "rules of thumb" for NMS in McCune and Grace (2002)]. Appendix B contains the rational for our choice in a 2-dimensional model. Our post hoc analysis of coefficients of determination gave an R^2 of 0.81 for Axis 1 and 0.14 for Axis 2. Both axes cumulatively explained 0.95 of the variability in plant communities using the ten plant metrics (N = 23 samples). Figures 3.8 and 3.9 show the relationship of the plant communities in the seven impoundments based on the ten plant metrics in 2010.

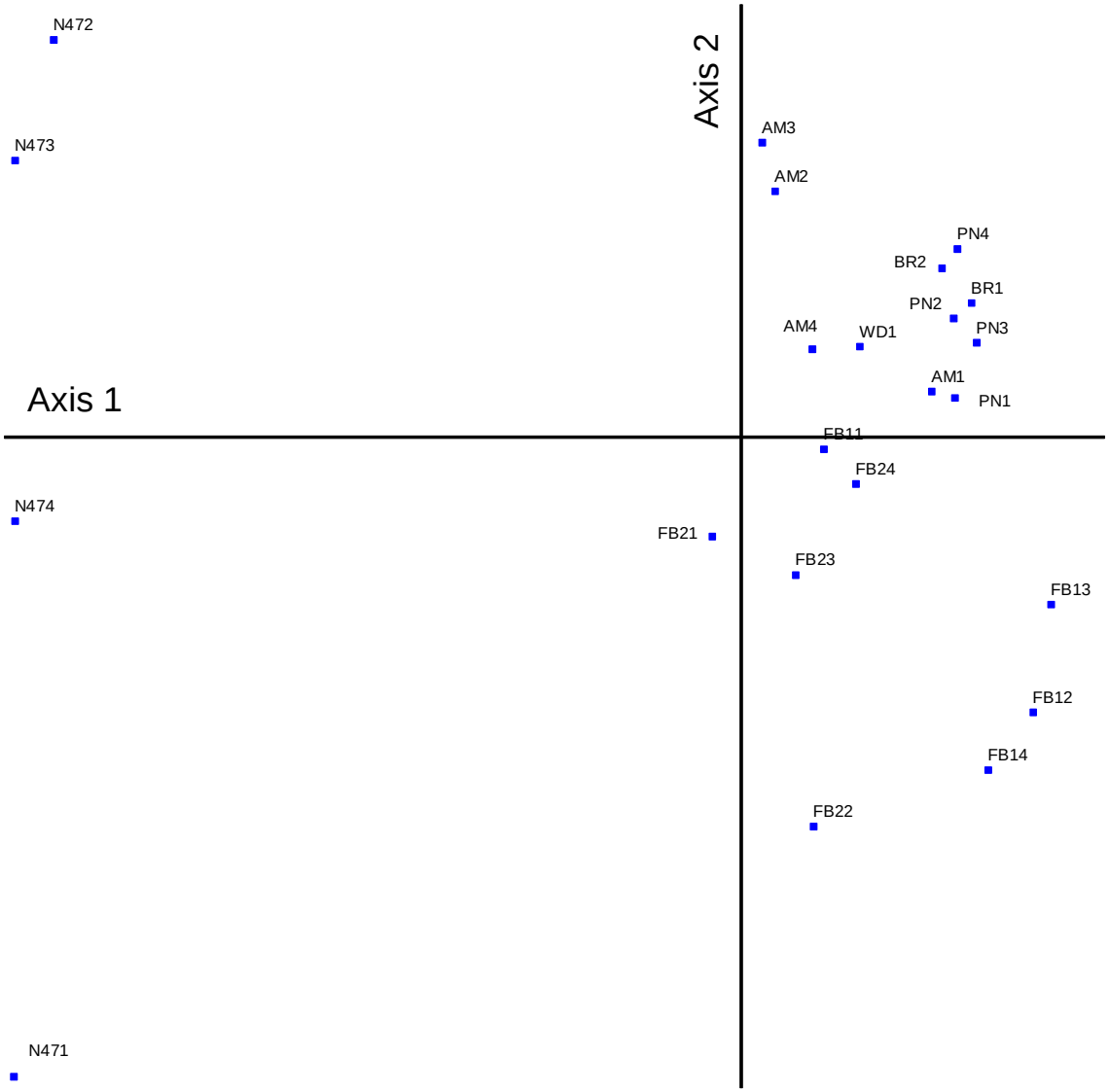


Figure 3.8. NMS ordination Axes 1 and 2 of plant communities by site during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 1 – 4 placed at the end of the site codes indicate sample months June, July, August, and September, respectively.

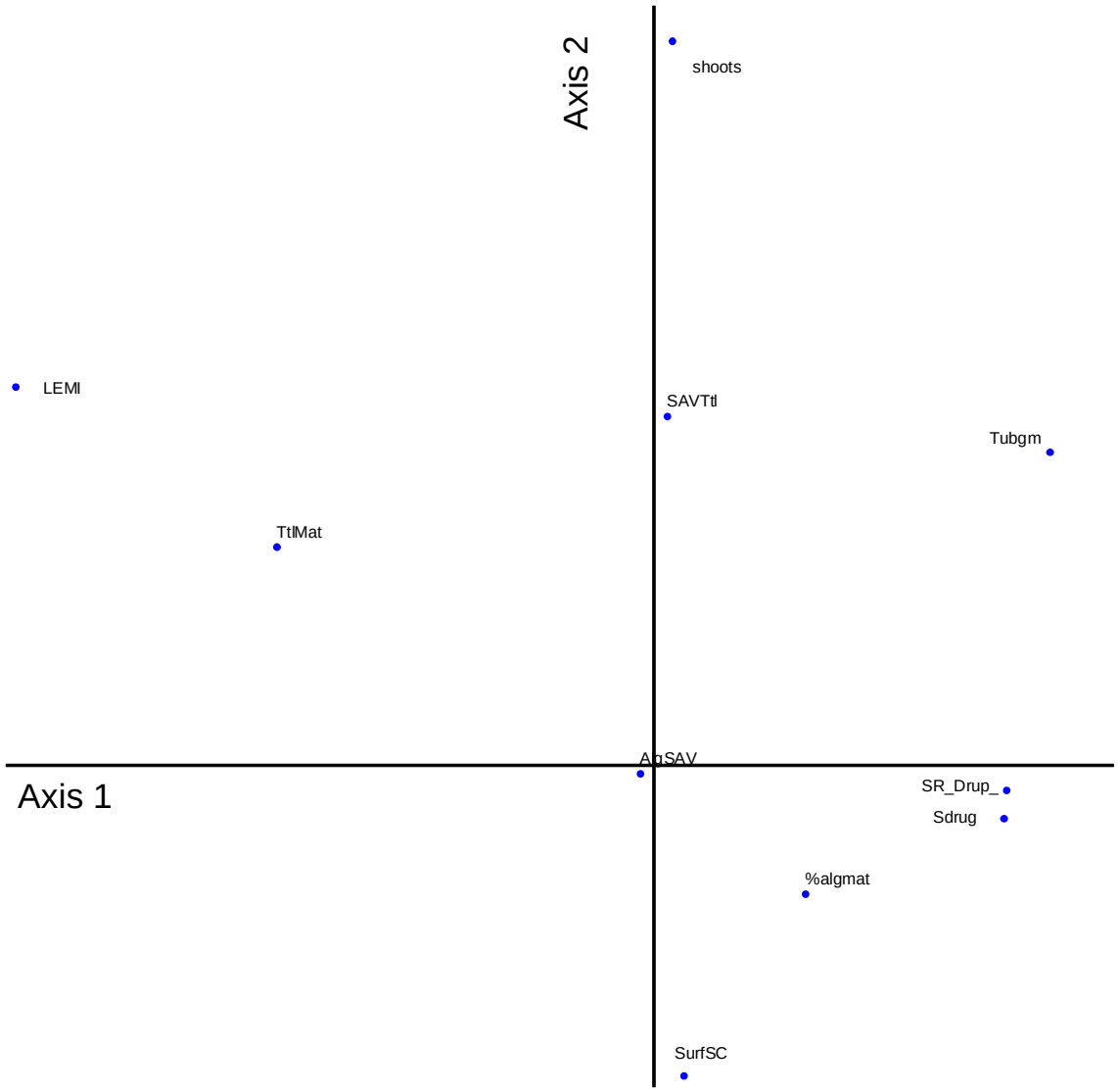


Figure 3.9. NMS ordination of plant metric community during 2010. LEMI = percent duckweed in the surface mat, %algmat = percent macroalgae in the surface mat, Ttlmat = total surface mat (including both LEMI and macroalgae), AlgSAV = epiphytes on SAV, shoots = SAV density (# branches m^2), SAVTtl = total percent cover SAV (*Stuckenia* and *Ruppia* combined), SurfSC = percent surface light in the subcanopy, Tubgm = tubers (g m^2), SRDrup = *Stuckenia* and *Ruppia* drupelets combined (g m^2), and Sdrug = *Stuckenia* drupelets alone (g m^2).

While these ordinations do not show causal effect, they are useful in accentuating the similarities and dissimilarities among metrics and sites that were measured. Figure 3.8 shows a major delineation between New State (N47) and the rest of the sites along Axis 1. Secondary differences (Axis 2, explaining 14% of the variability) lie between Ambassador (AM), Bear River Migratory Bird Refuge (BR), Public Shooting Grounds (PN and WD) and FB WMA (FB). It also shows that N47 June was different than N47 July and August but less so than in September,

perhaps due environmental stressor(s) affecting the phenological stages of sago pondweed there.

The ordination in Figure 3.9 indicates that our metrics have very little covariation or redundancy, with the exception of SRDrup (*Stuckenia* and *Ruppia* drupelets combined) and Sdrug (*Stuckenia* drupelets alone). Figure 3.9 collectively depicts relationships between the plant metric community. For instance, surface mats are typically dominated by duckweed (LEMI) or macroalgae (%algmat), aligned on opposing sides of Axis 1. During 2010, total surface mat (Ttlmat) was primarily dominated by duckweed and was closely associated with LEMI. Epiphytes on SAV (a categorical variable, AlgSAV) showed no influence with respect to either axis. SAV branch density (shoots) and percent cover (SAVTtl) showed an inverse relationship with percent surface light in the subcanopy (SurfSC) such that the higher the density, the lower the transmittance of light. Interestingly, tubers (Tubgm) and drupelets (SR_Drup, SDrug) showed an inverse relationship with duckweed surface mats. Sexual reproduction has been shown to be limited by insufficient light (Haag 1983), which could explain the inverse relationship between LEMI and drupelets but Hagg (1983) also demonstrated that drupelet production was frequently limited by lack of nutrients. It is difficult to make an ecological explanation of the relationship between the LEMI surface mat and tuber production using the metrics included in the ordination, which illustrates the point that other environmental relationships may be involved.

