Literature Review of Salinity Effects on Submerged Aquatic Vegetation (SAV) found in the Southern Indian River Lagoon and Adjacent Estuaries

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INTRODUCTION

As part of the Monitoring and Assessment Plan (MAP) of the Comprehensive Everglades Restoration Plan (CERP), the South Florida Water Management District (District) participates in: establishing pre-CERP baseline data of SAV (submerged aquatic vegetation) in the Southern Indian River Lagoon (SIRL), the St. Lucie Estuary, the Loxahatchee Estuary, and Lake Worth Lagoon; assessing the response of SAV in the referenced estuaries to the restoration of the Everglades system; and conducting research designed to elucidate cause-and-effect relationships between environmental variables influenced by the restoration plan and SAV health.

Submerged aquatic vegetation (SAV) in coastal systems provide structure and habitat for a wide variety of fauna, stabilize sediment, contribute to trophic pathways by providing a food source to herbivores and detritivores, and are important in nutrient uptake and cycling. Many species of commercially and recreationally important fin and shell fish species (e.g., blue crabs, shrimp, snook, red drum, etc.) utilize submerged aquatic vegetation as nursery areas due to the protective cover and food resources provided by these critically important habitats. In addition to providing vital nursery areas, some seagrass species are grazed directly by sea turtles, manatees, and waterfowl hence their common names of turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and widgeon grass (*Ruppia maritima)*, respectively. The habitat value of some of the more diminutive species (e.g., *Halophila* spp.) has not been investigated in great detail, but their rapid growth rates, high turnover, and ability to colonize deeper water make them important components of the SAV communities in coastal estuaries. In addition to seagrass, attached benthic macroalgae are also an important part of SAV communities in tropical and subtropical systems. Rhizophytic macroalgae in the genera *Halimeda*, *Penicillus*, *Caulerpa*, etc. can provide habitat, stabilize sediments, and provide a food resource to grazing fishes and invertebrates.

Eight target species have been identified as important components of the submerged aquatic vegetation in the District's study region of the southern Indian River Lagoon and associated estuaries. They are *Halodule wrightii, Syringodium filiforme, Thalassia testudinum, Halophila johnsonii, Halophila decipiens, Halophila engelmannii, Ruppia maritima,* and *Caulerpa prolifera*. The first seven species are true angiosperms (flowering plants) while the last, *C. prolifera*, is a green alga that grows attached to the bottom and often occurs in abundance in the Indian River Lagoon system. The District is developing tools to help predict impacts to SAV distribution, biomass, and growth as well as other parameters (e.g., morphometrics, production, diversity, etc.) due to changes in water management in the Southern Indian River Lagoon, the St. Lucie Estuary, the Loxahatchee Estuary, and Lake Worth Lagoon. These predictive tools will be developed using field data, controlled laboratory investigations, and information available in the published and unpublished literature. To contribute to the development of these tools a current literature review of salinity effects on the target SAV species was conducted. In addition, unpublished and ongoing research activities related to salinity effects on the species of interest were identified by contacting scientists engaged in research in this area.

LITERATURE REVIEW

Numerous published and unpublished articles were identified for the eight target species. Some of the papers provide observational data related to the occurrence of a particular species at some measured salinity while others provide quantitative data relating to the physiological effects of salinity on the plants. For some species, very little information was available. A complete list of articles referred to in developing this report is provided in Appendix I and a data base relating those citations specifically with reference to salinity along with the type of study (field or lab, observational or quantitative, etc.) is provided in Appendix II. A summary of the studies referenced in Appendix II is provided below for each of the target species.

Halodule wrightii

Halodule wrightii occurs from North Carolina south along the Atlantic and Gulf coasts, in the Caribbean to warm, temperate South America, northwestern Africa and possibly in the Indian Ocean and the Pacific coast of Mexico (den Hartog 1970). *H. wrightii* is widely distributed and common from the northern to most southern limits of the Indian River Lagoon and associated estuaries (Phillips 1960; Thompson 1978; Dawes et al. 1995; Morris et al. 2000; Provancha and Scheidt 2000). It is the dominant species in the lower portion of the St. Lucie Estuary (URS Greiner Woodward Clyde 1999), is common in Hobe and Jupiter Sounds between St. Lucie and Jupiter Inlets (Kenworthy and Fonseca 1996), occurs throughout the Loxahatchee River Estuary (WildPine Ecological Laboratory 2004), and is present in the Lake Worth Lagoon (Barnes Ferland and Applied Technology 2004). The extensive distribution of *H. wrightii* is likely due to its ability to grow over a wide range of salinity, temperature, and light regimes (Dunton 1996). The seagrass and water quality monitoring programs conducted in the IRL and associated estuaries by St. Johns and South Florida Water Management Districts have not been examined directly for the purpose of making correlations between salinity and species composition. Based on cursory examination of the seagrass distribution and water quality data, however, it is apparent that *H. wrightii* occurs within a wide range of salinity in the SIRL and associated estuaries in a pattern consistent with other field studies (Robert Virnstein, SJRWMD, personal communication; personal observation).

