The 2009 Report on SAV Condition in Farmington Bay and other Impounded Wetlands of Great Salt Lake

Prepared for:

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INTRODUCTION

Great Salt Lake and its wetlands is a Hemispheric Site within the Western Hemisphere Shorebird Reserve Network. As such, there is a complexity of habitat and wetland types defined within Great Salt Lake wetlands. These wetlands provide foraging, staging, breeding, and brood-rearing habitat to millions of migratory and resident shorebird and other waterbirds annually. Approximately 75% of all wetlands of Utah are found along the freshwater tributaries of Great Salt Lake totaling nearly 182,000 ha. Of these wetlands, nearly 61,000 ha are located in the southeast portion of the lake and surround Farmington Bay and over half of those wetlands (approximately 35,000 ha) are impounded and managed for waterfowl. Impounded wetlands are a prominent wetland type around the eastern shore of Great Salt Lake as much of the land is owned and managed by Federal and State agencies and private duck clubs. During recent history, noticeable algal and duck weed blooms have established regularly during the summer months in many of the impounded wetlands of Farmington Bay as well as the Bay itself raising concerns from waterfowl managers, scientists and public interest groups.

The Jordan River is the main source of water for Farmington Bay impounded wetlands and is composed primarily of treated sewage effluent from four major municipal waste water treatment plants having an ambient P concentration ranging from 0.9 to 1.3 mg l^{-1} (Miller and Hoven 2007). Several years of investigation lead by Dr. Theron Miller, formerly of Utah Department of Environmental Quality, Division of Water Quality (DWQ) was conducted 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 is supported. The study focused on impounded wetlands and waterfowl that use them because of the measurable aspects of trophic levels within these systems. 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 duck weed dieoff just as fall migrant waterfowl arrive (Miller and Hoven 2007; Hoven 2009, Hoven 2010). SAV is widely recognized as an important source of protein as leafy vegetation, drupelets, tubers, and macroinvertebrates associated with the vegetation for many of the waterfowl (Chamberlain 1959; Moore 1980; Kantrud 1990; Dennison et al. 1993; Winslow 2003), which raises the question of whether ample food is available when SAV beds die-off.

Development of a number of macrophyte assessment metrics identified good potential for showing responses related to the condition of the wetlands. Specifically, various aspects of SAV areal cover that focus on the establishment and duration of SAV beds throughout the growing season; the establishment and extent of surface mat cover; epiphyte and / or biofilm abundance; vertical extinction coefficients (K_d cm $^{-1}$); light compensation point; the ratio of variable to maximum fluorescence (Fv/Fm); and net photosynthesis rates (Pn). However, none of the metrics thus far, indicate clear relationships between wetland condition and water quality. During 2009, assessment of impounded wetland condition continued in order to capture year-to-year natural variability from environmental parameters and associated biological responses and to further refine some of the original metrics.

METHODS

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 capture 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 water from the Jordan River and empty 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. While the Inland Sea Shorebird Reserve (ISSR) receives water from the Northpoint Consolidated Canal, a diversion from Jordan River, previous work shows that salinity is more of a determining factor for SAV health than other water quality parameters (Hoven 2010) and was discontinued as a primary site. Public Shooting Grounds (PSG) was selected as a reference site and is situated at the north end of the lake on Bear River Bay. PSG receives its water from freshwater springs and some irrigation return flows. The Bear River Migratory Bird Refuge (BRBR) was added during 2008 in an attempt to fill an apparent data gap between nutrient enriched and reference conditions.

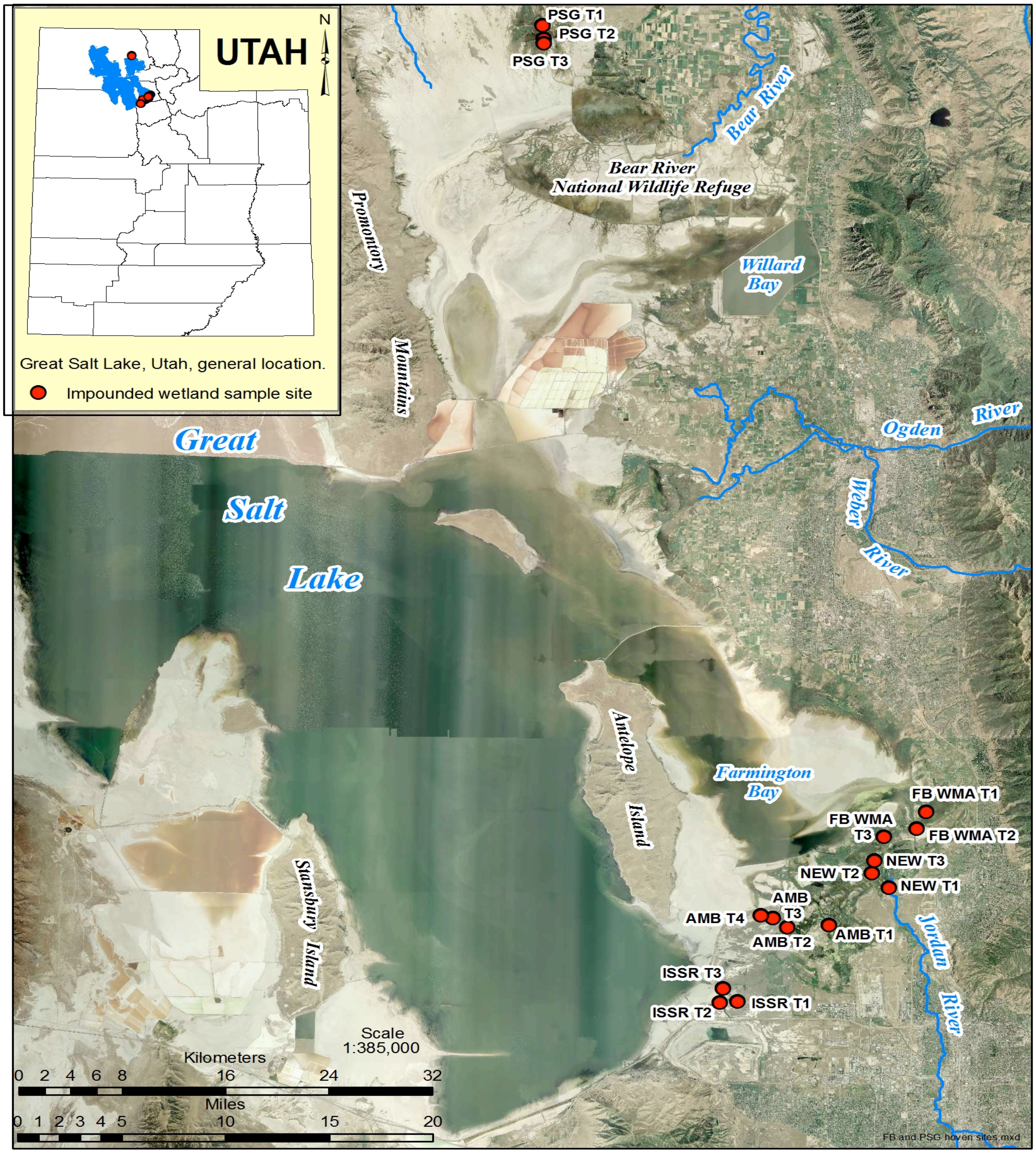


Figure 1. Eastern shore of Great Salt Lake, U.S.A. showing original impounded wetland sites of the State of Utah Division of Water Quality's study on ecological and beneficial use assessment of Farmington Bay wetlands. Reference sites are located at the PSG

(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 (not shown) were added in 2008 to represent moderate water quality conditions.

The majority of impounded wetlands of this study have sago pondweed and western fineleaf pondweed (*Stuckenia pectinata* and *S. filiformis* ssp. *occidentalis*, respectively) as the dominant SAV; however isolated impoundments have *Ruppia cirrhosa* co-dominant with *Stuckenia* spp., or as the dominant SAV. Occasional coon's tail (*Ceratophyllum demersum*), horned pondweed (*Zannichellia palustris*) and curly pondweed (*Potamogeton crispus*) grow as well (Hoven 2010). Sampling was conducted during early August to capture maximum distribution of SAV beds and surface mats and during early September. Sampling was completed by mid-September when the arrival of migrant waterfowl typically reaches a maximum (Paul and Manning, 2002) to evaluate SAV condition prior to heavy grazing pressure.

<u>SAV & SURFACE MAT PERCENT AREAL COVER</u>

Percent cover, species composition, and above ground biomass were determined after EPA Module 10. One square meter quadrat was 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 duck weed. The 2.0 m PVC poles were marked to show area designations (e.g., 1, 5, 10, 25, 30 %), a modification of the Daubenmire frame technique (Daubenmire 1959).

Percent cover of total SAV was conducted at replicate transects during September where room permitted. Replicate transects were positioned parallel and 25 m away from the original transects. If room permitted a third replicate (i.e. not near the far-shore) was performed. It was located an additional 25 m away. The same parameters were collected at all replicate transects as described above.

Percent cover SAV was further refined at selected sites by identifying the proportion of live leaves in the canopy. This was done to enable differentiation from standing stock of essentially barren, leafless shoots and shoots that still had leaves attached.

A qualified aquatic botanist recorded observations critical for documenting the seral ecological stage of the SAV and associated biota. Species composition was determined using floristic keys (Prescott 1969, Welsh 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. Extra care was taken to move slowly through the canopy in deep water to avoid pushing plants away from the core. At the sediment – core interface, any plant material falling outside of the core was cut with scissors until the core could be easily pushed into the sediment. Once the excess plants were cut, the core was pushed firmly through the sediment until the hardpan surface was reached. At that time, 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, and most shells, rocks, snails, and macroinvertebrates were discarded before placing the sample in a pre-labeled plastic bag and sealing it. At the lab, biomass samples were sorted by drupelets and tubers, dried for a minimum of 72 hrs at 34 °C and weighed. Biomass data were used to calculate bioenergetic carrying capacity for dabbling and diving ducks using the formula:

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

where DUD is duck use days, biomass is the designated food type for each foraging guild (i.e., drupletes versus tubers), TME = true metabolizable energy for each food (kcal/kg) from peer-reviewed literature, and DER = daily energy requirement per representative bird (from Johnson 2008).

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.

CNP TISSUE ANALYSIS OF SAV LEAVES

Three composite samples of the dominant species of SAV in each impoundment were collected for tissue carbon (as total organic carbon), nitrogen (as total nitrogen), and phosphorus (as total phosphorus) analyses during percent cover assessments. Plant samples were stored in a refrigerator in sealed plastic bags until they were processed. Processing included rinsing plants free of sediment and debris, wiping periphyton off with absorbent paper towels and hand selecting approximately 5 g (wet weight) bright green leaves with forceps. Leaves of similar length in a leaf cluster along the stem were used rather than shorter leaves on distal-most end of stems in an attempt to collect similarly-aged leaves. Leaves were kept under water while processing and once adequate sample was derived, the leaves were rinsed in distilled, deionized water and dried in aluminum foil trays at 34 ˚C for at least 72 hrs. The dried samples were quickly placed in clean, labeled sealed plastic bags and stored in a closed box prior to chemical analysis. Total carbon and total nitrogen using analytical method ASTM D5373, and total phosphorus using EPA Method 325.2 (ICP atomic emission spectroscopy) was conducted at Timpview Analytical Laboratories of Orem, UT. At the lab, samples from each site were composited to ensure adequate material for analysis.