Johnson et al. (2011) used the same technique to ordinate surface and pore water chemistry and found similar associations among the same sites in the pore water ordination axes 1 and 2 (Appendix C1, this report). Ordination of the surface water is also similar to the ordination of sites with respect to plant variables except for Ambassador (AM, Appendix C2). An inference may be made that differences and similarities among sites may be closely associated with geochemical processes that may ultimately be driving differences in biological responses. To investigate the likelihood of potential chemical – biological response relationships, we modeled the relationships between plant metrics and chemical surface water, sediment, and pore water variables.

4.0 PLANT AND SURFACE WATER, SEDIMENT AND PORE WATER CORRELATIONS

PLANT METRICS AND SURFACE WATER

A Pearson correlations matrix between plant metrics and surface water chemistry is presented in Appendix D1. Correlation coefficients with p-values < 0.10 were considered significant. X-y scatterplots were prepared to explore the significant relationships among the study sites. There was a positive relationship between Nitrate (NO_3 mg L^{-1}), phosphate (HPO_4 mg L^{-1}) and percent surface mat (Figure 4.1, $R^2 = 0.48$, p-value < 0.05; and $R^2 = 0.18$, p-value < 0.05, respectively). Of particular pertinence here is that FB12 and FB22 (FB WMA Units 1 and 2 during July) had surface mats of nearly 100% cover a few days before the sample date as mentioned above. Those data may have weakened the relationship for NO_3 and strengthened the relationship for HPO_4 had the timing of sampling been different.

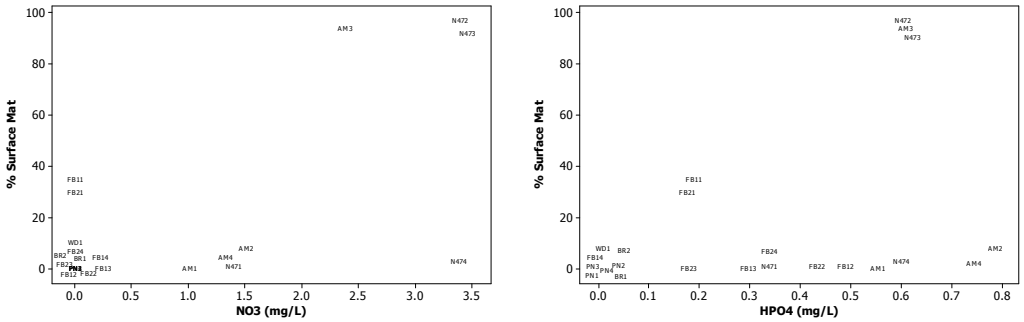


Figure 4.1. Percent surface mat versus surface water nitrate (NO_3 mg L^{-1}) and phosphate (HPO_4 mg L^{-1}) during 2010, (R^2 = 0.48, p-value < 0.05; and R^2 = 0.18, p-value < 0.05, respectively). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 1 – 4 placed at the end of the site codes indicate sample months June, July, August, and September, respectively.

Surface mats from the same impoundments that had positive correlations with surface water NO_3 and HPO_4 (N47 and AM) also had positive relationships with Se (Figure 4.2, R^2 = 0.34, p-value < 0.05). This suggests that factors other than NO_3 and HPO_4 may be involved in stimulating duckweed growth since AM and N47 are where LEMI is the dominant component of the surface mat from year to year (e.g., Appendix A1).

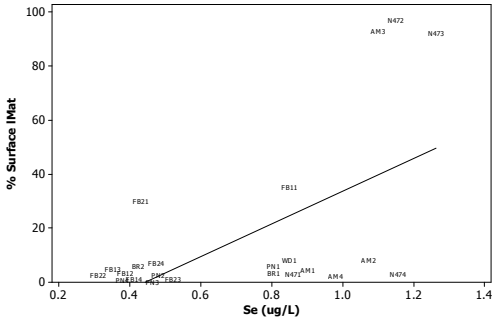


Figure 4.2. Percent surface mat versus surface water Se (µg L^{-1}) during 2010, (R^2 = 0.34, p-value < 0.05). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 1 – 4 placed at the end of the site codes indicate sample months June, July, August, and September, respectively.

Sago pondweed productivity is shown to have a strong relationship with high water column phosphate (Jones & Cullimore 1973; Jupp & Spence 1977; Anderson 1978; Pip 1978; Collins et al. 1987), yet SAV percent cover in our sites (which were mostly dominated by sago pondweed) showed a slight negative relationship with water column phosphate (Figure 4.3). Although percent cover is a surrogate for productivity, highly productive SAV at PSG may not be dependent on surface water phosphate, although water column P can precipitate out in systems that are high in $CaCO_3$ (such as at PSG) and still have high productivity of SAV as noted in Kantrud (1990).

Both emergent and submergent vegetation can derive all of their nitrogen and phosphorous requirements from sediments (Thiebaut and Muller 2003, Carr and Chambers 1998, Madsen and Adams 1988, Carignan and Kalff 1980). Carignan and Kalff (1980) reported that nine common species of aquatic macrophytes, including *S. pectinata*, obtained all of their phosphorus from the sediments when grown *in situ* in both mesotrophic and mildly eutrophic conditions. Although we

do not have sediment nutrient data from 2010, the negative relationship with water column phosphate in our study may suggest that some other factors are to be considered relative to SAV productivity across sites assuming water column and sediment nutrients are highly correlated. This assumption is based on the finding that nutrients mobilized from the sediment by plants are released in dissolved form as each shoot senesces and contribute to the water column nutrient pool (see review by Adams & Prentki 1982).

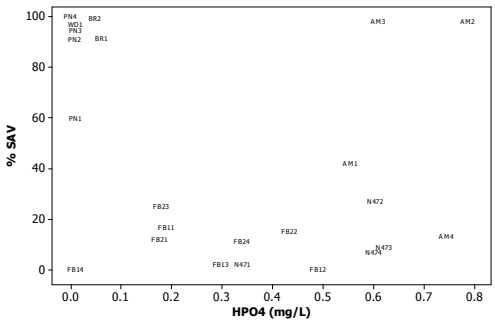
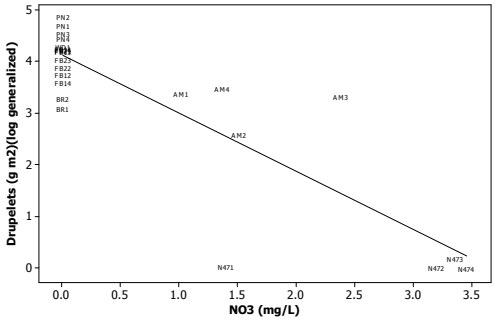
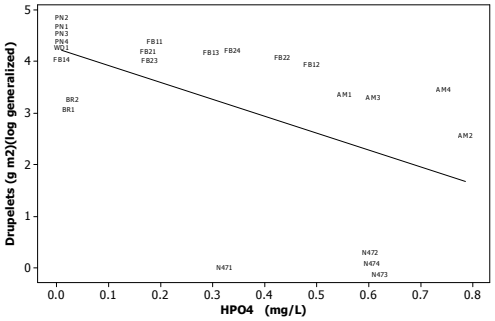


Figure 4.3. Percent SAV versus surface water phosphate (HPO_4 mg L^{-1}) during 2010, (R^2 = -0.12, p-value < 0.05). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 1 – 4 placed at the end of the site codes indicate sample months June, July, August, and September, respectively.

Relationships between drupelet biomass and nutrients (Figure 4.4) is counter to that observed by Hagg (1983), who noted that sexual reproduction was often limited by lack of water column nutrients. He also noted that insufficient light limited drupelet production but in our study, there was no correlation with percent surface light (r = -0.03, p-value = 0.90). Significant inverse relationships between drupelet biomass and nitrate and phosphate explained 76% and 30% of the variability, respectively; while surface water Se and Pb explained 38% and 18% of the variability, respectively.





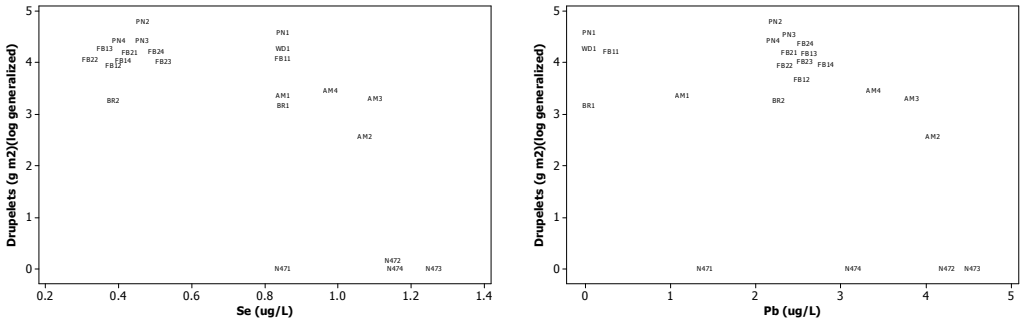


Figure 4.4 SAV drupelets (g m2) (log generalized) versus surface water NO_3 (mg L^{-1}), HPO_4 (mg L^{-1}), Se (µg L^{-1}), and Pb (µg L^{-1}) during 2010, (R^2 = -0.76, p-value <0.05; R^2 = -0.30, p-value < 0.05; R^2 = -0.38, p-value = < 0.01; and R^2 = -0.18, p-value < 0.05, respectively). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 1 – 4 placed at the end of the site codes indicate sample months June, July, August, and September, respectively.

PLANT METRICS AND SEDIMENT

A Pearson correlations matrix between plant metrics and surface water chemistry is presented in Appendix D2. Correlation coefficients with p-values < 0.10 were considered significant. X-y scatterplots were prepared to explore the significant relationships among the study sites. Significant negative correlations were observed between sediment THg, MeHg, Fe, Cr, and percent cover SAV (Figure 4.5; R^2 = -0.37, p-value < 0.05; R^2 = -0.26, p-value < 0.05; R^2 = -0.30, p-value < 0.05; R^2 = -0.41, p-value < 0.05, respectively).