Reported field distributions from estuaries in the Gulf of Mexico and along Florida's east coast have documented *H. wrightii* across a wide range of salinity (ca. 5-60 psu- see references below). In hyper-saline estuaries of Texas (Laguna Madre) *H. wrightii* has been documented at monthly average salinities of 45-52 psu with sparser stands occurring at the upper end of this salinity range (McMahan 1968), and Dunton (1996) documented salinities ranging from 5- 55 psu (measured at 1-3 month intervals) in *H. wrightii* meadows in estuaries along the south Texas coast (Laguna Madre, Guadalupe and Nueces Estuaries). In Dunton's (1996) study, greater biomass and shoot density occurred, however, within estuarine systems with higher overall average salinities (Laguna Madre with 38 psu $\pm$ 0.9 SD and Nueces with 30 psu $\pm$ 0.5 SD vs. Guadalupe with 17 psu $\pm$ 1.2 SD). Adair et al. (1994) also found *H. wrightii* to be the dominant species of seagrass in estuaries along the upper coast of Texas in a single July/August sampling period at sites with corresponding salinities ranging from 10-40 psu.

In the northeastern Gulf of Mexico (Apalachee Bay, FL) Zimmerman and Livingston (1976) documented *H. wrightii* presence in monthly samples over a 15-month sampling period at corresponding salinities (measured at time of sampling) ranging from 17-36 psu. In the final month of sampling, salinity measured 6 psu due to a heavy rainfall event. *H. wrightii* was present at this low salinity, but no subsequent sampling occurred to evaluate potential influence of reduced salinity on *H. wrightii* distribution and abundance.

Six years of annual assessment of benthic vegetation in Charlotte Harbor, FL indicated occurrence of *H. wrightii* at sites with monthly average salinities of 31.6 psu $\pm$ 4.48 SD for the dry season and 21.2 psu $\pm$ 7.94 SD for the wet season (Greenwalt-Bowell et al. 2006). In the Caloosahatchee Estuary, *H. wrightii* occurred in monthly samples over several years at salinities (on day of collection) ranging from 0 to over 35 psu with abundance (as measured by blade density) increasing as salinity increased (Doering et al. 2002).

In northeast Florida Bay *H. wrightii* occurred in abundance at intermediate positions along an estuarine gradient at stations with an average annual salinity of ca. 20-32 psu (Montague et al. 1989; Montague and Ley 1993), and Lirman and Cropper (2003) documented *H. wrightii* (in a single June sampling event) in Biscayne Bay, FL adjacent to the mainland and on a shallow shoal area in the center of bay. In their study, salinities based on mean daily averages over a one year period for eastern (from approximately center of bay east – oceanic influence) and western (approximately center of bay west - terrestrial influence of freshwater from run off and canals) portions of the bay were determined to be 33.1 $\pm$ 2.4 SD and 23.9 $\pm$ 4.8 SD, respectively.

Controlled laboratory investigations confirm *Halodule wrightii*'s ability to tolerate a wide range of salinities. Plants collected from Key Biscayne, FL (salinity ca. 33 psu) exhibited active growth (measured as leaf extension rates) during 2-week exposures to salinities ranging from 5 to 45 psu at 5 psu intervals (Lirman and Cropper 2003). While growth rates did not differ statistically among the different salinity treatments, peak leaf elongation occurred at 35 psu (0.22 cm/day) and the lowest rate occurred at the highest salinity tested, 45 psu (0.17 cm/day). Exposure to high and low salinities for longer periods of time, however, may be more detrimental to *H. wrightii* growth and survival. In earlier studies, McMillan (1974) exposed *H. wrightii* plants collected from Redfish Bay, TX to 23, 37, 50, 60 psu for 13 weeks. Plants subjected to 23 and 37 psu survived the 13-week exposure while those at 50 and 60 psu were severely discolored and dying at the end of the study.