WATER QUALITY PARAMETERS

Water quality parameters, collected by DWQ, were sampled approximately monthly during day light hours including: nitrate-nitrite and total phosphorus using standard EPA methods (353.2 and 365.2, respectively), dissolved oxygen (DO), pH, temperature, and electrical conductivity (EC) using Hydrolab® or In-Situ® multiprobe sondes. Measurements and sample collections were performed at designated outlet culverts (easily identifiable landmarks) that were located near biological sample collections (indicated by site location points on Figure 1).

STATISTICAL ANALYSIS

Data were analyzed using multivariate factor analysis. Water quality factors were determined following the methods outlined by Madon (2006). Of the eight parameters used, parameters that explained the least amount of variability, when ordinated in the second and third factors, were excluded to reduce the data to one ordination factor. All water quality data were transformed by Log10, using (Log10 (x + 1) for zeros). Percent cover data were first composited as total SAV per quadrat (i.e., % *Stuckenia spp*. plus % *Ruppia cirrhosa*) and transformed by arcsine√x, using arcsine (square root (0+3/8)/(15+3/4)) for zeros (Anscombe 1948). Univariate repeated measures were performed to assess whether the SAV in the impoundments were responding differently with respect to biological parameters among sites and across time. Chi-square goodness of fit was used for comparison of data with no replicates (e.g. duck use days).

RESULTS AND DISCUSSION

SAV PERCENT AREAL COVER

Percent cover of total SAV was significantly different among upstream sites ($F_{(df\ 4)}$ = 8.103, $P < 0.0001$) and between sampling periods ($F_{(df\ 4)}$ = 7.620, $P < 0.0001$) during August and September of 2009 (Figure 2). Upstream sites are those that first receive source waters, e.g., from the Jordan River or freshwater springs and irrigation return flows. Relevant to the ongoing study is the continued pattern of collapse and die-off of SAV beds at New State (N1) and Ambassador (A1) as in 2005 (Miller and Hoven 2007) and 2007 and 2008 (Hoven 2009; Hoven 2010). Interestingly, FBWMA Unit 1 (F1) had increased cover by early September of 2009, which was contrary to low establishment and subsequent die-off during previous years.

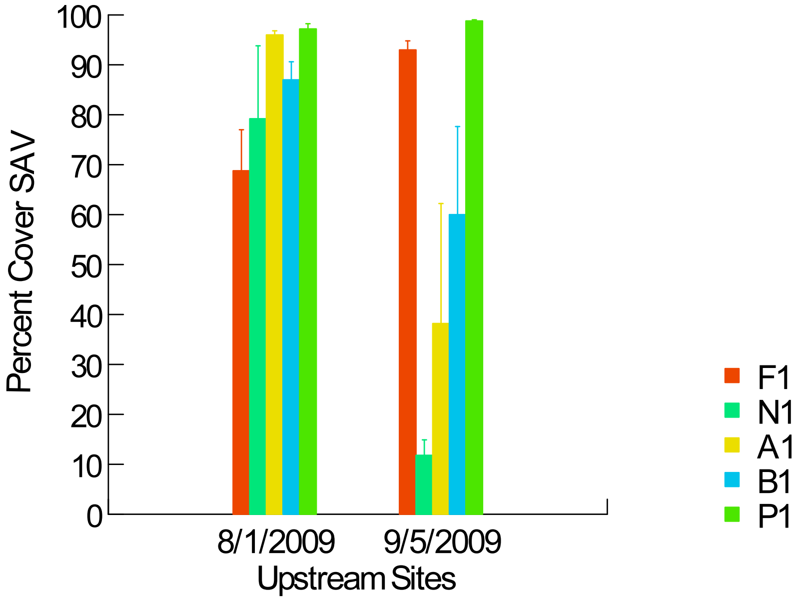


Figure 2. Percent cover total SAV at upstream impounded wetlands of Farmington and Bear River Bays of Great Salt Lake, 2009. F1 = FB WMA Unit 1, N1 = New State Pond 47, A1 = Ambassador W1, B1 = BRBR Unit 5C, P1 = Public Shooting Grounds Pintail Pond. (n = 5, mean ± se)

There was frequent precipitation during June 2009 such that the monthly average was greater than during June of the previous year both in the Lower Bear River and Farmington subwatersheds (Table 1). This was the case during 2005 and 2007 in Farmington as well. The August 2009 SAV coverage data indicated a delayed response to environmental conditions compared to previous years, in that F1 and N1 had some of the highest record of percent cover during that month in those impoundments. These data may indicate a dilution effect from sustained precipitation events through June.

While F1 did not show decline in percent cover by early September, N1 and A1 had severely and moderately reduced SAV cover, respectively. These differences were supported by photochemical responses of SAV in the respective impoundments as reported in Hoven (2010) whereby SAV from all three target ponds (F1, N1 and A1) had photosynthetic rates (Pn) below reference SAV during August (Table 2). By September, Pn of F1 improved and was higher than reference (3 vs. 2.3 μmol CO_2 m^2 s^{-1} for F1 and P1, respectively). SAV at N1 and A1 did not improve or did not respond to the experimental parameters (1.8 μmol CO_2 m^{-2} s^{-1}, and no data for N1 and A1, respectively). Refinement of the experimental parameters and further investigation during the 2010 growing season may verify whether these differences are significant.

Table 1. Percent of average monthly precipitation at two subwatersheds of Great Salt Lake: the Lower Bear River and Farmington, 2004 – 2009.

Lower BR	**2004**	**2005**	**2007**	**2008**	**2009**
Feb	86	88	116	110	96
March	44	92	66	95	130
April	78	83	66	60	114
May	125	118	51	106	77
June	82	171	77	96	342
July	77	21	88	12	49
Aug	151	84	74	105	87
Sept	120	47	106	51	62

Farmington	**2004**	**2005**	**2007**	**2008**	**2009**
Feb	96	90	117	119	117
March	43	142	72	64	123
April	107	127	67	67	136
May	73	164	61	69	75
June	129	246	237	58	299
July	63	25	19	0	44
Aug	155	61	17	160	61
Sept	61	45	100	51	80

Table 2. Photosynthetic rate of SAV (μmol CO_2 m^{-2} s^{-1}) at three target versus reference upstream impoundments at PAR of 1500 μE m^2 s^{-1} during August and September, 2009 (from Hoven 2010). F = FB WMA, N = New State Duck Club, A = Ambassador Duck Club, P = Public Shooting Grounds, nd = no data.

	August	September
F1	1.6	3
N1	1.8	1.8
A1	1.8	nd
P1	2.1	2.3

Sampling during 2009 was specifically aimed at refining the period of decline prior to the onset of heavy grazing by migratory waterfowl and illustrates how close the timing of SAV decline and arrival of the waterfowl are. Both 2008 (Hoven 2009) and 2009 data indicate that conditions of the SAV change rapidly between mid-August and early September in the impoundments that have environmental conditions that negatively impact the survival of SAV.

The principle axis determined by multivariate factor analysis of July data produced a water quality factor gradient showing increasing nutrients and total suspended solids (TSS) at one end, and increasing total dissolved solids (TDS), salinity, specific conductivity (SC), and pH at the other. The condition of SAV beds during September show a delayed and significant response to water quality conditions that were present during July (Figure 3, $F_{(df\ 1)} = 4.59$, $P = 0.099$, $r^2 = 0.534$).

Although July water quality data were the most complete of all months sampled, several parameters were missing from various sites, thereby precluding them from being included in the factor analysis. Reference data were excluded for this reason, which may have weakened the regression. Nonetheless, A2 and A3 are typically in better condition than upstream impoundments and provided a reference point for the analysis. F1 aligned with better water quality and high percent cover. N3 aligned with fair water quality and had comparable cover of SAV to F1. N1 and A1 both showed low SAV cover and poor water quality.

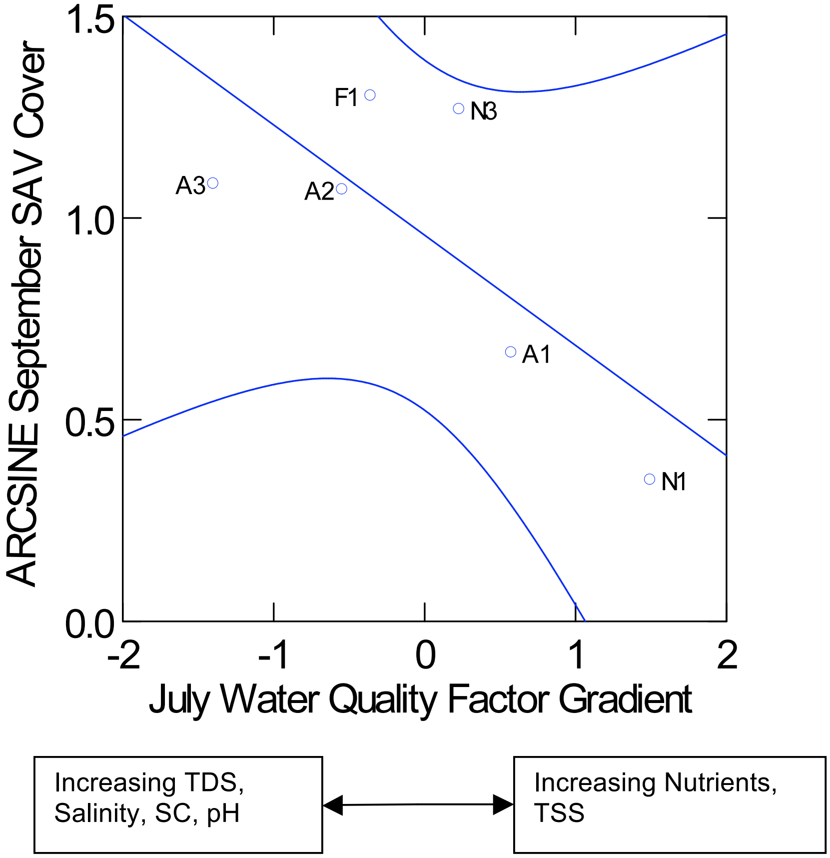


Figure 3. Arcsine transformed percent cover of SAV (± 95% confidence interval) versus the July water quality factor gradient (see text) at impoundments during the September sampling interval 2009 ($F_{(df\ 1)} = 4.59$, $P = 0.099$, $r^2 = 0.534$). A = Ambassador Duck Club, F = FB WMA, N = New State Duck Club. TDS = total dissolved solids, SC = specific conductivity, TSS = total suspended solids. Numerals show the successive impoundments at each study area.