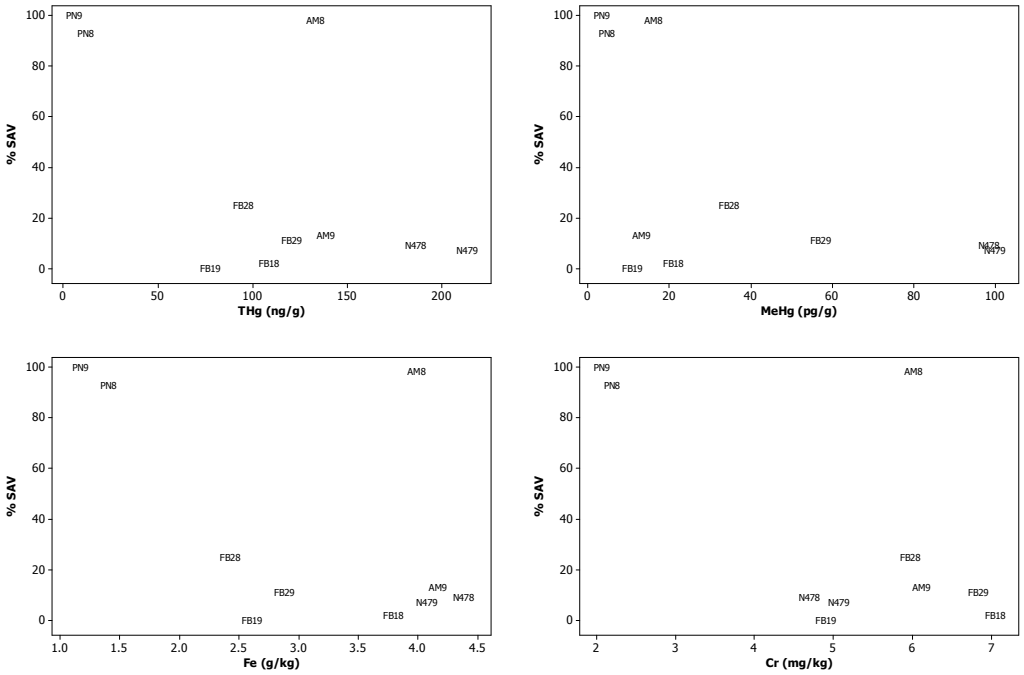


Figure 4.5. Percent SAV versus THg (ng g^{-1}), MeHg (pg g^{-1}), Fe (g kg^{-1}), and Cr (mg kg^{-1}) during 2010, (R^2 = -0.37, p-value < 0.05; R^2 = -0.26, p-value < 0.05; R^2 = -0.30, p-value < 0.05; R^2 = -0.41, p-value < 0.05, respectively). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1

and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 8 and 9 placed at the end of the site codes indicate sample months August, and September, respectively.

Total Hg, MeMg and Pb also had strong negative correlations with SAV tubers (g m^2)(log generalized) (Figure 4.6; R^2 = -0.44, p-value < 0.05; R^2 = -0.61, p-value < 0.05; and R^2 = -0.45, p-value < 0.05, respectively). Elevated levels of MeHg and Pb were found in N47 sediments, which had the lowest tuber production.

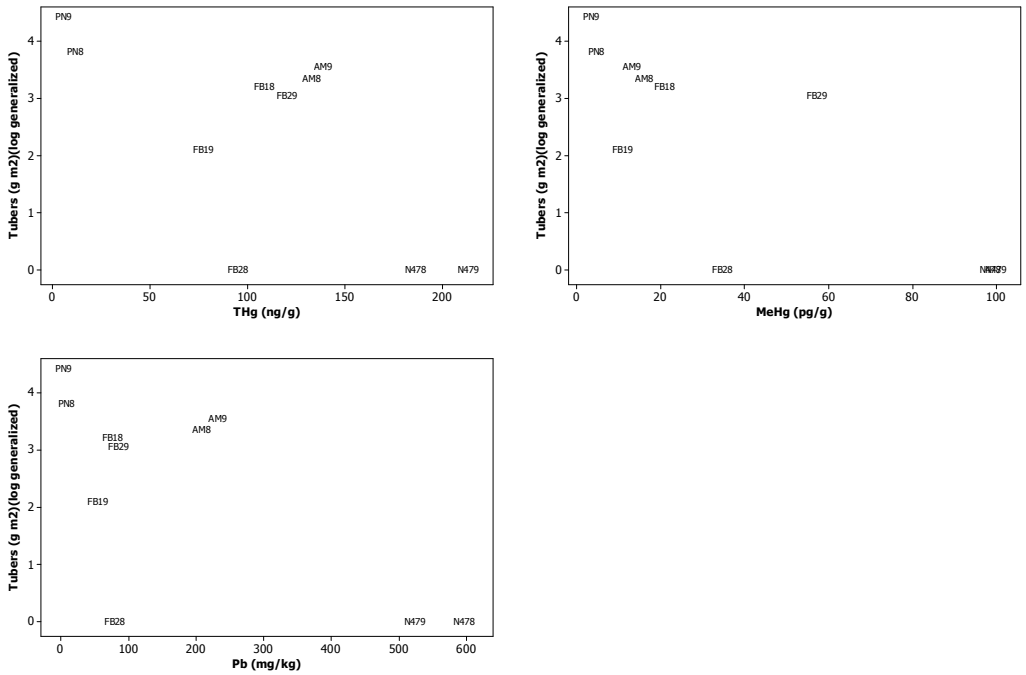


Figure 4.6. SAV tubers (g m2)(log generalized) versus THg (ng g^{-1}), MeHg (pg g^{-1}), and Pb (mg kg^{-1}) during 2010, (R^2 = -0.44, p-value < 0.05; R^2 = -0.61, p-value < 0.05; and R^2 = -0.45, p-value < 0.05, respectively). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 8 and 9 placed at the end of the site codes indicate sample months August, and September, respectively.

Strong negative correlations were also observed with THg, MeHg, Fe, Cu, Zn, Ag, Sb, Pb and drupelets (g m^2)(log generalized) (Figure 4.7; R^2 = -0.67, p-value < 0.05; R^2 = -0.77, p-value < 0.05; R^2 = -0.42, p-value < 0.05; R^2 = -0.49, p-value < 0.05; R^2 = -0.56, p-value < 0.05; R^2 = -0.41, p-value < 0.05; R^2 = -0.71, p-value < 0.05; and R^2 = -0.96, p-value < 0.05, respectively). At the highest levels of sediment Cu, Zn, and Ag, moderately low drupelet productivity was observed at Ambassador (AM8 and AM9), while very low drupelet productivity was observed at New State, which may be indicating that several factors were contributing to the low productivity at N47 rather than one factor alone. On an individual metal basis, MeHg and Pb explained 77% and 96%, respectively, of the variability among sites for drupelet production with N47 having the lowest drupelet biomass.

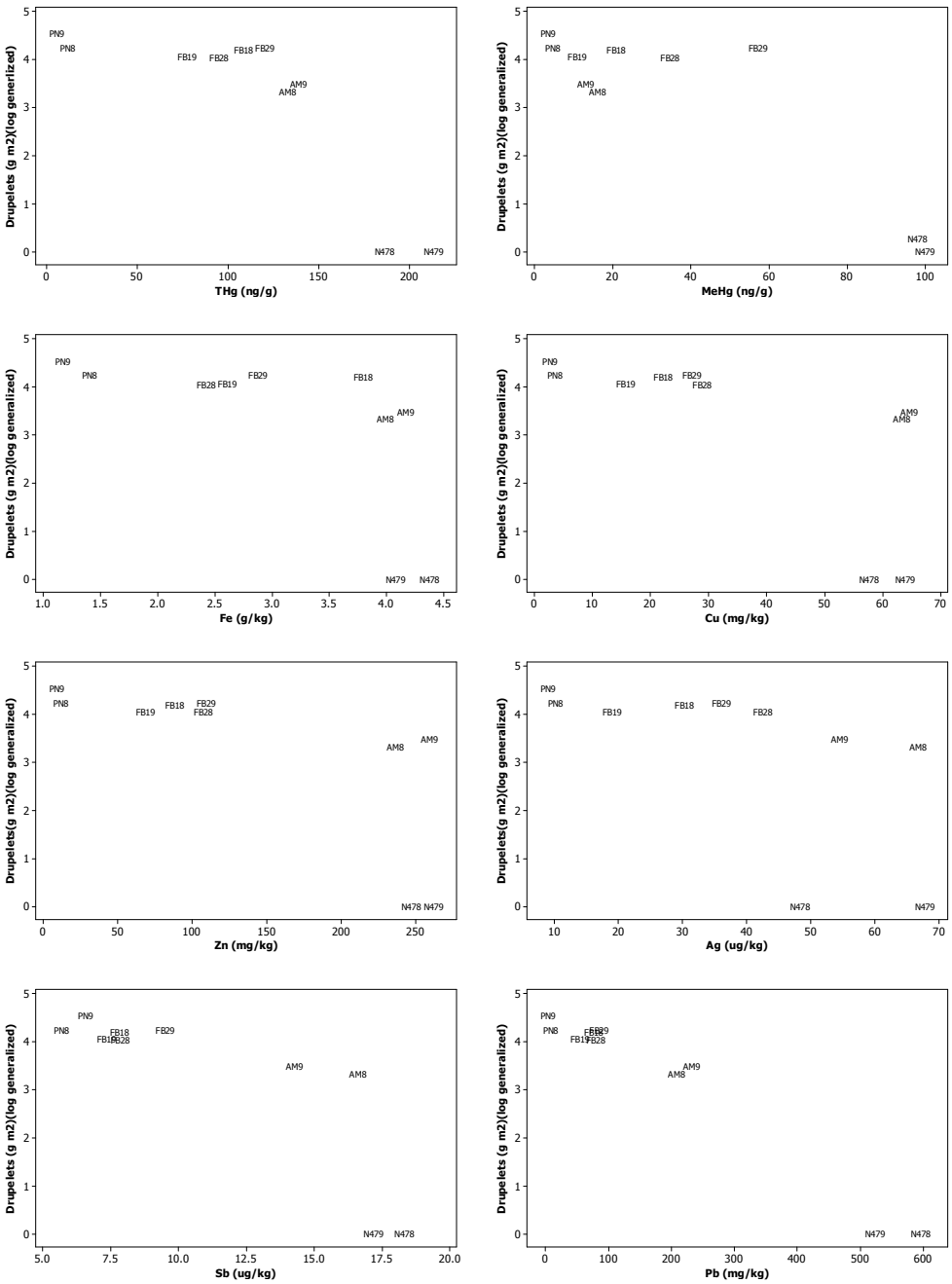


Figure 4.7. Drupelets (g m^2)(log generalized) versus THg (ng g^{-1}), MeHg (pg g^{-1}), Fe (g kg^{-1}), Cu (mg kg^{-1}), Zn (mg kg^{-1}), Ag (ug kg^{-1}), Sb (ug kg^{-1}) and Pb (mg kg^{-1}) during 2010, (R^2 = -0.67, p-value < 0.05; R^2 = -0.77, p-value < 0.05; R^2 = -0.42, p-value < 0.05; R^2 = -0.49, p-value < 0.05; R^2 = -0.56, p-value < 0.05; R^2 = -0.41, p-value < 0.05; R^2 = -0.71, p-value < 0.05; and R^2 = -0.96, p-value < 0.05, respectively). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 8 and 9 placed at the end of the site codes indicate sample months August, and September, respectively.