Doering et al. (2002) exposed *H. wrightii* to a lower range of salinities (3, 6, 12, 18, and 25 psu) for 10 weeks. Plants used in the study were collected from the Caloosahatchee Estuary. Date and salinity at time of collection were not provided, but experiments were conducted May - July. Net growth (r), based on change in number of blades or shoots over time using an exponential growth equation, $N_t = N_o e^{rt}$, decreased as salinity decreased, and a 50% loss of shoots occurred after 60 days at 3 psu. Net growth was near zero at 6 and 12 psu, and negative at 3 psu after 60 days exposure. These results are consistent with McMahan's (1968) earlier study where *H. wrightii* died at salinities < 3.5 psu after three weeks of exposure, but survived at 9 psu. McMahan (1968) documented the presence of green leaf tissue as well as the condition of roots after six weeks of exposure to salinities of 0, 3.5, 9, 17.5, 24.5, 35, 44, 52.5, 70, and 87.5 psu. Plants used were collected from Laguna Madre, TX. Salinity of the collection site was not reported, but the range of salinity for field sampling sites in the interior of the lagoon where *H. wrightii* commonly occurs was reported to be 45-52 psu. The number of total or partially green leaves was zero at 0, 3.5, 70, and 87.5 psu while the corresponding root condition was 'dead' at 0, 70, and 87.5 psu, and 'very poor' at 3.5 psu. Based on these results McMahan (1968) concluded that *H. wrightii* could tolerate salinities from > 3.5 to < 70 psu and identified an optimum of 44 psu.

McMillan and Moseley (1967) documented active growth (growth determined by addition of new leaf material after clipping) of plants collected from Redfish Bay, TX (salinity at collection site not indicated). In this study, salinity was gradually increased in outdoor concrete ponds and in temperature and light-controlled indoor tanks from ca. 30 psu up to ca. 75 psu over a 55 day period. The most rapid growth for *H. wrightii* occurred during the period when salinities were increasing from 30 to 50 psu. Koch et al. (2006) conducted similar studies in which plants collected from north-central Florida Bay were exposed to gradual increases in salinity from 35 to 70 psu at a rate of ca. 1.0 psu per day over a one month period to mimic changes in salinity due to evaporation in tropical climates. *H. wrightii* did not exhibit differences in growth (new shoot production ranged from ca. 3 to 6 shoots per day) among salinity treatments, but leaves became chlorotic and photosynthetic efficiency dropped at 70 psu. Over all photosynthetic efficiency, however, was still high across all salinity treatments indicating little effect of hyper-salinity on rates of photosynthesis.

Chesnes (2002) examined the role of salinity fluctuations on *H. wrightii* by assessing the loss of photosynthetic material (% of green tissue), and plant morphometrics under various manipulations of salinity amplitude (0, 7 or 14% of a mean salinity of 18 psu with 4 day wave period), wave periodicity (0, 4, and 8 day periods with salinity fluctuating from 0 – 36 psu around a mean of 18 psu), fluctuations around different mean salinities (9% amplitude around mean of 9 psu [min 0 max 18 psu] and 27 psu [min 18 and max 36 psu] over an 8 day period), and rapidness of change in salinity (stable, square, or pyramid wave types fluctuating from 4 to 32 psu around a mean of 18 psu over an 8 day period). Green leaf indices decreased with increases in salinity wave amplitude, wave periodicity, and suddenness of salinity change. *H. wrightii* survival was also greater when salinity fluctuated within higher salinity ranges (18 – 36 psu range with mean 27 psu) than when they fluctuated within lower salinity ranges (0 – 18 psu with mean 9 psu).

While *H. wrightii* can tolerate a wide range of salinities, reproduction and flowering may be restricted to a more narrow range. *H. wrightii* flowering in field populations in a Texas estuary has been associated with warming water temperatures that coincide with increasing salinity. McMillan (1976) documented salinities at time of flowering in the field between ca. 25 and 35 psu during May through late August. Fruit development of *H. wrightii* plants held at 6, 13, 27, 38, 51, and 64 psu at 23.5 and 27.5^{o}C under a 14-hour photoperiod showed a stronger effect of temperature, however, than salinity on fruit maturation. Fruits matured across all salinities in both temperature treatments, but the development was ca. one week faster at the higher temperature. Additional plants held at 13, 27 and 38 psu and 18.5^{o}C did not show signs of maturing (McMillan 1976).