Percent cover of total SAV in secondary impoundments indicates that by September, SAV respond similarly to or better than that recorded during August (upstream impoundments included for reference, Figure 4 a – e).

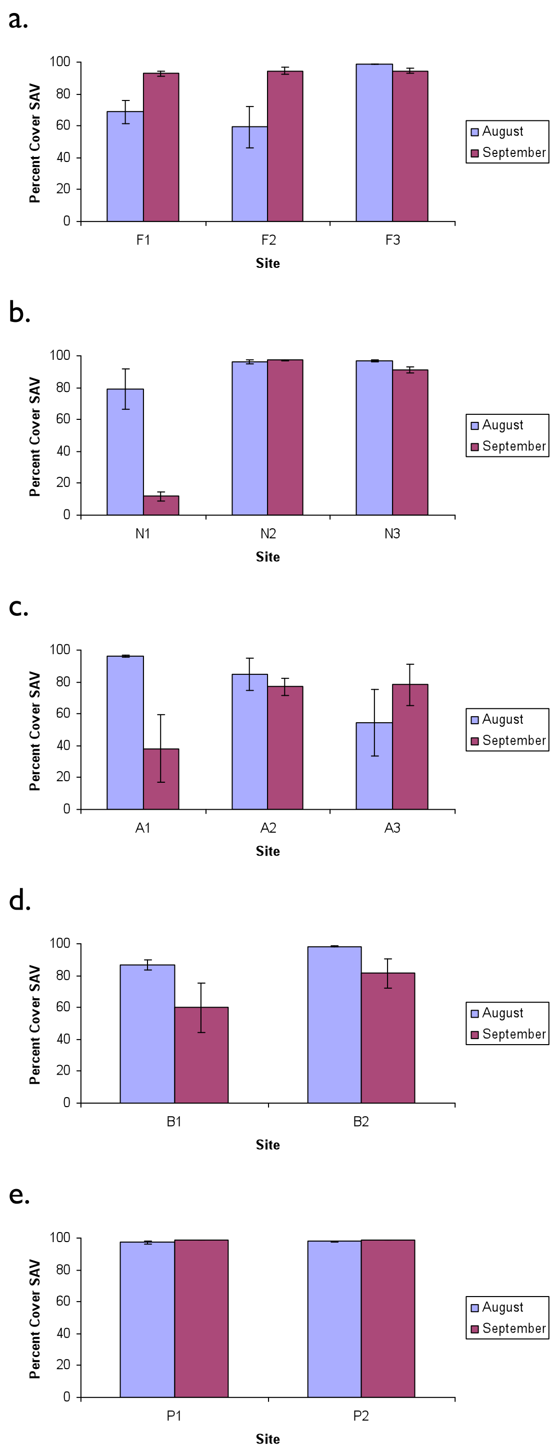


Figure 4 a – e. Percent cover of total SAV during August and September of 2009 at FB WMA (F 2 – F3), New State (N1 – N3), Ambassador (A1 – A3), BRBR (B1, B2) and Public Shooting Grounds (P1 – P3). (n = 5, mean ± se)

Similar to the response by SAV in F1, percent cover of total SAV increased by September in F2. This pattern was counter to that found during 2008 where percent cover of SAV outside carp exclosures was significantly reduced by grazing in secondary impoundments (Hoven 2010). Impoundments at Public Shooting Grounds continued to provide good reference conditions for the study as in previous years.

Through the various years of study of Farmington Bay and other Great Salt Lake impounded wetlands, the experimental design purported that one transect adequately represented conditions within an impoundment. Due to the reduced sampling time to complete one transect (i.e., no SAV biomass sampling), two to three replicate transects were conducted during 2009 when room permitted. There was no significant difference in percent cover of total SAV between any replicates for any of the sites except A1 ($F_{(df\ 1)} = 3.225$, $P = 0.110$, $r^2 = 0.287$), which was a weak relationship with high variance. Thus it was concluded that replicate transects did not provide additional characterization of percent cover of SAV in an impoundment.

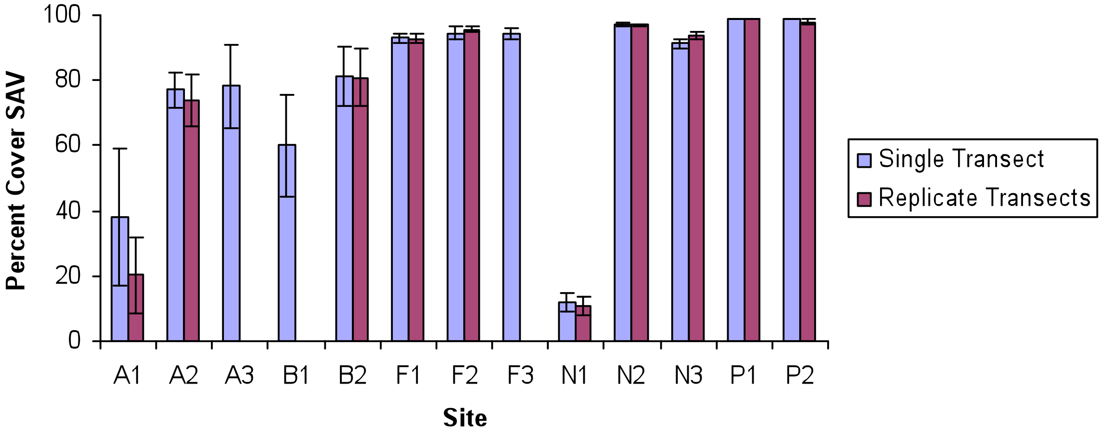


Figure 5. Comparison of percent cover of total SAV between single and replicate transects. A = Ambassador Duck Club, B = BRBR, F = FB WMA, N = New State Duck Club, P = Public Shooting Grounds. Numerals show the successive impoundments at each study area. (n = 5, mean ± se)

While percent cover of total SAV has repeatedly illustrated die-off in A1 and N1, there is a disparity in using this metric as a predictive tool of SAV die-off. During the years of studying SAV in Farmington Bay and other impounded wetlands of Great Salt Lake, there have been cases where standing stock of leafless, yet green (i.e., photosynthetic tissue) shoots were considered part of the SAV canopy and included in the percent cover record. Reasons for inclusion were that the green shoots were not dead (even though they were perhaps dying) and they were still upright in the water column providing potential substrate for macroinvertebrates. During September 2009, a preliminary attempt at separating healthy shoots with leaves (live leaves) versus the total SAV canopy was conducted at selected impoundments (Figure 6). Percent cover of live leaves versus total SAV was significantly different for A1 and B2 ($F_{(df\ 1)}$ = 2.729, P = 0.116, r^2 = 0.132; and $F_{(df\ 1)}$ = 27.35, P = 0.001, r^2 = 0.774, respectively). There was no significant difference between total SAV and live leaves percent cover at A2 or the reference impoundments (P1 and P2). Although there was fairly high percent cover of total SAV at B2 (81.4 ± 9.7), live leaf estimates were substantially lower (3.4 ± 0.5) on September 1st. By September 14th, percent cover of total SAV at B2 was reasonably high (80.4 ± 1.2, not shown), however, the leafless shoots were lying on the bottom and not floating in the water column. The inconsistency between percent cover of total SAV and live leaves at sites where environmental parameters may be challenging illustrates the potential for refining the percent cover SAV metric. Further, percent cover of live leaves may have some predictive quality as an SAV metric.

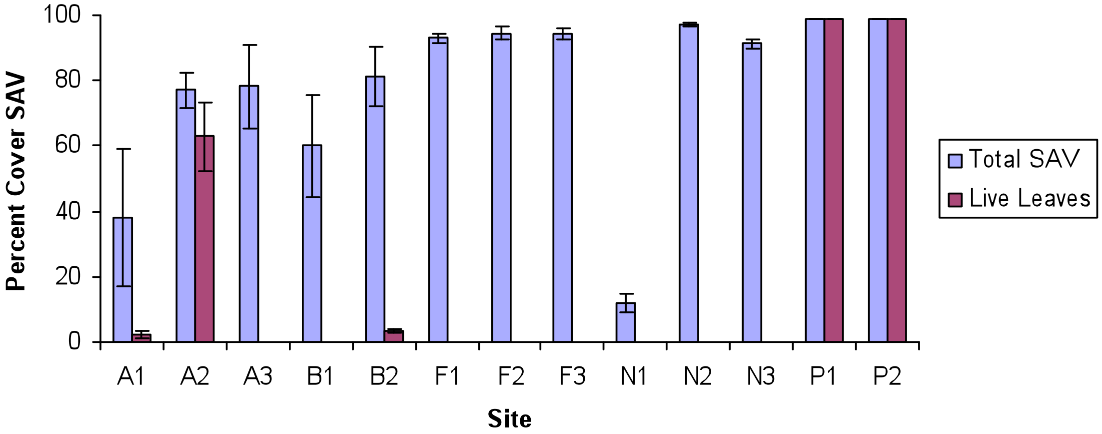


Figure 6. Comparison between percent cover of total SAV and percent cover live leaves at selected impoundments during September, 2009. A = Ambassador Duck Club, B = BRBR, F = FB WMA, N = New State Duck Club, P = Public Shooting Grounds. Numerals show the successive impoundments at each study area. (n = 5, mean ± se)

As in previous years, F1 is maintained with the greatest water depth of all sites in the study (Figure 7). 2009 was a wet management year for impoundments on the west of the access road at Public Shooting Grounds and thus water levels were higher during August 2009 than during "dry management" (or low water) of 2008 (37.5 cm ± 1.5 versus 22.2 cm ± 1.3, respectively). Likewise, A1 was filled to fall levels by August 2009 perhaps due to precipitation during June as opposed to lower levels that reflected low water availability during 2008 (34.7 cm ± 1.2 versus 24.1 cm ± 1.3).