Although sulfur-metalloid and other metalloid complexes tend to be very insoluble and not available for uptake by plant roots via absorption, certain biophysical processes can alter localized reducing conditions that free up metals for uptake by the plants. Anoxic sediments can become locally oxidized after the physical disturbance from storm activity and bioturbation, which is the disruption of sediment by feeding or burrowing activity of benthic organisms and fish. Exposure of reduced sediments via bioturbation breaks down metal sulfides into oxidized sulfate forms and releases free metal ions that will form bonds with organic ligands, organic materials, cation exchange sites on clays, and plant roots at uptake sites.

Another biophysical process that alters reducing conditions in the sediment occurs within the rhizosphere (root zone) of aquatic macrophytes. Nonsoluble metalloids (e.g., those bound with sulfide) are potentially available for uptake by plants since the rhizosphere is know to locally change reducing conditions of the sediment as oxygen is transported through gas exchange or diffusion out of the roots (Armstrong 1971; Armstrong & Wright 1975) and take up available metals (e.g., Lyngby & Brix 1982, 1987; Dunbabin et al. 1988; Williams et al.1994; Hoven 1998). Bonds in sulfide-metal complexes are briefly broken as roots come into contact with new sediment (via expansion and growth) and metals that are released become momentarily available for uptake.

METALS AND SAV

Wood (1974) categorized major metals and anthropogenic trace metals by their pollution potential as follows: a) non-critical (Fe, Rb, Sr, Al); b) toxic but very insoluble or rare (Ti, Hf, W, Zr, Ta, Nb, Re, Ga, La, Rh, Ir, Ba); and c) very toxic and relatively accessible (Be, Co, Ni, Cu, Zn, Sn, As, Se, Te, Pd, Ag, Cd, Pt, Au, Hg, Tl, Pb, Sb, Bi). Aquatic macrophytes have been well documented to take up, and in some cases concentrate, anthropogenic trace metals. However, it is not realistic to extrapolate responses and mechanisms of one species to other species because sediment and water conditions vary amongst sites and regions and individual species have different tolerances, uptake rates and storage sites (Guilizzoni 1991). Some of the physiological responses of SAV to anthropogenic trace metals include reduced photosynthesis, shoot length and weight in response to Cr (Guilizzoni 1991), and growth inhibition in response to Cu, Hg, Cd, Zn, Cr, Pb (Lyngby & Brix 1984).

Påhlsson (1989) described the following general plant toxicities of various elements. Zn is a micronutrient and plays an important role in protein synthesis (e.g., carbohydrates, nucleic acid and lipid metabolism) but excessive Zn can be toxic resulting in reduced shoot and root growth, chlorosis, and epidermis of roots becomes lignified. Copper is also an essential micronutrient as it is a component of several enzymes involved in carbohydrate, nitrogen and cell wall metabolism; it is also important in seed production, disease resistance, and water relations. Copper toxicity may results in small chlorotic leaves, early leaf fall, growth, stunted growth, initiation of root and toot lateral development are poor, which may lead to poor nutrient uptake. Cadmium is chemically similar to Zn and readily taken up by plants. There is a strong affinity of Cd ions for sulfhydroxyl groups of several compounds and phosphate groups in plant metabolism, which may explain its high toxicity. Cd toxicity results in stunted growth, small leaves, curled chlorotic leaves, red-brown coloration in leaf margins and veins. Photosynthesis and transpiration are also inhibited by Cd. Toxicity effects from Pb (but not specific to Pb) are smaller leaves, stunted growth, chlorotic leaves, leaves reddish and necrotic, roots blackened, decreased photosynthesis and respiration rates, decreased activity of several enzymes important to photosynthesis and nitrogen metabolism, and enhanced senescence. Although Fe is an essential micronutrient important to

chlorophyll synthesis, cytochromes, and nitrogenase function, Van Wijck et al. (1992) reported negative effects of elevated Fe in interstitial water on growth and biomass of sago pondweed.

PLANT METRICS AND PORE WATER

Although total concentration does not indicate availability and level of toxicity to plants and other organisms (Guilizzoni 1991), it was thought that pore water chemistry would have strong correlations with the plant metrics as it might reflect metal availability. Nonetheless, pore water correlations were generally less strong than those with sediment chemicals except Mn and Fe versus Drupelets (g m2)(log generalized) (Appendix D3; $r = -0.63$, p-value < 0.01; and $r = -0.93$, p-value < 0.01, respectively). Johnson et al. (2011) hypothesize that metals may be forming insoluble complexes with sulfide or other elements thereby removing them from pore water. Sulfur plays an important role in trace metal redox behavior (Reddy & DeLaune 2008) and these data imply that complexation likely occurs readily and that the site of uptake of metals by plants is where root cells actually contact the sediment.

While all sites except New State Pond 47 were sulfate-reducing, negative correlation with pore water sulfide and SAV metrics was not indicated. The same was true for surface water. Although there was no indication of negative correlation between sediment organic content, sediment sulfide content was not determined and will be an important factor to determine during future research. Sulfide is one of the most phytotoxic metabolites to estuarine and marine SAV (Van Wijck et al. 1992). While methanogenesis is more important in freshwater systems, sulfate becomes more available with increasing salinity. In nutrient enriched systems where light availability is reduced, photosynthetic rates are subsequently reduced and SAV are less able to oxygenate the rhizoshpere to ward off toxic effects from sulfide as reviewed by Koch (1992). Van Wijck et al. (1992) identified declining trends in *Potomogeton pectinatus* (*S. pectinata*) in sediments that ranged from 0.48 – 1.27 mg g^{-1} sulfide.

5.0 PLANT METRICS REFINEMENT

PERCENT SURFACE MAT

The utility of percent surface mat as a predictor of wetland condition should be revisited as we now have more robust data. Regression analysis of multiple years of data (2008 – 2010) of reduction of light transmittance within the SAV subcanopy by surface mats explains only 12% of the variability (Figure 5.1). Further, the relationship between percent cover SAV and percent cover surface mat (previously hypothesized as inverse due to shading effects, Hoven 2009) only explained 6% of the variability when 2008 – 2010 data were combined (Figure 5.2a). Inspection of light transmittance in the subcanopy reveals why surface mat cover is not a useful and predictive tool for the condition (as percent cover) of the underlying SAV.

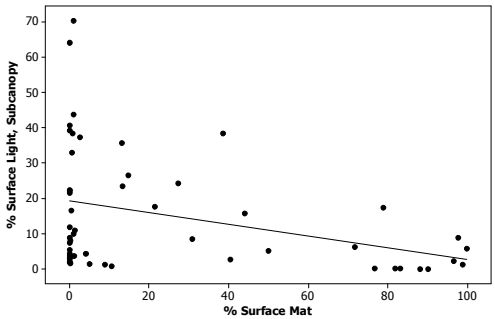


Figure 5.1. Percent surface light in the SAV subcanopy versus percent surface mat (R^2 = 0.12, p-value = 0.01), 2008 - 2010.

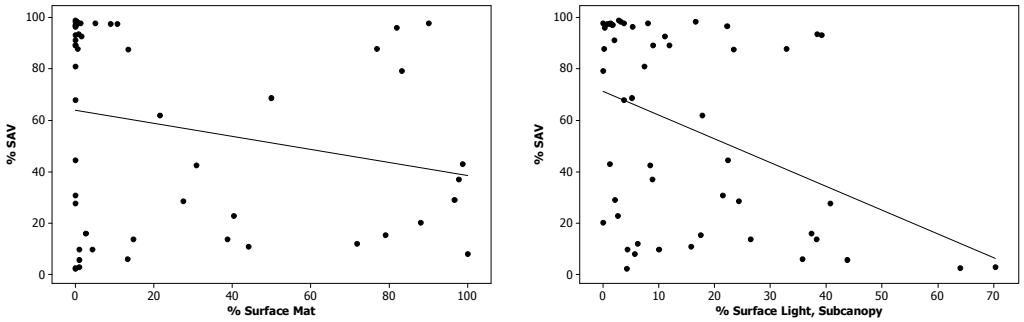


Figure 5.2. Percent SAV versus a) percent surface mat (R^2 = 0.06, p-value = 0.09); and b) percent SAV (R^2 = 0.17, p-value < 0.01), during 2008 – 2010.

While 17% of the variability in percent cover of SAV was explained by light transmittance within the SAV subcanopy (Figure 5.2b), it was an inverse relationship such that impoundments with the highest percent cover of SAV had decreased transmittance of surface light. That is, SAV in these impoundments are shade tolerant and are able to develop moderate to high percent cover when self-shading or shading from epiphytes and surface mats limit surface light transmittance and other environmental conditions are more or less favorable. Some of the highest percent cover SAV (near 100%) had less than 5% surface light in the subcanopy. This relationship was not a factor of depth of measurement (R^2 = < 0.01, p-value = 0.764). Certainly some SAV developed low percent cover and had low percent surface light, but some of the lowest percent cover SAV had the highest transmittance of surface light. This relationship was further supported in that 40% of the variability in percent surface light in the subcanopy was explained by the density of SAV shoots (as # branches m^2) (Figure 5.3, R^2 = 0.40, p-value < 0.01). Tomasko & Dawes (1989) demonstrated physiological integration in another clonal SAV where shaded clones connected to non-shaded shoots were ameliorated of localized light limitation and may partially explain low light tolerance of *Stuckenia sp*. and *Ruppia cirrhosa* of Great Salt Lake impounded wetlands.