Although *Halodule wrightii* can withstand the effects of a wide range of salinities, competition with other species may restrict its distribution and abundance. Phillips' (1960) early observations on the distribution of seagrasses in Florida indicated no apparent correlation between salinity and the presence of *H. wrightii*, and that *H. wrightii* was more tolerant of a wide range of salinity than other species. He noted that its distribution appeared to be influenced by the presence of other species such that where other species occurred in abundance *H. wrightii* often did not. Similarly in Biscayne Bay, FL *H. wrightii* is often restricted to areas close to the shoreline and near canal discharge points where daily mean salinity is lower and can vary 10-20 psu over the span of a few days while *Thalassia testudinum* dominates large areas of the rest of the bay where average daily salinities are higher and more stable (ranging from ca. 23-33 psu with SD of 2.4 – 4.8 depending on location in the bay) (Lirman and Cropper 2003). A comparable pattern occurs in regions of northeast Florida Bay where *H. wrightii* often dominates intermediate stations along an estuarine gradient (mean annual salinity range ca. 20-32 psu) while *T. testudinum* is more common at outer stations with higher, less variable salinity (mean annual salinity range ca. 25-35 psu), and *Ruppia maritima* becomes more abundant at intermediate and upper stations along the gradient where annual mean salinity ranges ca. 15-25 psu (Montague et al. 1989; Montague and Ley 1993). While *H. wrightii* does occur within the more central regions of Florida Bay where salinities are less affected by fresh water, *T. testudinum* is by far the local dominant with *H. wrightii* occurring in greater abundance along the mainland where there is greater influence of terrestrial inputs of fresh water (Zieman et al. 1989).

Along Texas' upper coast Adair et al. (1994) documented *H. wrightii* across a wide range of salinities, but found that it dominated in the 30-40 psu range while *Ruppia maritima* was more common in salinities of 10-30 psu. McMahan (1968) found that *H. wrightii* occurred in Laguna Madre, TX (a typically hyper-saline lagoon) at salinities ranging between 45-52 psu, while *Syringodium filiforme* was the dominant vegetation near gulf passes where salinity was 31-33 psu. Species shifts with long-term temporal changes in salinity have also been documented in the Laguna Madre. Quammen and Onuf (1993) evaluated changes in the distribution of seagrass in the lagoon from the 60's, 70's, and 80's. In 1965 the lower lagoon was dominated by *H. wrightii* with a meadow of *S. filiforme* and patches of *T. testudinum* occurring close to the gulf opening near Port Isabel, and a bare deep area was present north of Port Mansfield. In 1974 the area of bare bottom and the *S. filiforme* bed had expanded greatly at the expense of *H. wrightii*. By 1988 almost the entire length of the lower lagoon basin was dominated by *S. filiforme* at intermediate depths on the east side, and *T. testudinum* had replaced *H. wrightii* in the southern area of the lagoon. Concomitant with the changes in the distribution of seagrasses was a general reduction in salinity. Historical salinity records indicate salinity values commonly in excess of 60 psu in the 1940's. Since 1967 salinities have rarely exceeded 40 psu. They attributed the species shifts to maintenance of inlets and dredging of channels that increased water exchange between the lagoon and the Gulf of Mexico moderating the salinity conditions making it more suitable for species that are less tolerant of hyper-saline waters.

In Charlotte Harbor, *H. wrightii* was the most common species in areas with the widest range of salinity (wet season range ca. 8 to 32 psu with mean 21.20 psu $\pm$ 7.94 SD, dry season range ca. 23 to 38 psu with mean 31.6 psu $\pm$ 4.48 SD) while other species (*T. testudinum* and *S. filiforme*) were more common in regions with higher and less variable salinity regimes (*T. testudinum* wet season range ca. 12 to 35 psu with mean 24.6 $\pm$ 6.14 SD, dry season range ca. 28 to 38 psu with mean 33.4 $\pm$ 3.48 SD and *S. filiforme* wet season range ca. 20 to 35 psu with mean 28.90 $\pm$ 4.67 SD, dry season range ca. 28 to 38 psu with mean 34.70 $\pm$ 2.72 SD) (Greenwalt-Bowell et al. 2006), and in the Caloosahatchee Estuary *H. wrightii* is typically replaced downstream by *T. testudinum* and upstream by *Vallisneria americana* (Doering et al. 2002).

Other environmental factors interacting with salinity can influence the distribution and abundance of submerged aquatic vegetation. Modeling can be a useful way to examine the potential interactive effects of multiple environmental factors affecting growth, production, and species composition of seagrass meadows. Modeling exercises incorporate field and laboratory data to make predictions of how changes in water quality may affect distribution and abundance of target seagrass species. Fong and Harwell (1994) created a mathematical model using published data on temperature, salinity, nutrient, and light requirements for three species of seagrass, *Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme*. Their model predicted that *H. wrightii* would be the community dominant under high nutrient conditions with extremes in temperature and salinity. The model only considered responses to seasonal and spatial changes in salinity levels, and did not consider the effects of shorter-term fluctuations in salinity.

Lirman and Cropper (2003) further developed the model to include a short-term salinity response function, and additional data from field and laboratory studies specific to Biscayne Bay, FL were used in model parameterization. They concluded that freshwater inputs and associated decreases in salinity would influence the distribution and growth of individual species of seagrass as well as influence competitive interactions between them that could result in species replacements under certain conditions. According to their model runs for Biscayne Bay, only when mean salinity values for the western portion of the bay were reduced by 20 psu year round would *H. wrightii* out-compete and replace *T. testudinum*.