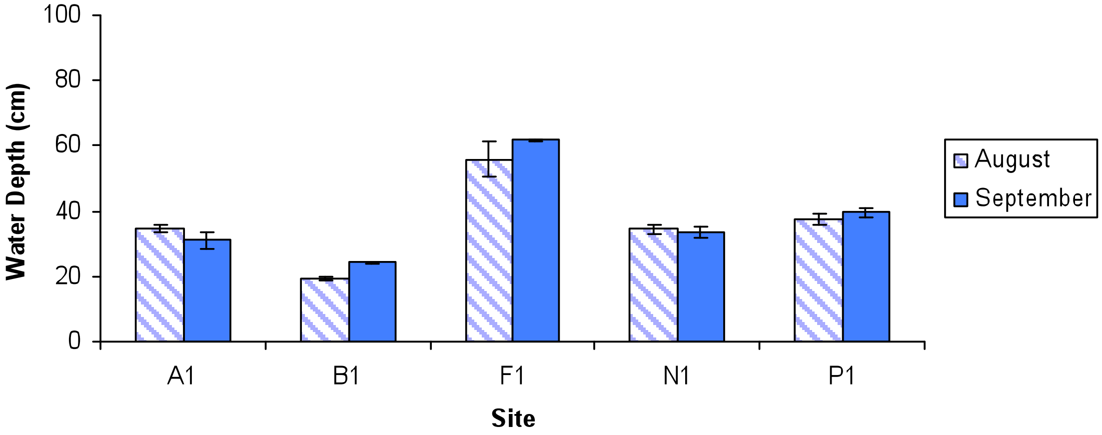


Figure 7. Average water depth at upstream impoundments during August and September 2009. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. (n = 5, mean ± se)

SURFACE MATS AND EPIPHYTIC ALGAE

Surface mats formed on the same upstream impoundments during 2009 as previous years (Figure 8, Hoven 2009; Hoven 2010). Maximum distribution of the surface mats tends to form by July and either dies off (F1 and N1) or is sustained (A1). Typically, macroalgae forms dense mats earlier than duck weed and duck weed persists longer than the macroalgae (Hoven 2010). These are the same impoundments where SAV die-off has been recorded previously (Miller and Hoven 2007; Hoven 2009; Hoven 2010) and during 2009 (A1 and N1).

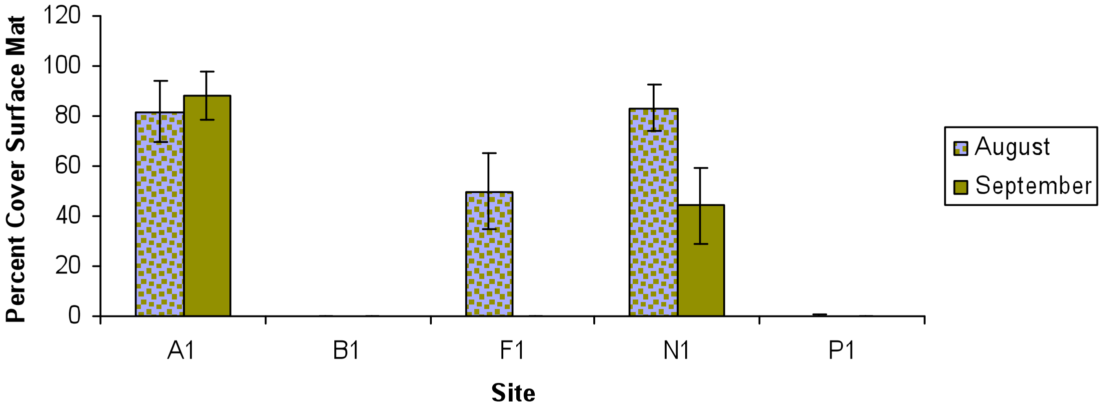


Figure 8. Percent cover surface mat in upstream impoundments during August and September 2009. Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. (n = 5, mean ± se)

LIGHT

Kemp et. al. (1981) demonstrated that *Stuckenia pectinata* (STPE) does not sustain photosynthetic activity ≥ respiration below 60 µE m^2 s^{-1}(the light compensation point), which is the equivalent of 2.7% surface light (June - July average surface PAR = 2241 µE m^2 s^{-1} ± 24.5 se) in Great Salt Lake impounded wetlands. The light compensation point for *Potomogeton perfoliatus* falls between 50 – 100 µE m^2 s^{-1} (Goldsborough 1983, as described in Twilley et al. 1985). While *S. pectinata* grows in the impoundments, *S. filiformis* and *Ruppia cirrhosa* are the dominant SAV species and they may have different light requirements than *S. pectinata*. Seagrasses and freshwater SAV require a minimum of 15 – 25% (depending on the species) of surface light to be available at their leaf surface (Dennison and Alberte 1986; Dennison et al. 1993). Here, 15% has been used to set the upper conservative limit for the potential range where the light compensation point may fall for SAV in Great Salt Lake impounded wetlands (Figures 9 – 11).

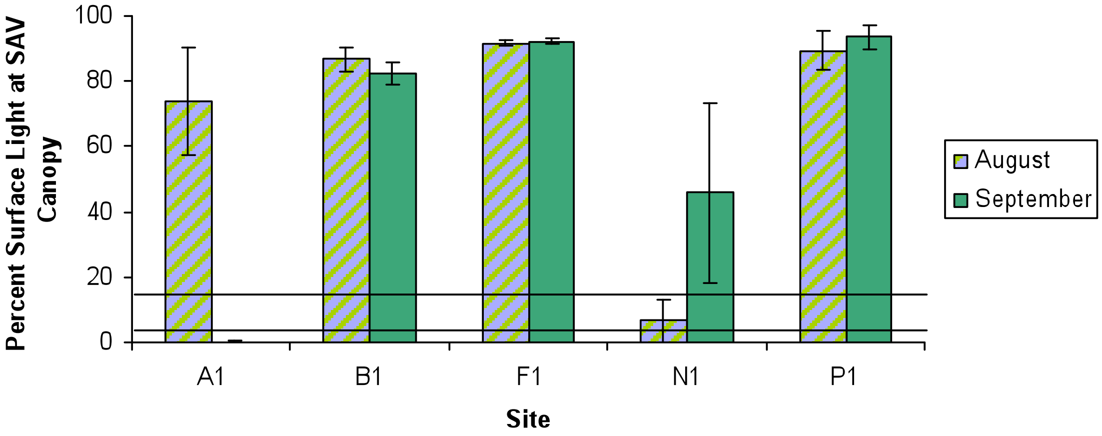


Figure 9. Percent surface light at the SAV canopy of upstream impoundments during August and September 2009. Vertical lines drawn at approximately 15% and 2.7% show the range where the light compensation point for the dominant species in the impoundments may fall. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. (n = 3, mean ± se)

Measured light penetration at various locations in the vegetative strata reveal the effects of shading by competing biota e.g., surface algal and duck weed mats and epiphytic algae, at the SAV canopy, subcanopy and under surface mats (Figures 9 – 11). Percent surface light at the SAV canopy is significantly lower at N1 during August (Figure 9, $F_{(df\ 4)} = 16.261$, $P \leq 0.0001$, $r^2 = 0.867$) and at A1 and N1 during September ($F_{(df\ 4)} = 9.193$, $P = 0.002$, $r^2 = 0.786$). Only N1 and A1 fall within or below the light compensation point range during August and September, respectively.

Percent surface light is significantly lower within the subcanopy of SAV in A1 and N1 (Figure 10, $F_{(df\ 4)} = 44.218$, $P \leq 0.0001$, $r^2 = 0.946$) and in P1 and F1 compared to B1 during August. Low percent surface light in P1 is likely due to self-shading since SAV in that impoundment have repeatedly been observed to grow densely. Percent surface light is significantly lowest within the subcanopy of SAV in A1 and P1 during September ($F_{(df\ 4)} = 3.195$, $P = 0.062$, $r^2 = 0.561$). Low values in P1 are again likely due to self-shading. Percent surface light values fell within or bellow the light compensation point range during August and September for all upstream impoundments except B1. Since SAV in P1 is likely self-shaded and maintains high percent cover total and live leaves of SAV, the

SAV species of this study are tolerant of low light conditions when other environmental parameters are adequate for growth. When signs of die-off occur in certain impoundments that also have low light conditions for SAV, additional environmental parameters must be pushing SAV physiological limits below sustained productivity.

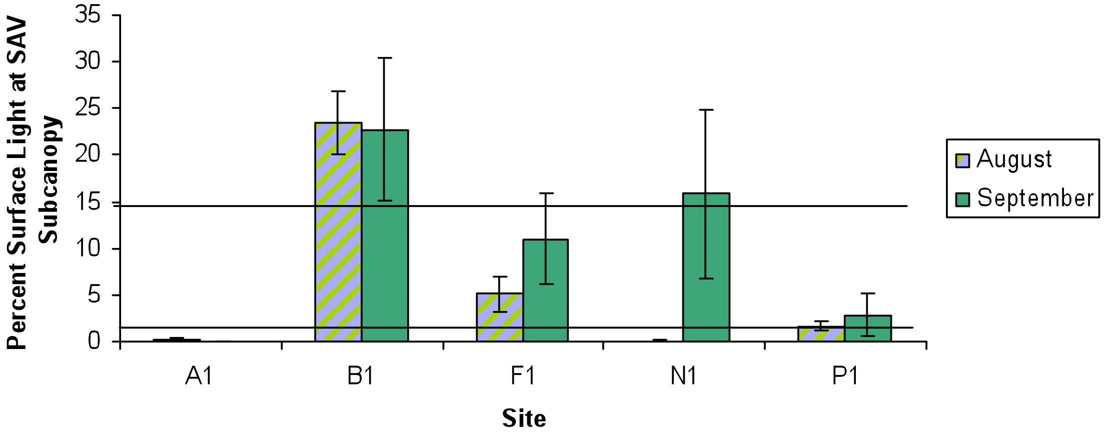


Figure 10. Percent surface light within the SAV subcanopy of upstream impoundments during August and September 2009. Vertical lines drawn at approximately 15% and 2.7% show the range where the light compensation point for the dominant species in the impoundments may fall. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. (n = 3, mean ± se)

Of the impoundments where surface mats form, light penetration into the water column was equally diminished at A1, F1 and N1 during August (Figure 11). By September, A1 had significantly lower percent surface light than N1 ($F_{(df\ 1)} = 3512.43$, $P \leq 0.0001$, $r^2 = 0.999$). There was only a thin cover of surface mat left in N1, however it did not reduce light penetration greatly. Percent surface light values fell within or bellow the light compensation point range during August and September for SAV growing in A1, F1, and N1 during August and again in A1 during September. The sustained SAV density in F1 indicated that it endured low light conditions during August as well as the other potentially stressful environmental parameters during 2009.