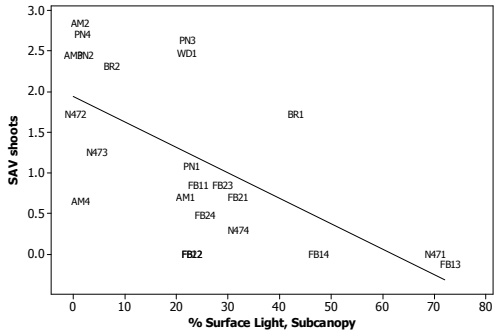


Figure 5.3. Percent SAV versus percent surface light in the SAV subcanopy during 2010 (R^2 = 0.40, p-value < 0.01). AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB = FB WMA Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet. Numerals 1 – 4 placed at the end of the site codes indicate sample months June, July, August, and September, respectively.

Detrimental shade effects from surface mats do not seem to be indicated in Great Salt Lake impounded wetlands. Furthermore, using percent surface mat as a metric of impounded wetlands condition is undermined by the fact that the mere presence of an algal dominated surface mat is susceptible to wind events. Strong winds can move and condense surface mats toward one end of an impoundment (except when the entire surface water is covered) as well as cause them to sink. Additionally, sago pondweed is a stress tolerant plant capable of multiple regenerative strategies as offshoots of the main stem and secondary tubers can mature later in the growing season after early shoots have senesced (Kantrud 1990).

SAV PERCENT COVER AND BRANCH DENSITY

Percent cover of SAV provides a basis for the overall biological response to environmental conditions in a wetland. Although it does not provide direct linkage with beneficial use, indirect implications are important relative to presence or absence of a food base of many waterfowl species. Kantrud (1986) reported that a single sago pondweed dominated lake supported a large percentage of the continental population of canvasbacks during their one-month fall staging, which implies that senescence did not occur until after the staging period. Further, grazing pressure by waterfowl that depend on SAV (including sago pondweed) for part or all of their diet from the fall through early spring does not affect SAV biomass presumably in healthy systems (Winslow 2003; Sandsten et al. 2005). Shoots of sago will senesce after fruiting bodies (drupelets) form, however younger shoots continue to grow and flower as these pseudo-annuals translocate soluble carbohydrates downward for tuber formation (Hangelbroek et al. 2002; Best and Boyd 2003). Senescence of an entire bed occurs later during the fall, e.g., October (Kantrud 1990) provided stressors are not prevalent (Best and Boyd 2003).

Although sago pondweed is considered to be fairly stress tolerant, sago populations have been known to senesce prematurely, e.g., those in a polluted stream in Wisconsin began senescing as early as the end of July (Madsen 1986 as referenced in Kantrud 1990). Healthy populations flower June through September (Iowa DNR 2001). Best & Boyd (2003) included a wide range that reflects the period of time when sago pondweed communities senesce completely that incorporated stressors such as temperature, grazing, water transparency, water level, pH and levels of oxygen on CO_2 assimilation at light saturation in their simulated model for growth. With recurring premature die-off of SAV in some of the Great Salt Lake impounded wetlands, recording

percent cover SAV is useful in identifying that a problem exists provided that reference (or pseudo-reference) conditions are included. However, using this metric without seasonal replication will not account for temporal and spatial variability relative to annual fluctuation in environmental conditions (both natural and human-induced).

A more sensitive metric may be SAV branch density. While percent cover generally captures declining trends, it does not appear to consistently pair with impoundments that have lower SAV productivity (as above ground biomass, indirectly measured as branch density, tuber and drupelet biomass). Nor does it always show declining trends prior to the arrival of fall migrant waterfowl. SAV branch density data indicated declining trends by or before August, which may indicate that conditions are less than favorable for SAV growth at a particular site and provide a good predictive tool.

SAV TUBER AND DRUPELET BIOMASS

Quantification of food production for waterfowl as biomass of tubers and drupelets provides a direct linkage between biological response and beneficial use. These metrics can be translated into bioenergetic carrying capacity for an impoundment as described below. One of the foremost concerns of wildlife managers and agencies is whether the managed wetlands are providing ample food for waterfowl that depend upon it. In cases where premature SAV senescence occurs, the importance of seasonality in supporting beneficial use is amplified.

Biomass data were used to calculate bioenergetic carrying capacity for dabbling and diving ducks in Hoven (2010b) using the formula:

DUD = Biomass * TME * Acreage / DER by foraging guild

where DUD is duck use days, biomass (kg/ha) is the designated food type for each foraging guild (i.e., drupelets versus tubers), TME = true metabolizable energy for each food (kcal/kg) from peer- reviewed literature: 1.42 kcal/g for drupelets; 4.02 kcal/g for tubers; and DER = daily energy requirement per representative bird (2-year September average from Johnson 2008).

Bioenergetic carrying capacity was not calculated for the 2010 data due to insufficient water at two of the four potential sites and insufficient waterfowl count data at the third site. However, drupelet and tuber biomass were determined for all sites and will be available for future comparisons.

SAV HABITAT STRUCTURE METRIC FOR MACROINVERTEBRATES

SAV branch density, water depth and epiphyte diversity (as a descriptive class, e.g., filamentous, gelatinous / loosely attached, etc.) or load (as quantitative % cover) could be used to develop a new metric that would help define habitat structure for macroinvertebrates. Future work related to developing such a metric is described below.

6.0 FUTURE RESEARCH

Refinement of biological response with robust pore water and sediment chemistry is needed. A better understanding of nutrient sources that are associated with SAV health and surface mat development are still needed. Although surface water correlations with plant metrics identified an inverse relationship between NO3, HPO4 and percent SAV, and a positive correlation between NO3, HPO4 and percent LEMI in surface mats, future sampling and analysis should focus on the

potential for pore water and sediment as important nutrient sources for these two vegetative components. This will further our understanding of the role of nutrient sources and distribution of SAV, duckweed and macroalgae in the impoundments. Additionally, it will be important to understand the role of sediment sulfide in the health of SAV.

Chlorophyll fluorescence has the potential as a useful diagnostic tool for analyzing the health of SAV. The physiological implications as detected by chlorophyll fluorescence are that SAV from Ambassador W1 and New State Pond 47 endured stress (Figure 1.7). Refinement of the methodology may help to reduce the variability in samples within sites and emphasis on defining a healthy range of chlorophyll fluorescence will be important. Linking physiological responses with surface water, pore water and sediment chemistry will help identify direct cause-effect relationships between stressors and biological response.

Physiological implications from Figure 1.7 also suggest further work towards understanding uptake and the potential for translocation of metals that can be potentially toxic to the plants and / or wildlife that eat them would be useful in understanding the relationships described in Section 3. Specifically, some aquatic plants are known to have mechanisms in place to either prevent uptake or sequester some metals in the cell walls of roots or translocate metals and store them in reproductive tissues. Other plants have no known safeguard mechanisms and may be susceptible to toxicity issues. It will be important to understand whether the levels of metals existing in the sediment and pore water are bioavailable for uptake and assimilation by the SAV and whether toxicity issues are a potential explanation for SAV die-off (e.g., MeHg, Fe, Cr, and Pb). Van Wijck et al. (1992) found *P. pectinatus* (*S. pectinata*) to show diminished photosynthetic activity and root respiration at high Fe^{2+} concentrations. It will also be important to determine whether biomaccumulation of metals in tubers and drupelets such as MeHg, Cu, Zn, and Pb poses a threat to wildlife that eat plant reproductive parts for nourishment. For instance, Welsh & Denny (1979, 1980) found that Pb accumulated but did not translocate from roots to shoots of *P. pectinatus* and a related taxon, and Cu translocated from roots to shoots readily.

Development of SAV habitat structure metric for macroinvertebrates could be useful for managers desiring to improve food-base diversity for waterfowl. For waterfowl that are omnivorous and seek out macroinvertebrates as sources of protein, it will be useful to understand what conditions present the best habitat structure for macroinvertebrates that associate with the SAV community. To date, there are several metrics (along with new metrics) that could be used to develop an SAV habitat structure metric. SAV branch density, combined with water column height, and quantitative epiphyte cover (previously qualitatively derived) could give a better indication of macroinvertebrate diversity simply because plants that grow in deeper water tend to grow longer to reach better light conditions and tend to have more interstitial space between shoots. Additionally, water and sediment chemistry relationships with epiphyte community need to be better understood. Sediment nutrient relationships have yet to be determined as a potential driver of the epiphyte community (much of the surface mat develops initially on the bottom and rises through the plant canopy to the surface). Epiphytes provide forage and shelter for many macroinvertebrates. Surface water chemistry only moderately correlated with surface mat development (primarily nutrients and duckweed). Ultimately, we will need to compare macroinvertebrate diversity with plant and chemistry metrics to develop a meaningful SAV habitat structure metric.

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APPENDIXES

APPENDIX A

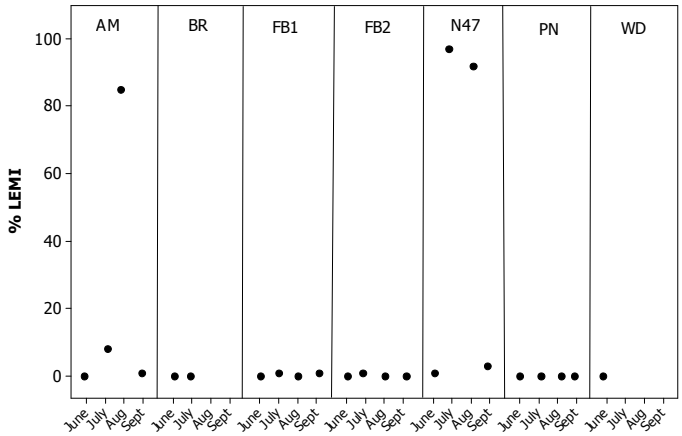


Figure A1. Mean (n = 5) percent cover of Lemna minor (LEMI, duckweed) in surface mats at eight impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

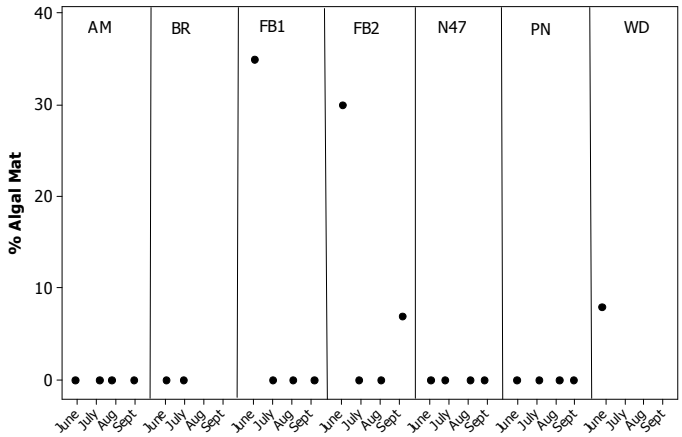


Figure A2. Mean (n = 5) percent cover of percent macroalgae in surface mats at eight impounded wetlands of GSL during 2010. AM = Ambassador W1, BR = Bear River Migratory Bird Refuge Unit 4C, FB1 and FB2 = Farmington Bay Wildlife Management Area Units 1 and 2, N47 = New State Pond 47, PN = Public Shooting Grounds Pintail Pond outlet, WD = Public Shooting Grounds Widgeon Pond inlet.