Fourqurean et al. (2003) used an extensive seagrass and water quality data base from Florida Bay to forecast potential changes to seagrass distributions with alterations of freshwater delivery to northeast Florida Bay through the Everglades. Mean salinity, salinity variability, light, sediment depth, and nutrients were important predictor variables in the model. Model runs predicted that increased freshwater input would result in expansion of species such as *H. wrightii* that are more tolerant of reduced salinity.

Madden and McDonald (2006) also developed a seagrass community model to evaluate the effects of salinity on seagrasses in Florida Bay. The model currently predicts changes in gC/m^2 of *H. wrightii* and *T. testudinum* under different scenarios, and work is in progress to include *R. maritima*. The baseline calibration of the model interpolates instantaneous salinity from salinity data measured at 15 minute intervals. Baseline model predictions indicate that *H. wrightii* is better adapted to moderate to low salinities (ca. 15-30 psu). Sensitivity analyses performed over several salinity averaging schemes (daily, 7-day, 14-day, 30-day, and monthly) indicate that *T. testudinum* expands at the expense of *H. wrightii* as the averaging period increases. Increasing the averaging period increases overall salinity and diminishes variability by reducing the frequency of extreme salinity spikes.

Thalassia testudinum

Thalassia testudinum, or turtle grass, is considered a climax species in subtropical and tropical seagrass communities. It is distributed throughout the Gulf of Mexico and Florida Bay, the Caribbean, and in coastal waters and estuaries along the east central coast of Florida (Dawes 1998). Its distribution in the Indian River Lagoon extends from Sebastian Inlet south (Thompson 1978; Dawes et al. 1995; Morris et al. 2000). In the Southern Indian River Lagoon and associated estuaries it has been documented in the Loxahatchee River estuary in small patches (WildPine Ecological Laboratory 2004), in low abundance in the Lake Worth Lagoon (Barnes Ferland and Applied Technology 2004), in the lower portions of the St. Lucie Estuary (Woodward-Clyde 1998), and in the IRL near St. Lucie Inlet and the mouth of the St. Lucie Estuary (Virnstein and Cairns 1986; Morris et al. 2000).

T. testudinum is considered a stenohaline, marine species with optimum reported salinities based on field distributions and laboratory studies ranging from ca. 25-40 psu (see references below). Phillips (1960) reported the presence of *T. testudinum* at sites throughout Florida with salinities ranging ca. 20-40 psu and even as low as 10 psu following a rainstorm. He noted a correlation between salinity > 25 psu and *T. testudinum* dominance at his sample stations and concluded the optimum salinity was between ca. 25 and 38 psu. This conclusion was based on similarity in plant growth and distribution among sites across this range of salinity. In Adair et al.'s (1994) summer survey of Texas estuaries in the Galveston and Matagorda Bay areas *T. testudinum* occurred at salinities of 30-40 psu (measured at time of seagrass collection), but it was not the dominant species in the region. Similarly Quamman and Onuf (1993) documented *T. testudinum* beds near passes connecting Laguna Madre, TX to the Gulf of Mexico with the closest salinity recorder indicating values of ca. 30-40 psu.

In the northeastern Gulf of Mexico (Apalachee Bay, FL), Zimmerman and Livingston (1976) found *T. testudinum* in monthly samples over a 15-month sampling period at corresponding measured salinities ranging from 17-36 psu. In the final month of sampling, salinity was reduced to 6 psu due to rainfall. *T. testudinum* was present at this low salinity, but subsequent effects of the reduced salinity on abundance and distribution of *T. testudinum* were not determined. In annual surveys of submerged aquatic vegetation conducted September through December in the Charlotte Harbor area of Florida's west coast, Greenwalt-Bowell et al. (2006) found that over a 6 year study period *T. testudinum* occurred at sites with dry-season salinities ranging from ca. 28 to 38 psu with mean 33.4 $\pm$ 3.48 SD and wet-season salinities ranging from ca. 12 to 35 psu with mean 24.6 $\pm$ 6.14 SD.

Lirman and Cropper (2003) found a similar distribution for *T. testudinum* in Biscayne Bay on the southeast coast of Florida. They surveyed benthic vegetation throughout the bay in a single June sampling event to quantify the distribution of seagrass. They divided the bay into two salinity zones based on mean daily salinity values; the east side of the bay with higher and more stable salinities (mean 33.1 psu $\pm$ 2.4 SD), and the west side of the bay with lower and more variable salinity (mean 23.9 psu $\pm$ 4.8 SD) due to the influence of runoff and canal discharges. *T. testudinum* was the dominant vegetation in both salinity zones being replaced by *H. wrightii* only along the margins of the western side of the bay where the immediate effects of freshwater runoff and canal discharge can lower salinity 10 - 20 psu over the span of a few days. Along an estuarine gradient in northeast Florida Bay *T. testudinum* occurred in greater abundance at outermost stations with an average annual salinity of ca. 25-35 psu (Montague and Ley 1993), and it has been documented as the dominant vegetation within Florida Bay (Zieman et al. 1989).