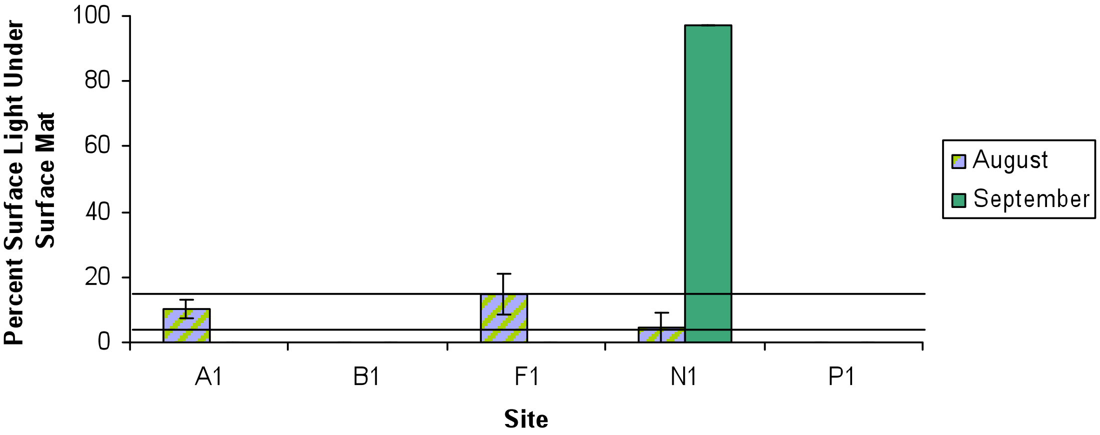


Figure 11. Percent surface light the surface mat of upstream impoundments during August and September 2009. Vertical lines drawn at approximately 15% and 2.7% show the range where the light compensation point for the dominant species in the impoundments may fall. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. (n = 3, mean ± se)

A related metric that expresses the fractional attenuation of light per unit distance is the vertical extinction coefficient. The Lambert Beer vertical extinction coefficient ($I_z = I_0 e^{-K_d z}$), used here as

$K_d = \ln I_{z1} - \ln I_{z2} / z_2$ (Lind 1985)

where
K_d = vertical extinction coefficient of light attenuation
I_z = is the light intensity at depth z
I_0 = Light intensity at surface

was expressly developed to detect abnormally high (or low) light altering strata within the total water column when several values are compared. In the Great Salt Lake impoundments, light altering strata are the surface mat-forming macroalgae and duck weed as well as loosely associated epiphytic algae that all compete for light, which is a different scenario than deeper systems that experience light limiting conditions for SAV due to phytoplankton and TSS in the water column (Stevenson et al. 1993; Philips et al. 1995; UMRCC WQTS 2003; Kemp et al, 2004). During 2009, SAV in Farmington Bay impounded wetlands were exposed to similar low light conditions as 2008 (Hoven

2009). Sub-canopy K_d cm^{-1} above 0.3 occurred at A1 (both months), N1, N2, N3 (August), N3 (September) and P2 (August, Table 3). K_d cm^{-1} above 0.3 represents reference conditions in dense beds of SAV where self-shading may occur. P2 tends to develop small patches of macroalgal surface mats during July and August (elevated K_d cm^{-1} of 0.69) but the mats die off by September (K_d cm^{-1} of 0.3). 2009 subcanopy K_d cm^{-1} were similar to those of 2008, however, K_d cm^{-1} under surface mats were substantially lower during 2009 than 2008 (Hoven 2009). Lower K_d cm^{-1} implies less light altering strata or simply put, less thick or extensive surface mats, which may have been related to dilution from higher levels of June precipitation that subsequently delayed algal and duck weed response.

Table 3. Vertical extinction coefficients (K_d cm^{-1}) at the subcanopy of SAV and under the surface mat (when present) during August and September of 2009.

	Subcanopy		**Under Mat**	
SITE	**August**	**September**	**August**	**September**
A1	0.40	0.66	0.55	0.91
A2	0.06	0.07	.	.
A3	0.14	0.10	.	.
B1	0.19	0.19	.	.
B2	0.14	0.07	.	.
F1	0.10	0.11	.	0.66
F2	0.06	0.06	0.19	.
F3	.	0.13	0.24	.
N1	0.60	0.25	.	0.16
N2	0.49	0.23	0.58	0.55
N3	0.78	0.51	0.54	0.70
P1	0.28	0.27	.	.
P2	0.69	0.30	0.98	.

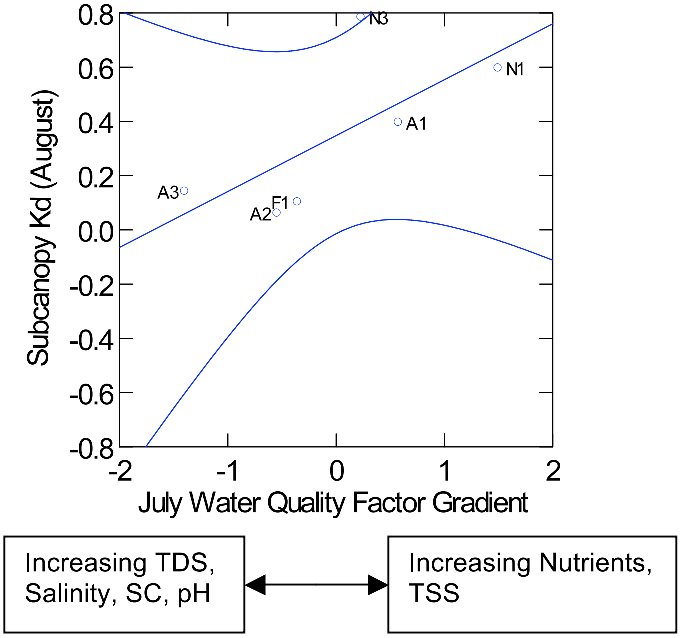


Figure 12. Subcanopy K_d cm^{-1} (± 95% confidence interval) versus the July water quality factor gradient at impoundments during the August sampling interval 2009 ($F_{(df\ 1)}$ = 3.756, P = 0.125, r^2 = 0.484). A = Ambassador Duck Club, F = FB WMA, N = New State Duck Club. TDS = total dissolved solids, SC = specific conductivity, TSS = total suspended solids. Numerals show the successive impoundments at each study area.

Assessment of the abundance of epiphytic algae and / or biofilm on SAV as qualitative amounts of epiphytic cover shows a heavy burden of the epiphytic biota at all upstream impoundments except the reference site (P1) during August 2009 (Table 4). A1, B1 and N1 maintained heavy burdens by the September sampling period. One of the primary factors known to negatively affect growth of *Stuckenia pectinata* and SAV in general is increased attenuation of light from increased chlorophyll a, epiphytes and macroalgae, and / or total suspended solids (Twilley et al. 1985; Kantrud 1990; Dennison et al. 1993; Stevenson et al. 1993; and Fourqurean et al. 2003). The presence of epiphytes alone may not be detrimental to SAV growth if photosynthetically active radiation (PAR) is not attenuated; however, if there is an extensive epiphytic community on SAV leaves, low light intensities (< 20% of surface incident light) at the leaf surface has been correlated with SAV decline (Twilley et al. 1985).

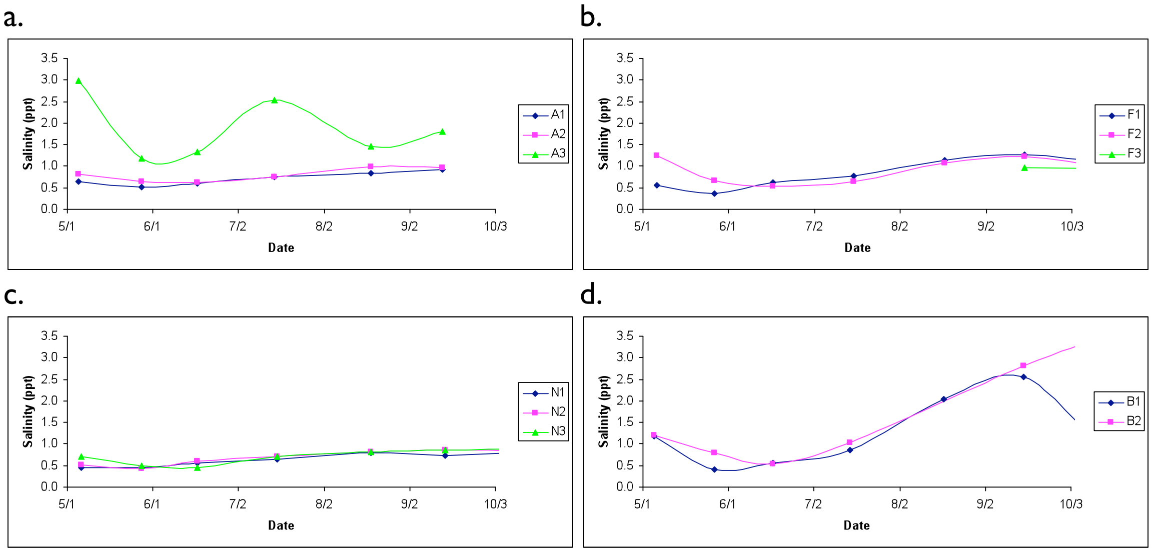
Table 4. Abundance of epiphyte and / or biofilm on SAV in upstream impoundments during August and September of 2009. Red = abundant, yellow = common, aqua = rare cover. n = 5, ± (se)

	August		**September**	
A1	3	(0.0)	3	(0.2)
B1	3	(0.1)	3	(0.0)
F1	3	(0.0)	2	(0.0)
N1	3	(0.2)	3	(0.1)
P1	1	(0.0)	2	(0.0)

3 = ABUNDANT
2 = COMMON
1 = RARE

WATER QUALITY DATA

A1, A2, F1, F2, N1, N2, and N3 have very similar seasonal patterns of water column salinity (Figure13 a, b, c). Moderate fluctuation in salinity occurs at A3 due to evaporative processes related to shallowness and water management issues (Figure 13a). B1 and B2 water column salinity are comparable to Ambassador, FB WMA and New State during mid-summer, but rises to moderate levels during the fall (Figure 13d). The higher levels may be indicative of natural levels as the nearby reference site demonstrates, and the lower levels during the summer could be related to dilution of salts by deep water management regimes at BRBR (Figures 13d, e).