APPENDIX B

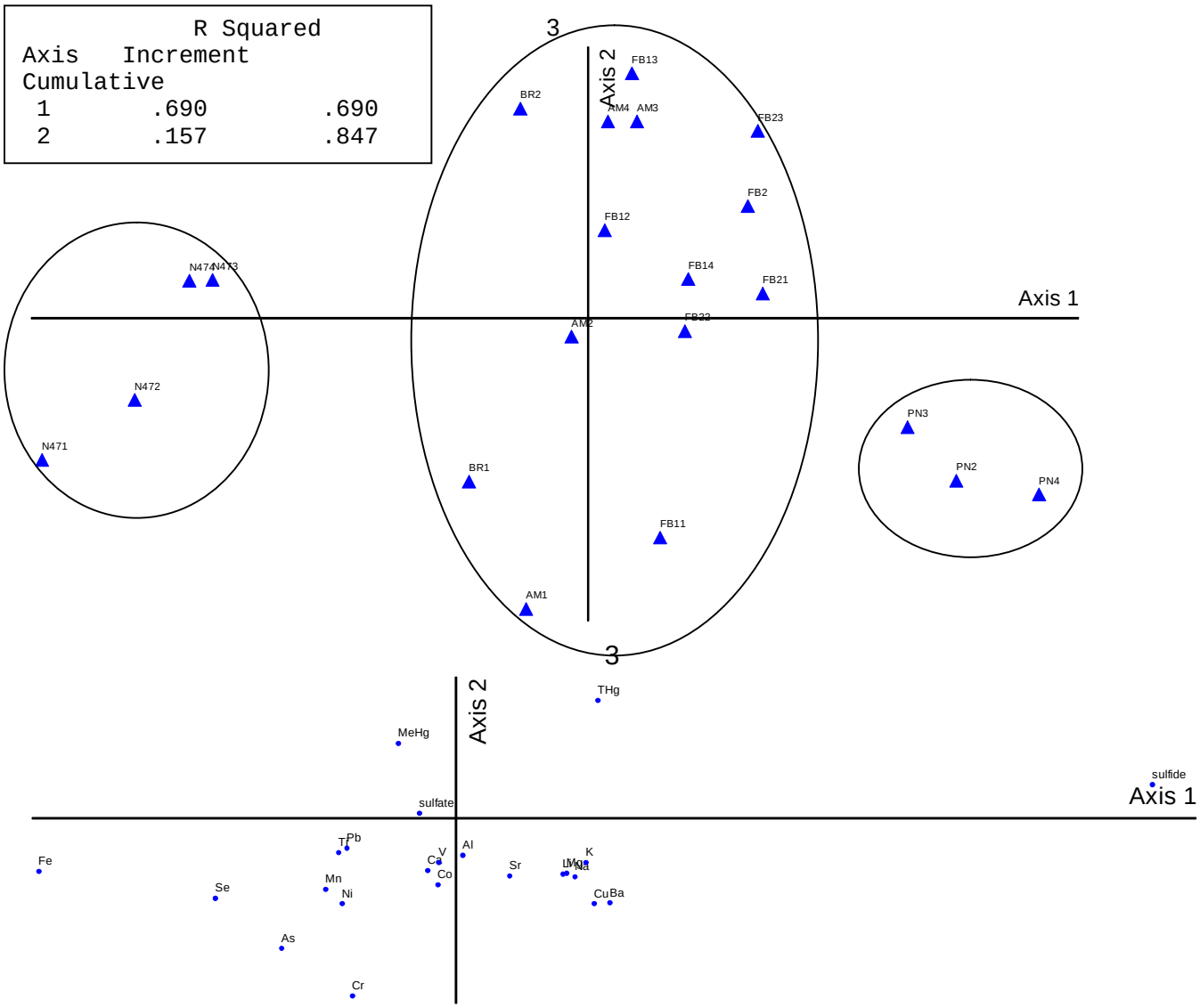
Table B1. Non metric multidimensional scaling (NMS) stress in relation to dimensionality (number of axes) of ten plant community metrics at seven impoundments (N = 23 samples) collected in 2010. LEMI = % LEMI (Lemna minor) in the surface mat, TtlMat = % total surface mat, %algmat = % macroalgae in the surface mat, AlgSAV = categorical classification of extent of epiphytic algae on SAV, shoots = branch density (# branches m^{2}) of SAV shoots, SAVTtl = % cover SAV (including Ruppia cirrhosa, Stuckenia filiformis and S. pectinata), Tubgm = SAV tubers (g m^2), SRDrup = Stuckenia sp. and Ruppia drupelets (g m^2), SDrug = Stuckenia sp. drupletes only (g m^2), and SurfSC = % surface light in the SAV subcanopy. Tubgm2, Shoots, SRDrupgm2, and Sdrug were log generalized transformed.

STRESS IN RELATION TO DIMENSIONALITY (Number of Axes)

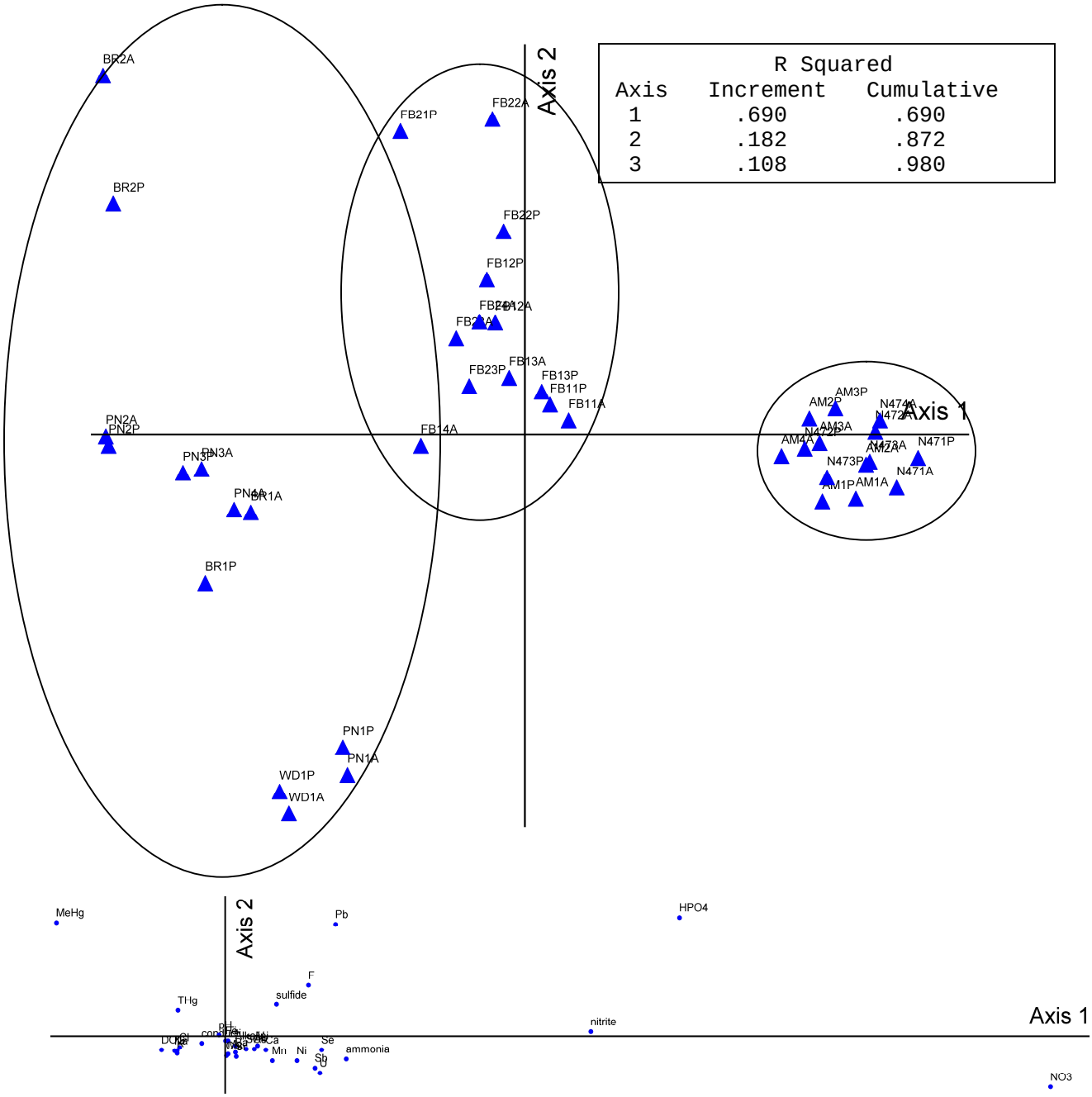
	Stress in real data 250 run(s)			Stress in randomized data Monte Carlo test, 250 runs			
Axes	Minimum	Mean	Maximum	Minimum	Mean	Maximum	p
1	15.482	35.028	55.168	20.045	43.992	55.175	0.0040
2	8.967	10.403	38.268	11.000	19.106	38.268	0.0040
3	5.581	5.777	7.178	6.389	10.050	14.514	0.0040
4	2.660	2.702	6.112	4.331	6.603	17.160	0.0040
5	1.880	2.044	2.423	2.770	4.454	6.216	0.0040
6	1.177	1.411	2.017	1.869	3.079	4.290	0.0040

p = proportion of randomized runs with stress < or = observed stress
i.e., p = (1 + no. permutations <= observed)/(1 + no. permutations