Although *T. testudinum* is distributed across salinities ranging from ca. 25 to 40 psu, greater abundance and production are usually associated with higher (ca. 30-40 psu) and more stable salinity. Zieman et al. (1989) sampled 108 stations throughout Florida Bay in the summer of 1984 for biomass and leaf production. While salinity measurements were not provided, production of *T. testudinum* increased to the south and west, and was lower in the northeast corresponding to salinity gradients in the bay.

Tomasko and Hall (1999) found an overall weak, but significant relationship between productivity and salinity over a broad range of salinities (ca. 5 to 35 psu -measured at the time production estimates were being made) for *T. testudinum* in Charlotte Harbor, FL. Production estimates were made at approximately 2-3 month intervals between April 1995 and August 1996. Salinity was measured at the start and end of each production measurement period and then averaged (n=2 for each time production was estimated). When they compared average production for time periods with average salinities < 20 psu to time periods with average salinities > 20 psu there was significantly lower production during low salinity than during high salinity periods.

Tomasko and Hall's (1999) results are consistent with those of Irlandi et al. (2002) where greater production and biomass of *T. testudinum* occurred on the eastern side of Biscayne Bay, FL where salinities were higher and more stable (ca. 30-35 psu) than on the western side of the bay where salinities were lower (ca. 20-25 psu) and more variable due to the influence of freshwater discharges from canals and runoff. Zieman (1975), also working in Biscayne Bay, found that *T. testudinum* growth and production were reduced in the field at salinities below their optimum of ca. 30 psu, but that plants recovered when salinities returned to more favorable levels approaching the optimum 30 psu.

Zieman et al. (1999) examined long-term data sets of water quality and seagrass abundance and production in Florida Bay and found a clear and negative relationship between summer growth rates of *T. testudinum* and water column salinities ranging between 25 and 55 psu. This relationship, however, did not hold for winter samples suggesting an interaction between some other environmental factor (temperature and/or light) and salinity.

Several controlled laboratory studies manipulating salinity have demonstrated maximum growth rates and/or optimum photosynthetic performance to be between 30-40 psu for *Thalassia testudinum* (see references below). McMillan (1974) subjected *Thalassia* plants collected from Redfish Bay, TX to salinities of 5, 10, 13, 18, 23, 37, 50, 60 psu for 3 months. Plants lost all green tissue at 5 psu, retained some green tissue at 10 psu and survived between 10-50 psu for 2 weeks, but mortality began to occur at 60 psu after 2 weeks. Similarly Berns (2003) found that seedlings grown from field collected seeds exhibited reduced photosynthetic performance above and below the 30-40 psu optimum and died after 28 days exposure to 0 and 60 psu, the low and high salinities tested. Plants collected from Key Biscayne, FL (salinity ca. 33 psu) exhibited active growth (measured as leaf extension rates) during 2-week exposures to salinities ranging from 5 to 45 psu at 5 psu intervals (Lirman and Cropper 2003). In that study, *T. testudinum* demonstrated peak leaf elongation rates at 40 psu (0.08 cm/day), and growth decreased gradually as salinity decreased. At 5 psu leaf extension rates were on average 0.05 cm/day, and mean leaf extension rates were lowest at 45 psu (0.03 cm/day). No mortality was reported for the 2-week exposure period.

McMillan and Moseley (1967) examined the influence of hyper-salinity on *Thalassia testudinum*. They documented active growth (growth determined by addition of new leaf material after clipping) of plants collected from Redfish Bay, TX (salinity at collection site not indicated). In that study, salinity was gradually increased in outdoor concrete ponds and in temperature and light-controlled indoor tanks from ca. 30 psu up to ca. 75 psu over a 55 day period. The most rapid growth for *T. testudinum* occurred for the indoor plants during the period when salinities were increasing from 30 to 60 psu. After reaching 60 psu at day 40, growth leveled off. In the outdoor ponds plants continued to exhibit positive growth up to 70 psu.