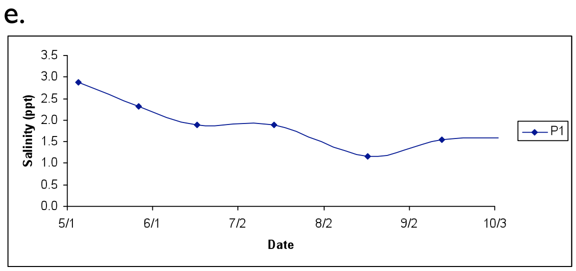
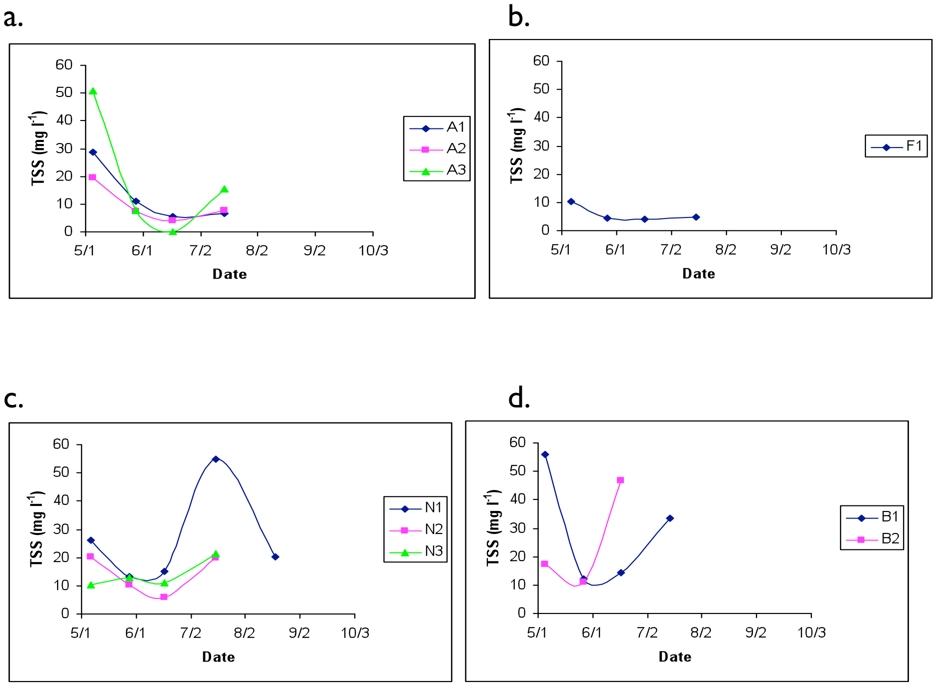


Figure 13 (a – e). Salinity at upstream impoundments during 2009. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. n = 1

Differences between seasonal levels of total suspended solids (TSS) among impoundments are shown in Figure 14. A1 – A3 have moderate to highly elevated levels during spring runoff but fall to lower levels during the summer months (Figure 14a). B1 has high TSS during the spring runoff and rises to high levels again (as does B2, Figure 14d) during the summer. N1 has high TSS during the summer as well (Figure 14c).



e.

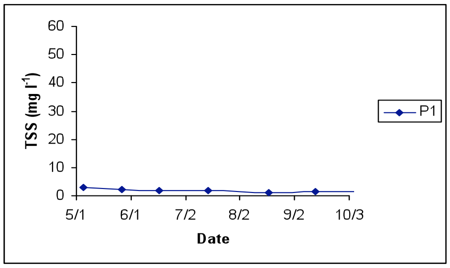


Figure 14 (a – e). Total suspended solids (TSS) at upstream impoundments during 2009. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. n = 1

Available nitrate – nitrite data show fluctuating levels in both A1 and N1 (Figure 15a, b).

a. b.

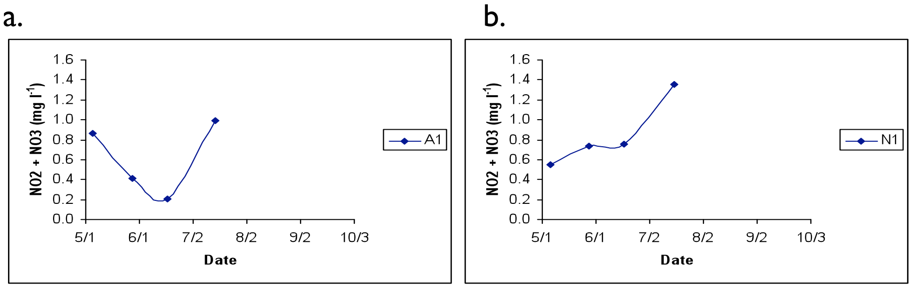


Figure 15 (a, b). Nitrate - nitrite at upstream impoundments during 2009. A1 = Ambassador W1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. n = 1

Fluctuating levels of ammonia are evident in F1 and N1 during the growing season (Figure 16b, c). A1 – A3, F2, N2, N3, B1 and B2 all show reduced levels of ammonia that are comparable to reference levels (P1) after spring runoff (Figure 16a – e).

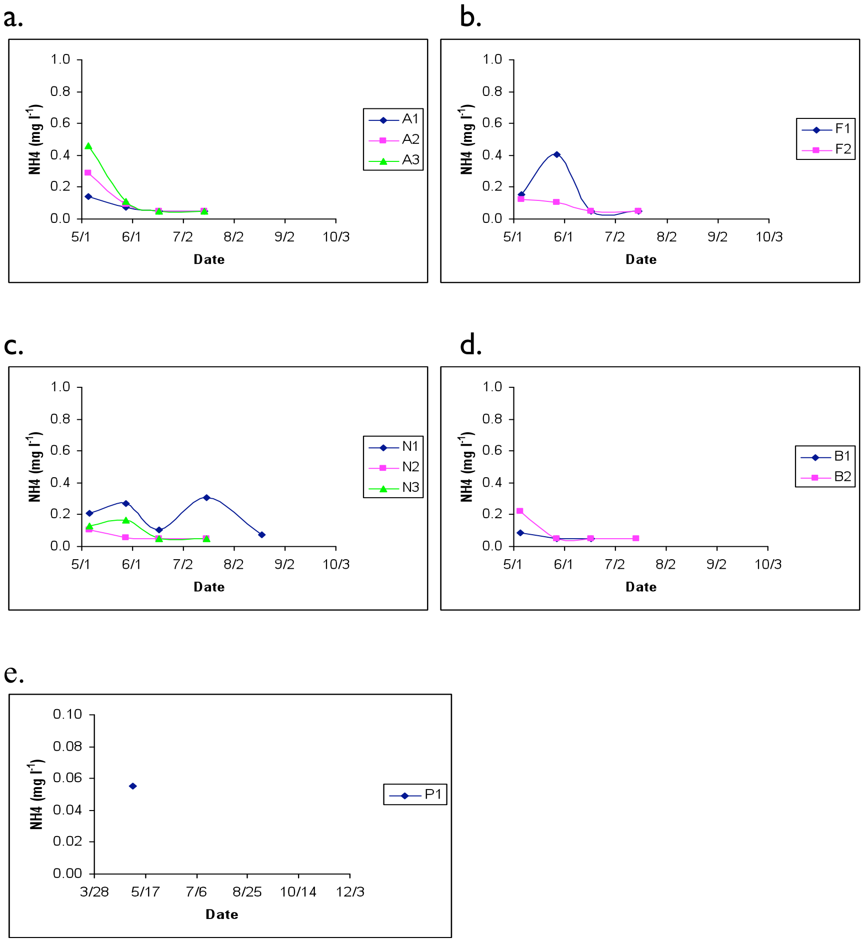


Figure 16 (a – e). Ammonia at upstream impoundments during 2009. A1 = Ambassador W1, F1 = FB WMA Unit 1, N1 = New State Pond 47, B1 = BRBR Unit 5C. n = 1

Water column P is frequently an order of magnitude higher in target impoundments compared to reference levels (Figure 17 a – e). However, some levels drop within the range of reference ponds after spring runoff (A2, A3, F1, and N3). P levels in other impoundments rise or remain stable during the growing season (F2, N1, N2, B1 and B2). P levels in P1 also rises slightly during the growing season, however it is still low.

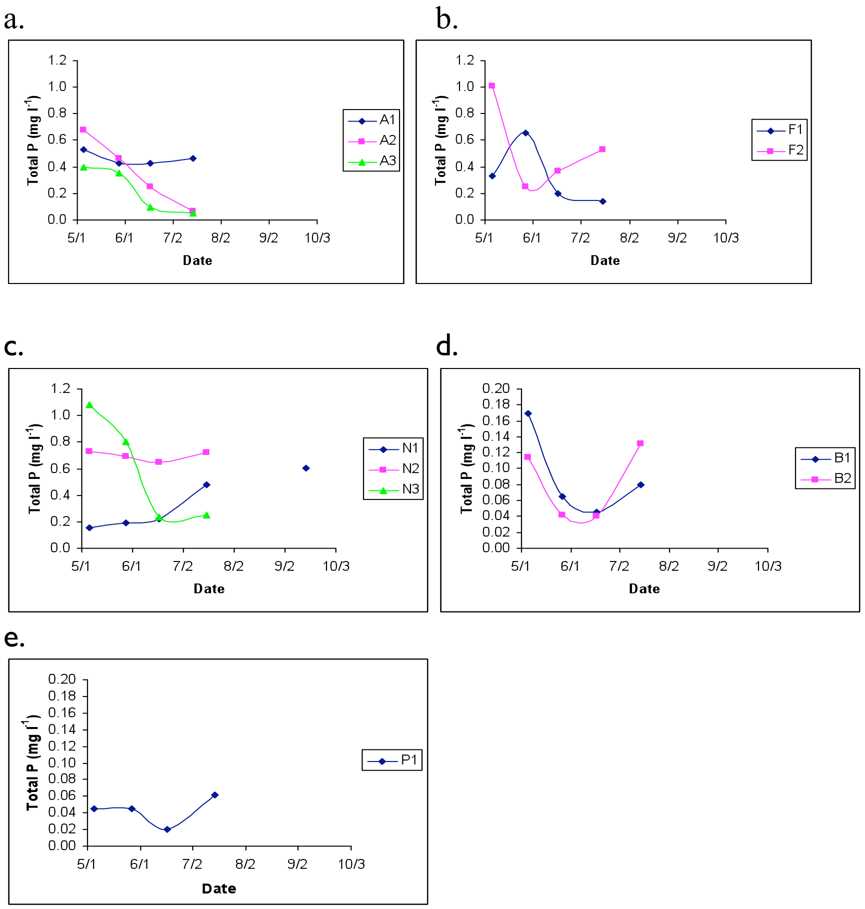


Figure 17 (a – e). Phosphorus at upstream impoundments during 2009. A1 = Ambassador W1, B1 = BRBR Unit 5C, F1 = FB WMA Unit 1, N1 = New State Pond 47, P1 = Public Shooting Grounds Pintail Pond. n = 1

Water column nutrients that rise during the summer months often occurred during July, which typically has very low precipitation from year to year (Table 1). It would seem plausible that macroalgae that develop dense surface mats and dense epiphytic communities in the SAV canopy in those same impoundments would draw the nutrient levels down through absorption and uptake, particularly if water flows are low during the summer. Natural fluctuations from internal cycling within the wetlands may explain increased levels, which has been documented in constructed wetlands (Kadlec and Knight 1996, Kadlec and Wallace 2009). Such fluctuations have also been found to occur on a dial basis in Ambassador W1 (Decatoldo, et al. in press).

Carbon, nitrogen and phosphorus levels in SAV tissues were analyzed for variation within sites to determine whether it is necessary to collect replicate samples rather than one composite per impoundment (Figure 18). There was very little variance in both carbon and nitrogen, however, there was some variance in phosphorus levels, particularly in samples from A2, A3, and B2. Since the samples had low variance in carbon and nitrogen, and tissue phosphorus levels were significantly different among sites ($F_{(df\ 12)} = 5.465$, $P \leq 0.0001$, $r^2 = 0.716$), it seems reasonable to use one composite per site in future collections.