APPENDIX C1. PORE WATER ORDINATION AXES 1 AND 2 (JOHNSON ET AL. 2011)



APPENDIX C2. PORE WATER ORDINATION AXES 1 AND 2 (JOHNSON ET AL. 2011)



APPENDIX D1. SURFACE WATER ELEMENTS AND NUTRIENTS AND PLANT METRIC CORRELATIONS (PEARSON CORRELATION r IN UPPER CELLS, P-VALUE LOWER CELLS)

	Tubgm	%algmat	%LEMI	%TtlMat	AlgSAV	SAVTtl	shoots	%SurfSC	SRDrupgm2
%algmat	-0.042								
	0.851								
%LEMI	-0.277	-0.155							
	0.201	0.479							
%TtlMat	-0.274	0.137	0.956						
	0.206	0.532	0						
AlgSAV	-0.426	0.277	0.095	0.165					
	0.043	0.201	0.665	0.451					
SAVTtl	0.566	-0.201	-0.008	-0.051	-0.419				
	0.005	0.358	0.972	0.817	0.046				
shoots	0.505	-0.113	0.229	0.204	-0.284	0.925			
	0.014	0.609	0.294	0.35	0.188	0			
%SurfSC	-0.349	0.075	-0.421	-0.403	-0.228	-0.468	-0.634		
	0.102	0.735	0.046	0.057	0.296	0.024	0.001		
SRDrupgm2	0.519	0.233	-0.562	-0.478	-0.109	0.294	0.131	-0.028	
	0.011	0.284	0.005	0.021	0.62	0.173	0.551	0.899	
pH	0.289	0.229	-0.47	-0.394	-0.117	0.411	0.27	-0.009	0.786
	0.181	0.293	0.024	0.062	0.594	0.051	0.213	0.966	0
sulfide	-0.284	-0.03	-0.073	-0.081	0.226	-0.26	-0.327	0.031	0.195
	0.189	0.893	0.742	0.713	0.3	0.231	0.128	0.888	0.373
nitrite	-0.052	-0.297	0.461	0.38	0.124	0.016	0.158	-0.362	-0.666
	0.815	0.168	0.027	0.074	0.572	0.943	0.472	0.089	0.001
phosphate	-0.212	-0.205	0.442	0.391	0.156	-0.314	-0.217	-0.153	-0.526
	0.331	0.347	0.035	0.065	0.477	0.144	0.321	0.487	0.01
ammonia	0.062	-0.282	-0.022	-0.105	-0.29	0.193	0.072	0.221	-0.307
	0.779	0.192	0.919	0.632	0.18	0.377	0.745	0.311	0.154
Alkalinity	0.146	-0.355	0.087	-0.017	0.016	0.088	0.132	-0.183	0.079
	0.506	0.096	0.695	0.937	0.942	0.691	0.55	0.404	0.722
F	-0.32	-0.086	0.371	0.339	0.261	-0.404	-0.234	-0.237	-0.328
	0.136	0.695	0.081	0.113	0.23	0.056	0.282	0.276	0.127

D1 Cont'd	Tubgm	%algmat	%LEMI	%TtlMat	AlgSAV	SAVTtl	shoots	%SurfSC	SRDrupgm2
Cl	0.447	-0.21	-0.273	-0.335	-0.3	0.569	0.528	-0.218	0.514
	0.033	0.336	0.208	0.118	0.164			0.318	0.012
NO3	-0.381	-0.242	0.762	0.687	0.18	-0.178	0.032	-0.292	-0.87
	0.073	0.266	0	0	0.41	0.418	0.884	0.177	0
HPO4	-0.161	-0.18	0.472	0.423	0.197	-0.345	-0.213	-0.28	-0.554
	0.463	0.411	0.023	0.044	0.368	0.107	0.329	0.195	0.006
SO4	0.178	-0.481	0.321	0.186	-0.007	0.138	0.271	-0.465	-0.143
	0.416	0.02	0.135	0.395	0.973	0.529	0.211	0.025	0.514
Na	0.441	-0.175	-0.263	-0.316	-0.337	0.595	0.557	-0.201	0.493
	0.035	0.426	0.225	0.142	0.116	0.003	0.006	0.359	0.017
Mg	0.161	-0.213	-0.053	-0.115	-0.257	0.231	0.215	-0.051	0.209
	0.463	0.33	0.812	0.603	0.237	0.29	0.324	0.817	0.338
K	0.436	-0.254	-0.224	-0.299	-0.358	0.629	0.572	-0.224	0.471
	0.037	0.242	0.305	0.166	0.093	0.001	0.004	0.303	0.023
Ca	-0.338	-0.062	0.24	0.221	0.198	-0.324	-0.301	0.112	-0.446
	0.115	0.777	0.271	0.311	0.365	0.131	0.163	0.61	0.033
THg	0.157	0.013	-0.18	-0.174	-0.018	0.167	0.11	-0.116	0.381
	0.474	0.952	0.41	0.427	0.936	0.447	0.617	0.598	0.073
MeHg	-0.158	-0.005	-0.244	-0.247	0.285	-0.171	-0.285	-0.012	0.27
	0.471	0.983	0.262	0.257	0.187	0.436	0.187	0.958	0.213
Li	0.466	-0.209	-0.228	-0.29	-0.324	0.617	0.598	-0.263	0.451
	0.025	0.339	0.296	0.18	0.131	0.002	0.003	0.225	0.031
Be	0.023	0.199	-0.255	-0.196	-0.181	0.139	-0.023	0.287	0.04
	0.918	0.364	0.24	0.37	0.41	0.528	0.918	0.184	0.856
Al	0.137	0.009	-0.214	-0.213	0.031	0.323	0.193	0.065	0.044
	0.532	0.968	0.326	0.329	0.888	0.133	0.378	0.767	0.841
Ti	0.053	-0.141	-0.265	-0.308	0.156	-0.025	-0.163	0.144	0.022
	0.812	0.52	0.221	0.153	0.476	0.909	0.458	0.513	0.922
V	-0.286	0.072	0.15	0.171	0.072	-0.421	-0.454	0.455	-0.154
	0.186	0.745	0.494	0.435	0.745	0.045	0.03	0.029	0.484
Cr	-0.077	0.093	-0.247	-0.222	-0.273	0.088	-0.092	0.492	-0.064
	0.727	0.671	0.255	0.31	0.208	0.69	0.675	0.017	0.772

D1 Cont'd	Tubgm	%algmat	%LEMI	%TtlMat	AlgSAV	SAVTtl	shoots	%SurfSC	SRDrupgm2
Fe	0.265	0.072	-0.131	-0.109	-0.008	0.42	0.33	-0.071	-0.084
	0.221	0.743	0.553	0.62	0.972	0.046	0.124	0.746	0.702
Co	0.068	0.024	-0.124	-0.114	0.03	0.164	0.099	0.025	-0.05
	0.756	0.912	0.572	0.603	0.893	0.455	0.652	0.909	0.819
Ni	-0.244	0.175	0.14	0.194	0.162	-0.301	-0.309	0.202	-0.35
	0.261	0.424	0.525	0.376	0.462	0.163	0.152	0.355	0.102
Cu	0.193	0.025	0.306	0.321	-0.199	0.484	0.622	-0.354	0.016
	0.377	0.91	0.156	0.135	0.362	0.019	0.002	0.097	0.942
Zn	-0.054	-0.013	-0.154	-0.159	-0.086	0.189	0.096	0.167	0.066
	0.806	0.952	0.483	0.468	0.698	0.387	0.662	0.445	0.765
As	-0.057	-0.053	0.393	0.383	-0.111	0.038	0.057	-0.157	-0.352
	0.797	0.809	0.064	0.071	0.613	0.864	0.795	0.475	0.1
Se	-0.219	-0.071	0.604	0.583	0.044	0.03	0.17	-0.286	-0.692
	0.315	0.748	0.002	0.003	0.842	0.892	0.438	0.186	0
Sr	0.081	-0.233	0.121	0.054	-0.079	0.308	0.318	-0.233	-0.028
	0.713	0.284	0.582	0.807	0.72	0.153	0.139	0.284	0.898
Mo	0.245	-0.468	0.476	0.343	-0.137	0.245	0.411	-0.558	-0.331
	0.26	0.024	0.022	0.109	0.535	0.26	0.051	0.006	0.123
Ag	-0.005	0.229	-0.242	-0.176	-0.175	0.119	-0.047	0.326	0.011
	0.982	0.294	0.267	0.422	0.426	0.588	0.831	0.129	0.962
Cd	-0.044	0.203	-0.254	-0.196	-0.163	0.11	-0.058	0.342	0.015
	0.843	0.353	0.243	0.37	0.457	0.616	0.793	0.111	0.945
Sb	-0.194	0.005	0.251	0.254	0.062	-0.241	-0.246	0.202	-0.459
	0.375	0.98	0.247	0.242	0.78	0.268	0.258	0.355	0.028
Ba	0.004	-0.258	-0.033	-0.11	-0.243	0.063	-0.049	0.064	-0.028
	0.985	0.235	0.881	0.616	0.264	0.774	0.823	0.772	0.898
Tl	-0.047	-0.403	-0.018	-0.136	-0.066	0.32	0.214	-0.043	0.031
	0.83	0.056	0.935	0.535	0.763	0.136	0.326	0.846	0.887
Pb	-0.164	-0.308	0.595	0.504	0.205	-0.208	0.031	-0.384	-0.433
	0.454	0.152	0.003	0.014	0.349	0.34	0.889	0.071	0.039
U	-0.101	0.147	0.185	0.231	0.156	-0.42	-0.386	0.183	-0.263
	0.648	0.502	0.399	0.29	0.477	0.046	0.069	0.404	0.225

APPENDIX D2. SEDIMENT ELEMENTS AND NUTRIENTS AND PLANT METRIC CORRELATIONS (PEARSON CORRELATION r IN UPPER CELLS, P-VALUE LOWER CELLS)