Koch et al. (2006) assessed the influence short-term (3 days) pulsed increases in salinity on *T. testudinum* (plants collected from Florida Bay in July) maintained hydroponically (with roots in separate medium maintained at 35 or 40 psu) by measuring leaf growth and photosynthetic response when subjected to salinities ranging from 35 to 70 psu. Rates of photosynthesis were lower as salinity increased, especially above 45 psu, and leaf growth rates declined beyond 45 psu with plants growing significantly faster at 35 psu (ca. 3.5 mm/day) than at salinities $\geq$ 55 psu (ca. 1.5 mm/day). Koch et al. (2006) also exposed *T. testudinum* planted in sediment to gradual increases in salinity from 35 to 70 psu at a rate of ca. 1.0 psu per day over a one month period to mimic changes in salinity due to evaporation in tropical climates. Only at the highest salinities (65 and 70 psu) did leaf elongation and photosynthetic performance decrease. Plants grew across all salinities, but growth rates were less than 2 mm/day in the highest salinity treatments. Shoot densities remained fairly stable throughout the experiment across the range of salinities, but decreased by 25% in the 65-70 psu treatments.

Doering and Chamberlain (2000) examined the influence of lower salinities on *T. testudinum* plants collected from the Caloosahatchee Estuary during the summer/wet season (salinity ca. 25-30 psu) and in the winter/dry season (salinity ca. 30-35 psu) by exposing them to salinities of 6, 12, 18, 25, and 35 psu for 43 days. In both seasons plants survived exposure to 6 psu, but plant morphometrics, including number of blades, number of blades/shoot, and biomass of blades, were less than the other salinity treatments. Plants in 12-35 psu had similar morphometric characteristics with no differences in number of blades, number of blades/shoot or biomass among the different salinities over the 43 day exposure period. Final length of blades at the end of experiment, however, increased as salinity increased. While elongation and production occurred at all salinities, elongation rates of newly formed blades were also positively correlated to salinity and highest between 18-35 psu.

Chesnes (2002) examined the role of salinity fluctuations on *T. testudinum* by assessing changes in leaf coloration as an indication of loss of photosynthetic material and measuring leaf and rhizome morphometrics before and after exposure to various manipulations of salinity amplitude (0, 7 or 14% of a mean salinity of 18 psu with 4 day wave period), wave periodicity (0, 4, and 8 day periods with salinity fluctuating from 0 – 36 psu around a mean of 18 psu), fluctuations around different mean salinities (9% amplitude around mean of 9 psu [min 0, max 18 psu] and 27 psu [min 18, max 36 psu] over an 8 day period), and rapidness of change in salinity (stable, square, or pyramid wave types fluctuating from 4 to 32 psu around a mean of 18 psu over an 8 day period). Biological parameters of *T. testudinum* were negatively correlated with increasing salinity wave amplitudes, frequencies, and suddenness of change, and the effect of salinity fluctuation dampened when salinity fluctuated within a range of higher salinities (18 – 36 psu range with mean 27 psu) than when they fluctuated within lower salinity ranges (0 – 18 psu with mean 9 psu). He also looked at the interaction of salinity fluctuation and light on photosynthetic performance (measured as oxygen evolution) and found salinity fluctuation to have more of an influence on *T. testudinum* survival than reduction of light.

Controlled manipulations of multiple environmental factors and multivariate analyses of field data emphasize the importance of interactions between salinity and other environmental variables such as temperature and nutrient conditions. When temperature and salinity from field sites were both taken into consideration Tomasko and Hall (1999) saw the greatest production of *T. testudinum* at ca. 25-35 psu and 25-30^{o}C. Production was lowest at salinities < 15 psu with warm water temperatures indicative of the summer rainy season and at salinities of 20-35 psu with cooler water temperatures representative of winter time conditions. Koch and Erskine (2001) examined the interactive effects of sulfides with temperature and salinity and found sulfides in conjunction with high salinity (55-60 psu) and high temperature had a negative effect on *T. testudinum* while sulfides alone did not. Plants also survived at high salinity (55-60 psu) without sulfides but growth was lower than in controls at 36 psu. Kahn and Durako (2006) included ammonium levels as a variable in their study to address how seedlings respond to salinity and nutrient conditions. Plants exhibited decreased survival at 10, 50, and 60 psu (optimum 30-40 psu) and increased levels of ammonium further decreased growth at low salinity.

Fong and Harwell's model (1994) (see model discussion above) predicted that *T. testudinum* would be the community dominant under normal bay or estuarine conditions in subtropical and tropical systems that are typically characterized as having high light levels ($\geq$ 425 μmol photons/m^2/day), moderate seasonal variability in temperature (ca. 20-26^{o}C) and salinity (ca. 30-45 psu), and low water column nutrient conditions (which would limit epiphyte growth). Lirman and Cropper's (2003) further refinement of the model predicted that growth rates of *T. testudinum* would be expected to decrease with lowered salinity, but that it would still dominate nearshore communities of Biscayne Bay unless mean salinity values were drastically reduced by 20 psu year round. As predicted by the Fourqurean et al. (2003) model for Florida Bay, increased freshwater input to northeast Florida Bay would result in decreased abundance of *T. testudinum* and expansion of other species that are more tolerant of reduced salinity such as *Halodule wrightii* and *Ruppia maritima*. Similarly Madden and McDonald's (2006) model for Florida Bay predicts that *T. testudinum* will be the dominant species under hyper-saline conditions, and as the averaging period for salinity increases from daily up to monthly (including 7-day and 14-day periods in between) *T. testudinum* will expand as *H. wrightii* decreases due to an overall increase in average salinity along with reductions in salinity variation.