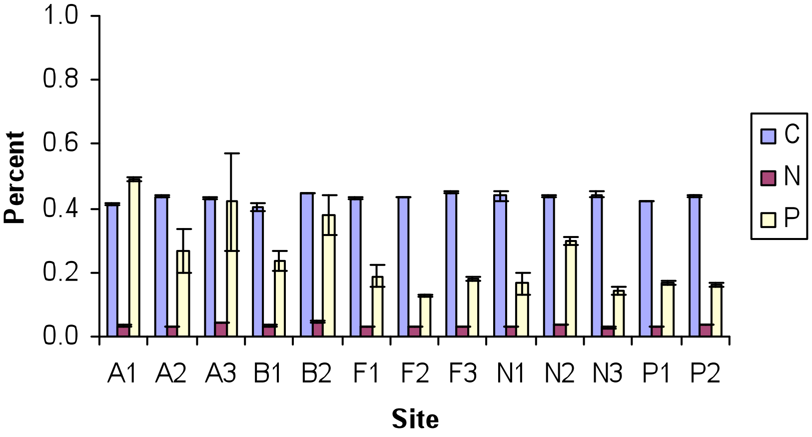


Figure 18. Percent carbon (C), nitrogen (N), and phosphorus (P) in SAV leaf tissue during August 2009.

While 2009 leaf N was not correlated with 2007 sediment N ($P = 0.357$), leaf P was positively correlated with sediment P (Figure 19, $F_{(df\ 1)} = 3.262$, $P = 0.032$, $r^2 = 0.109$). Although SAV leaf CNP is not a likely candidate as an assessment metric due to the labor intensive processing, expense, it still seems necessary to monitor benchmark nutrient levels in the plant tissue until other environmental parameters are shown to explain disparity in biological responses among target impoundments.

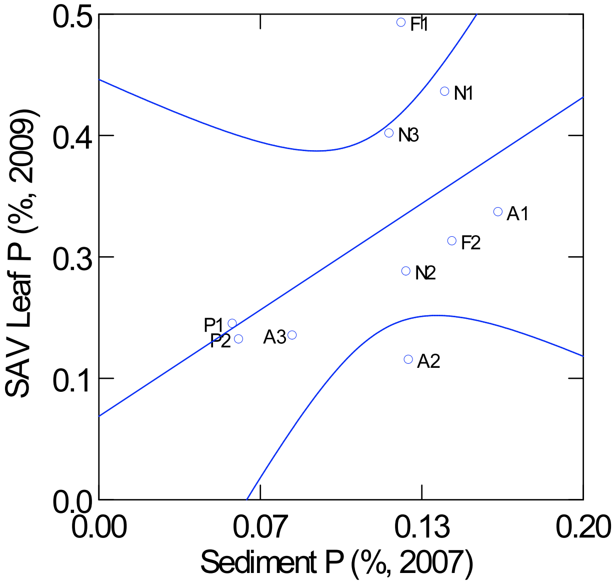


Figure 19. 2009 percent SAV leaf P (± 95% confidence interval) versus 2007 percent sediment P at Farmington Bay and other Great Salt Lake impounded wetlands. A = Ambassador Duck Club, B = BRBR, F = FB WMA, N = New State Duck Club, P = Public Shooting Grounds. Numerals show the successive impoundments at each study area.

BIOENERGETIC CARRYING CAPACITY OF IMPOUNDED WETLANDS

Data presented in this report thus far focus on trophic level shifts within impoundments as part of the development of assessment metrics of biological response to varying environmental parameters. Further emphasis on understanding whether beneficial uses for waterfowl, including their necessary food chain are supported, can be evaluated by determining whether their dietary needs are being satisfied. During 2009, SAV biomass cores were collocated in impoundments were waterfowl were collected to determine the available food at the time of grazing. Number of tubers per m^2 were not significantly different between F1 and B2 (Figure 20), however F1 had significantly higher tuber weight (Figure 21), $F_{(df\ 1)}$ = 2.436, P = 0.136, r^2 = 0.119). Drupelet number and weight were not significantly different between F1 and B2.

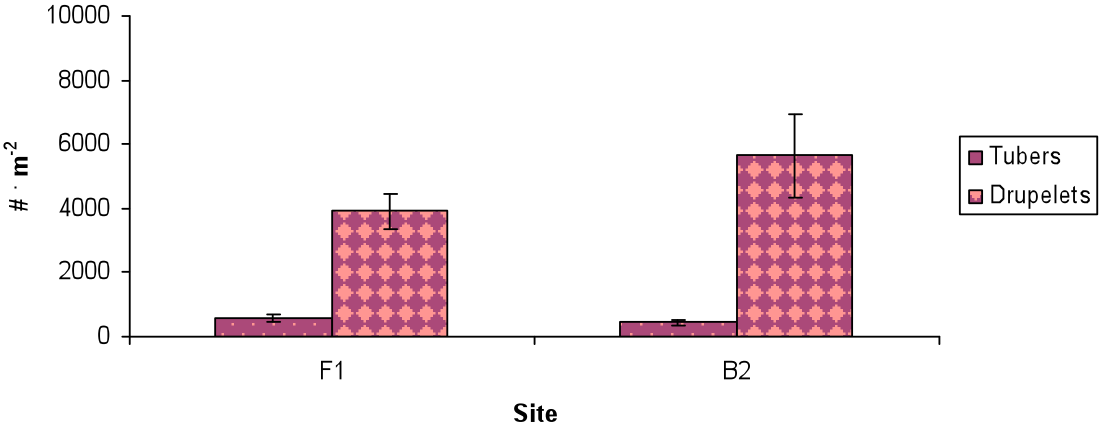


Figure 20. Number of SAV tubers and drupelets ($\# \cdot m^{-2}$) during mid-September, 2009. (n = 10, mean ± se)

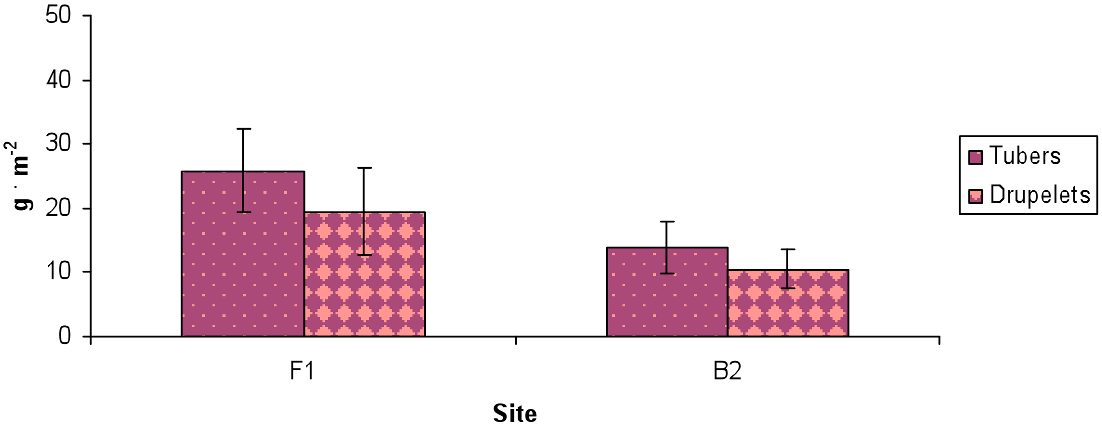


Figure 21. SAV tubers and drupelets ($g \cdot m^{-2}$) during mid-September, 2009. (n = 10, mean ± se)

Duck use days (bioenergetic carrying capacity) of the two impoundments were determined following assumptions by Johnson (2008; Figure 22). Foraging guilds are defined by food item preference and feeding methods. Dabblers acquire most of their energetic requirements from aquatic invertebrates, drupelets and seeds. Example birds within this guild are: Green-winged Teal, Mallard, Northern Pintail, Northern Shoveler, American Widgeon, Cinnamon Teal. Divers eat primarily roots and tubers of SAV.

Example divers are: Redheads, Canvasbacks, and Ring-necked Ducks. A third guild of foraging waterfowl is grazers, which obtain most of their energetic requirements from leafy plant material. Examples of grazers are: Coot and Gadwall. Since above ground biomass was not determined during 2009, the bioenergetic carrying capacity was not determined for the grazers. Instead, calculations were determined for divers and dabblers only. Acreage was provided for Units 1, 2 and Turpin, combined, therefore FB WMA DUD was normalized to B2 acreage for comparison sake. Also, macroinvertebate biomass data was not available to include in the dabbler diet at this time, thus DUD for dabblers is a conservative estimate at F1. SAV in FI provided higher DUD for both divers and dabblers ($x^2 = 1.6^{-34}$, df $_1$, $P < 0.0001$, $x^2 = 7.9^{-46}$, df $_1$, $P < 0.0001$, respectively) than in B2. Refinement of DUD from 2010 data will include total acreage by impoundment and inclusion of macroinvertebrate biomass for the dabbler bioenergetic carrying capacity.

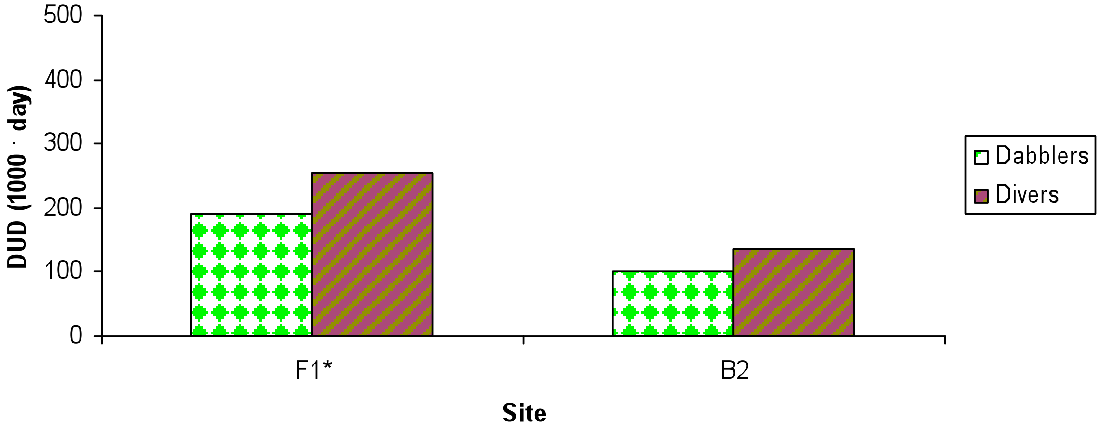


Figure 22. Duck use days (DUD) for dabblers and divers using Farmington Bay Unit 1 (F1) and Bear River Bird Refuge Unit 4C (B2) during September of 2009. * = equivalent acreage as B2. Dabbler diet composed of drupelets only (invertebrates excluded).