	Tubgm	LEMI	TtlMat	AlgSAV	SAVTtl	shoots	SurfSC	SR_Drup_gm2
%LOI	0.18	0.011	0.052	0.174	-0.313	-0.442	0.223	0.241
	0.618	0.976	0.886	0.63	0.378	0.201	0.537	0.502
THg	-0.664	0.432	0.429	0.649	-0.606	-0.289	-0.024	-0.819
	0.036	0.213	0.216	0.042	0.063	0.418	0.949	0.004
MeHg	-0.782	0.345	0.328	0.552	-0.507	-0.109	-0.031	-0.883
	0.008	0.328	0.355	0.098	0.134	0.764	0.932	0.001
Li	0.4	-0.234	-0.18	0.007	-0.11	-0.308	0.318	0.704
	0.252	0.516	0.618	0.985	0.762	0.387	0.371	0.023
Be	0.022	0.38	0.413	0.295	-0.249	-0.198	-0.112	-0.13
	0.952	0.278	0.235	0.407	0.488	0.584	0.758	0.72
Na	0.609	-0.451	-0.436	-0.658	0.469	0.174	0.169	0.745
	0.062	0.191	0.207	0.039	0.171	0.631	0.64	0.013
Mg	0.259	-0.277	-0.221	0.02	-0.102	-0.174	0.283	0.629
	0.47	0.439	0.539	0.955	0.78	0.631	0.429	0.051
Al	0.13	0.27	0.311	0.255	-0.249	-0.234	-0.045	0.009
	0.721	0.45	0.382	0.477	0.489	0.516	0.901	0.981
K	0.544	0.255	0.284	-0.305	0.144	0.006	-0.107	0.154
	0.104	0.477	0.427	0.391	0.692	0.987	0.768	0.672
Ca	0.581	0.125	0.176	-0.483	0.582	0.525	-0.41	0.456
	0.078	0.73	0.628	0.157	0.077	0.119	0.239	0.186
Ti	0.231	0.397	0.449	0.07	0.039	0.02	-0.21	0.044
	0.521	0.256	0.193	0.848	0.915	0.957	0.56	0.905
V	-0.012	0.009	0.057	0.329	-0.449	-0.519	0.389	0.269
	0.975	0.981	0.875	0.353	0.193	0.124	0.266	0.452
Cr	-0.256	0.081	0.113	0.54	-0.643	-0.583	0.354	-0.054
	0.475	0.824	0.755	0.107	0.045	0.077	0.315	0.882
Mn	0.527	-0.066	-0.001	-0.182	0.267	0.226	-0.194	0.601
	0.117	0.857	0.997	0.614	0.456	0.529	0.591	0.066
Fe	-0.421	0.513	0.512	0.495	-0.546	-0.339	0.001	-0.651
	0.226	0.129	0.13	0.146	0.102	0.339	0.997	0.041

D2 cont'd	Tubgm	LEMI	TtlMat	AlgSAV	SAVTtl	shoots	SurfSC	SR_Drup_gm2
Co	-0.196	0.463	0.489	0.396	-0.41	-0.283	-0.004	-0.33
	0.588	0.177	0.151	0.257	0.239	0.428	0.992	0.352
Ni	0.02	0.502	0.535	0.142	-0.079	0.024	-0.245	-0.185
	0.956	0.14	0.111	0.696	0.829	0.948	0.496	0.608
Cu	-0.439	0.552	0.557	0.498	-0.299	0.011	-0.362	-0.703
	0.205	0.098	0.095	0.143	0.402	0.976	0.304	0.023
Zn	-0.471	0.547	0.548	0.529	-0.347	-0.019	-0.347	-0.746
	0.17	0.101	0.101	0.116	0.326	0.959	0.326	0.013
As	-0.187	0.492	0.534	0.364	-0.165	0.028	-0.271	-0.228
	0.606	0.149	0.112	0.302	0.649	0.938	0.45	0.526
Se	0.277	0.494	0.511	-0.129	0.215	0.234	-0.437	-0.164
	0.439	0.146	0.131	0.722	0.552	0.515	0.206	0.651
Sr	0.642	-0.023	-0.002	-0.803	0.764	0.637	-0.338	0.459
	0.045	0.95	0.995	0.005	0.01	0.048	0.34	0.183
Mo	0.39	-0.091	-0.044	-0.44	0.538	0.453	-0.178	0.654
	0.265	0.802	0.903	0.204	0.109	0.189	0.623	0.04
Ag	-0.492	0.48	0.496	0.483	-0.276	-0.007	-0.254	-0.64
	0.148	0.16	0.145	0.157	0.441	0.984	0.478	0.046
Cd	-0.086	0.492	0.51	0.326	-0.111	0.087	-0.452	-0.381
	0.814	0.148	0.132	0.358	0.76	0.812	0.19	0.277
Sb	-0.462	0.702	0.699	0.422	-0.205	0.123	-0.438	-0.838
	0.179	0.024	0.024	0.224	0.569	0.736	0.206	0.002
Ba	0.46	0.361	0.395	-0.442	0.547	0.576	-0.547	0.072
	0.181	0.306	0.259	0.201	0.102	0.081	0.102	0.843
Tl	-0.334	0.595	0.596	0.394	-0.213	0.08	-0.43	-0.7
	0.346	0.07	0.069	0.26	0.555	0.827	0.215	0.024
Pb	-0.674	0.577	0.548	0.468	-0.372	0.007	-0.263	-0.982
	0.033	0.081	0.101	0.173	0.29	0.986	0.463	0
U	0.275	0.036	0.093	0.026	-0.018	-0.123	0.092	0.496
	0.443	0.921	0.798	0.943	0.961	0.736	0.801	0.145

APPENDIX D3. PORE WATER ELEMENTS AND NUTRIENTS AND PLANT METRIC CORRELATIONS (PEARSON CORRELATION r IN UPPER CELLS, P-VALUE LOWER CELLS)

	Tubgm	%algmat	%LEMI	TtlMat	%AlgSAV	SAVTtl	shoots	%SurfSC	SRDrupgm2
sulfide	0.422	0.19	-0.379	-0.308	0.148	0.118	0.051	-0.229	0.853
	0.057	0.409	0.09	0.175	0.521	0.611	0.825	0.318	0
sulfate	-0.027	-0.168	0.217	0.176	-0.049	-0.079	-0.028	0.012	-0.225
	0.907	0.467	0.345	0.445	0.834	0.732	0.906	0.96	0.328
THg	0.179	-0.434	0.104	-0.02	0.159	0.103	0.2	-0.358	0.206
	0.438	0.049	0.655	0.931	0.492	0.658	0.384	0.111	0.371
MeHg	-0.13	-0.515	-0.13	-0.291	0.195	0.034	-0.059	0.082	-0.068
	0.575	0.017	0.573	0.201	0.397	0.883	0.801	0.725	0.769
Li	0.315	0.139	-0.237	-0.205	-0.205	0.477	0.495	-0.243	0.438
	0.164	0.549	0.301	0.372	0.372	0.029	0.023	0.288	0.047
Na	0.195	0.248	-0.247	-0.186	-0.149	0.315	0.346	-0.12	0.429
	0.398	0.279	0.28	0.42	0.52	0.164	0.125	0.606	0.052
Mg	0.318	0.306	-0.347	-0.26	-0.093	0.259	0.254	-0.135	0.577
	0.16	0.177	0.123	0.254	0.688	0.257	0.267	0.558	0.006
Al	0.264	0.174	-0.531	-0.497	-0.055	0.112	-0.062	0.165	0.241
	0.247	0.451	0.013	0.022	0.814	0.629	0.79	0.476	0.293
K	0.371	0.235	-0.31	-0.248	-0.152	0.465	0.466	-0.264	0.601
	0.098	0.305	0.172	0.278	0.51	0.034	0.033	0.248	0.004
Ca	-0.112	0.021	0.149	0.149	-0.026	-0.065	0	-0.108	-0.324
	0.629	0.928	0.52	0.519	0.912	0.779	0.999	0.641	0.153
Ti	-0.401	0.071	0.354	0.356	0.197	-0.347	-0.256	0.032	-0.798
	0.071	0.759	0.116	0.113	0.393	0.123	0.262	0.892	0
V	0.24	0.196	-0.42	-0.369	-0.1	0.14	-0.054	0.183	0.107
	0.294	0.394	0.058	0.1	0.666	0.546	0.817	0.427	0.643
Cr	-0.128	0.277	-0.209	-0.142	-0.068	-0.055	-0.162	0.3	-0.174
	0.579	0.225	0.364	0.54	0.77	0.813	0.483	0.186	0.452
Mn	-0.113	-0.199	0.341	0.274	0.019	0.156	0.172	-0.216	-0.626
	0.626	0.388	0.131	0.229	0.933	0.5	0.457	0.348	0.002
Fe	-0.493	-0.223	0.458	0.371	0.041	-0.205	-0.053	0.065	-0.932
	0.023	0.331	0.037	0.098	0.859	0.373	0.821	0.781	0

D3 cont'd	Tubgm	%algmat	%LEMI	TtlMat	%AlgSAV	SAVTtl	shoots	%SurfSC	SRDrupgm2
Co	-0.123	0.171	0.163	0.206	0.177	-0.338	-0.236	-0.047	-0.158
	0.596	0.459	0.479	0.371	0.442	0.134	0.302	0.84	0.494
Ni	-0.192	0.027	0.253	0.251	0.055	0.015	0.05	-0.084	-0.572
	0.405	0.906	0.269	0.272	0.812	0.949	0.828	0.716	0.007
Cu	0.155	0.084	-0.303	-0.299	-0.151	0.247	0.277	-0.125	0.279
	0.502	0.718	0.182	0.187	0.514	0.281	0.224	0.589	0.221
As	-0.204	-0.002	0.323	0.294	-0.027	0.029	0.122	0.055	-0.535
	0.375	0.995	0.154	0.195	0.907	0.901	0.6	0.813	0.013
Se	-0.281	-0.33	0.499	0.39	0.101	-0.101	0.052	-0.211	-0.762
	0.218	0.144	0.021	0.081	0.664	0.663	0.824	0.359	0
Sr	0.337	-0.166	-0.007	-0.057	-0.214	0.467	0.523	-0.372	0.089
	0.135	0.473	0.977	0.807	0.351	0.033	0.015	0.097	0.703
Ba	0.446	0.031	-0.277	-0.268	-0.211	0.522	0.501	-0.313	0.43
	0.043	0.894	0.224	0.24	0.358	0.015	0.021	0.167	0.052
Pb	-0.329	0.012	0.724	0.706	0.07	-0.019	0.221	-0.309	-0.683
	0.146	0.958	0	0	0.762	0.935	0.336	0.173	0.001
U	0.039	0.318	0.02	0.117	-0.195	-0.122	-0.154	0.282	0.163
	0.866	0.16	0.933	0.613	0.397	0.599	0.506	0.215	0.48