SUMMARY

Submerged aquatic vegetation (SAV) of Farmington Bay impounded wetlands has shown different responses to growing conditions in upstream verses downstream impoundments (Miller and Hoven 2007; Hoven 2009; Hoven 2010), yet there is still a question as to whether there is a direct link with water column nutrient concentrations associated with Jordan River vs internal cycling of N and P or even the potential effect(s) of sediment toxicity from sulfides or solubalized toxic metals such as copper, zinc, arsenic or cadmium. Both percent cover SAV and surface mat show significant responses to increasing nutrients in some impoundments, however, the responses are not consistent among all impoundments. During 2007 and 2008, F1 developed very little or only moderate surface mats, respectively. Both years, SAV in F1 did not develop substantial beds and (as in 2005) showed decline as the waterfowl arrived in the early fall. During 2009, F1 SAV developed fairly high cover that was sustained into the fall, demonstrating the variability of response within one impoundment.

When considering water nutrient sources and their affect on biological response, it isn't clear whether water or sediments play stronger roles. And to add more complexity, it isn't always the same impoundments that don't fit the expected relationships. During 2008, F1and N2 both had elevated water column nutrients and both developed low surface mat cover (Hoven 2009). During that same time, F1 developed very low percent cover SAV, while N2 developed a high percent cover of SAV. Further, F1 and A2 show different levels of SAV leaf tissue P when plotted against sediment P (this report, Figure 19). F1 and A2 have comparable sediment P, however, F1 SAV leaves had high levels of P and A2 SAV had low levels of P. A2 showed increasing SAV cover as the season progressed and did not decline during 2008. During 2007, A2 maintained a moderate level of SAV cover into the fall (Hoven 2010). Thus there are responses within the current framework that are not predictable.

It has been suggested that super-shaded conditions from macroalgae and duckweed contribute to the collapse of SAV in Farmington Bay impounded wetlands (Hoven, 2010). While competition for light from other biota and shading from elevated total suspended solids in the water column have been documented as important factors determining the survival of SAV (Twiley et al 1985, Dennison et al. 1993; Fourquerean et al. 2003; Kemp at al. 2004), review of the 2008 data reveals only a weakly significant inverse relationship between percent cover surface mat and SAV (Figure 23, $F_{(df\ 1)} = 3.722$, $P = 0.078$, $r^2 = 0.237$). There was no significant relationship during 2009 for the same parameters ($P = 0.196$). This may be due to the data gaps in water quality relegating a weak factor analysis or that such differences are the result of environmental factors that have not yet been measured, such as sediment chemistry, or simply that conditions during 2009 were different. P2 and F2 fall outside the 95% confidence interval such that there was high percent cover of SAV and moderately high percent cover of surface mat at P2; and moderately high percent cover of SAV and high percent cover of surface mat at F2. Conversely, there was fairly low percent cover of SAV and low percent cover surface mat at both A2 and I2. While low vegetative growth at I2 can be explained by salinity and or temperature limitations, there are possibly other parameters not yet covered by the current assessment metrics that may help clarify our understanding of biological response to environmental parameters in the impoundments. These parameters may be significant data gaps that relate to the health and survival of SAV and need further investigation.

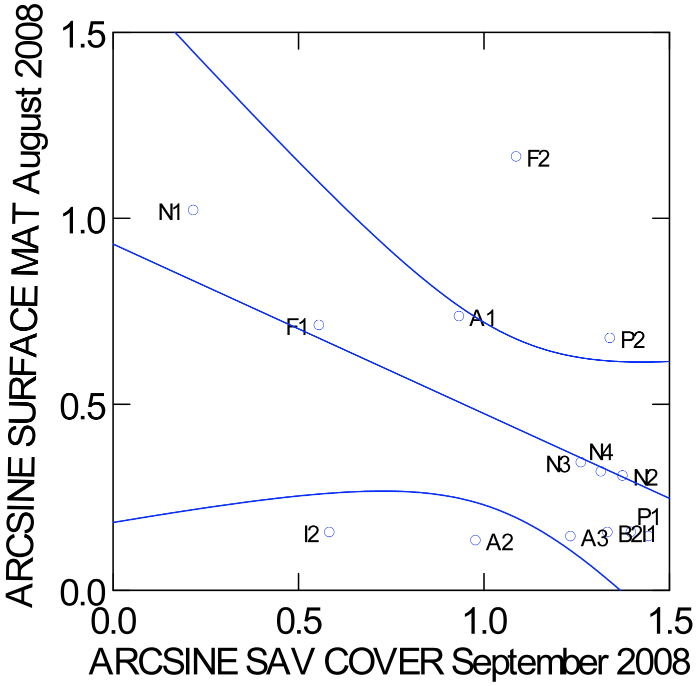


Figure 23. September arcsine transformed SAV cover versus August surface mat during 2008.

Investigation of the rhizosphere (root zone) environment of SAV with respect to organic content and sulfide toxicity may provide additional answers as to why the SAV are unable to persist in some impounded systems. High sediment organic content has been identified as potentially limiting to the survival of seagrasses and freshwater SAV (Barco and Smart 1983) and healthy beds of *Potamogeton pectinatus* (*S. pectinata*) were found in sediment with less than 26 mg C g^{-1} (Van Wijck et al. 1992). Although the mechanism is not clearly understood, there is likely a high oxygen demand for roots of SAV growing in sediment with high organic content due to the tendency of organic-rich sediment to have higher concentrations of phytotoxic metabolites. High light requirements are necessary for plants to oxygenate the rhizosphere in high organic sediment as discussed by Koch (2001). 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 *P. pectinatus* in sediments that ranged from 0.48 – 1.27 mg g^{-1} sulfide. It would be important to identify whether sediment organic content and sulfide confound the effects of shading on SAV survival in Great Salt Lake impounded wetlands and whether the current framework of metrics are better explained.

REFERENCES

Anderson, M.G. & B.J. Low. 1976. Use of sago pondweed by waterfowl on the Delta Marsh, Manitoba. Journal of Wildlife Management 40: 233-242.

Barko, J.W. & M. Smart. 1983. Effects of organic matter additions to sediments on the growth of aquatic plants. Journal of Ecology 71: 161-175.

Chamberlain, J. L. 1959. Gulf coast marsh vegetation as food of wintering waterfowl. Journal of Wildlife Management 23(1):97-102.

Dennison, W. C. and R.S. Alberte. 1986. Photoadaptation and growth of *Zostera marina* L. (eelgrass) along a depth gradient. Journal of Experimental Marine Biology and Ecology 98: 265-282.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. Bioscience 43: 86-94.

Fourqurean, J.M., J.N. Boyer, M.J. Durako, L.N. Hefty, and B.J. Perterson. 2003. Forecasting responses of seagrass distributions to changing water quality using monitoring data. Ecological Applications 13(2): 474-489.

Goldsborough, W.J. 1983. Response of the submerged vascular plant, *Potomogeton perfoliatus* L., to variable light regimes in an estuarine environment. M.S. thesis, Universtiy of Maryland.

Hoven, H.M. 2009. SAV assessment method metrics development for impounded wetlands of Great Salt Lake. The Institute for Watershed Sciences, Kamas, Utah. 38 pp.

Hoven, H.M. 2010. Submerged Aquatic Vegetation of Impounded Wetlands of Farmington Bay, Great Salt Lake. Final Report to DWQ for the 2007 EPA Wetland Program Development Grant. The Institute for Watershed Sciences, Kamas, Utah. 71 pp.

http://www.wcc.nrcs.usda.gov/cgibin/precip.pl?state=utah. National Water And Climate Center, USDA NRCS.

Kadlec, R.H. & R.L. Knight. 1996. Treatment Wetlands. First Edition, CRC Press: Boca Raton, Florida.

Kadlec and Wallace. 2009. Treatment Wetlands. Second Edition, CRC Press: Boca Raton, Florida.

Kantrud, H.A. 1990. Sago pondweed (*Potomogeton pectinatus* L.): A literature review. U.S. Fish and Wildlife Service, Fish and Wildlife Resource Publication 176.

Kemp, W.M., R. Batuik, R. Bartelson, P Bergstrom; V. Carter, C.L. Gallegos, W. Hunley, L. Karrh, E. W. Koch, J. M. Landwehr, K. Moore, L. Murray, M. Naylor, N.B. Rybicki, J.C. Stevenson, and D.J. Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water quality, light regime, and physical-chemical factors. Estuaries 27(3): 363-377.

Kemp, W.M., W.R. Boynton, J.C. Stevenson, and J. Means, eds. 1981. Submerged aquatic vegetation in Chesapeake Bay: Its ecological role in bay ecosystems and factors leading to its decline. Final Grant Report to U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, Md.

Koch, E.W., Beyond Light: Physical, Geological, and Geochemical Parameters as Possible Submersed Aquatic Vegetation Habitat Requirements. Estuaries 24(1): 1-17.

Lind, O.T. 1985. Handbook of common methods in limnology. Kendall/Hunt Publishing Co., Dubuque, Iowa. 199 p.

Miller, T.G. and H.M. Hoven. 2007. Ecological and Beneficial Use Assessment of Farmington Bay Wetlands: Assessment and Site-Specific Nutrient Criteria Methods Development Phase I, Progress Report to USEPA, Region VIII.

Moore, R.L. 1980. Aspects of the ecology and hunting economics of migratory waterfowl on the Texas High Plains. Masters thesis, Texas Tech University. 80 pp.

Nolet, B.A., A. Gyimesi, R.H.G. Kiaassen. 2006. Prediction of bird-day carrying capacity on a staging site: a test of depletion models. Journal of Applied Ecology 75: 1285-1292.

Petrie, M.J., R.J. Drobney, D.A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. Journal of Wildlife Management 62: 1147-1152.

Phlips, E.J., T.C. Lynch & S. Badylak. 1995 Chlorophyll *a*, tripton, color, and light availability in shallow tropical inner-shelf lagoon, Florida Bay, USA. Marine Ecology Progress Series 127: 223-234.

Purol, D.A. 1975. Metabolizable energy of cellulose, three natural foods and three diets of mallards. Thesis, Michgan State University, East Lansing.

Stevenson, J.C., L.W. Staver & K.W. Staver. 1993. Water quality associated with survival of submersed aquatic vegetation along an estuarine gradient. Estuaries 16(2): 346-361.

Twilley, R.R., W.M. Kemp, K.W. Staver, J.C. Stevenson & W.R. Boynton. 1985. Nutrient enrichment of estuarine submersed vascular plant communities. 1. Algal growth and effects on plant production of plants and associated communities. Marine Ecological Progress Series 23: 179-191.

UMRCC WQTS. 2003. Proposed Water Quality Criteria Necessary to Sustain Submersed Aquatic Vegetation in the Upper Mississippi River. Upper Mississippi River Conservation Committee Water Quality Technical Section.

Van Wijck, C., C.J. de Groot & P. Grillas. 1992. The effect of anaerobic sediment on the growth of *Potamogeton pectinatus* L: The role of organic matter, sulfide and ferrous iron. Aquatic Botany 44: 31-49.

Winslow,C.J. 2003. Estimation of waterfowl food abundance in coastal freshwater marshes of Louisiana and Texas. Louisiana Sate University. 59 pp.