Syringodium filiforme

Syringodium filiforme occurs throughout the Gulf of Mexico, Florida Bay and up the east coast of Florida to northern Indian River, the Carribbean Sea, Bermuda and the Bahamas (den Hartog 1970; Phillips 1960). *S. filiforme* does not occur, however, throughout the entire range of the Indian River Lagoon (IRL) complex. Within the IRL complex it occurs in the Mosquito Lagoon, the Banana River, in the Indian River Lagoon proper from Sebastian Inlet to Vero Beach, and South of Ft. Pierce Inlet all the way to Jupiter Inlet, but it does not occur in the central region of the lagoon near Melbourne (Phillips 1960; Thompson 1978; Kenworthy and Fonseca 1996; Morris et al. 2000; Provancha and Scheidt 2000). In the associated estuaries of the SIRL *S. filiforme* was not reported as being present in the lower St. Lucie Estuary (URS Greiner Woodward and Clyde 1999), but it does occur in the Loxahatchee River Estuary (WildPine Ecological Laboratory 2004). It is a primary component of seagrass beds (along with *H. wrightii*) in Hobe and Jupiter Sounds (Kenworthy and Fonseca 1996), and is present in low abundance in Lake Worth Lagoon (Barnes Ferland and Applied Technology 2004).

Distributional data indicate that *S. filiforme* generally occurs at salinities ranging from ca. 20-35 psu (see references below). McMahan (1968) documented *S. filiforme* meadows in Laguna Madre, TX near passes connecting the lagoon to the Gulf of Mexico where salinity was 31-33 psu. In Apalachee Bay, FL (northeastern Gulf of Mexico), Zimmerman and Livingston (1976) documented the occurrence of *S. filiforme* in monthly samples over a 15-month sampling period at salinities ranging from 17-36 psu (measured at time of sampling). In the final month of sampling, salinity was reduced to 6 psu due to a heavy rainfall event. While *S. filiforme* was present at this salinity, the effects of the low-salinity event on subsequent distribution and abundance were not determined. Greenwalt-Bowell et al. (2006) documented the presence of *S. filiforme* over 6 years of annual sampling (fall sampling period) at stations in Charlotte Harbor, FL with a wet season salinity range of ca. 20 to 35 psu (mean 28.90 $\pm$ 4.67 SD) and a dry season salinity range of ca. 28 to 38 psu (mean 34.70 ± 2.72 SD). Lirman and Cropper (2003) found *S. filiforme* during a June sampling period primarily around Key Biscayne in Biscayne Bay, FL on the eastern side of bay where annual daily salinity averages 33.1 ± 2.4 SD, and in Florida Bay, FL *S. filiforme* generally occurs in deeper areas (ca. 3 m) of more oceanic influence (Zieman et al. 1989). Phillips' (1960) survey of seagrasses in Florida indicated *S. filiforme* occurring at a site with salinity as low as 10 psu. This, however, was an unusually low salinity record with normal salinities at the site being ca. 20 psu.

Phillips (1960) also documented large stands of *S. filiforme* from Sebastian to St. Lucie Inlet, FL at salinities ranging between 22 and 35 psu, and large stands of *S. filiforme* have been documented in the northern Indian River, FL at salinities of ca. 20-30 psu (Gilbert and Clark 1981), and in the northern Banana River, FL at salinities of 26-32 psu (Hanisak 2002). Provancha and Scheidt (2002) documented *S. filiforme* in the Banana River and Mosquito Lagoon along some of their monitoring transects between 1983 and 1996 in low abundance (< 5 % cover). Salinities in the Banana River ranged from ca. 12 to 30 with a mean ca. 20-25 psu, and salinities in Mosquito lagoon ranged from ca. 20 to 40 with a mean of ca. 30 psu over the study period.

Syringodium filiforme's inability to withstand higher salinities outside its optimum of ca. 20-35 has been fairly well documented in experimental studies. Early work done by McMillan and Moseley (1967) suggested that *S. filiforme* was the least tolerant to increasing salinities from 28.8 to 70 psu of all species tested including *Thalassia testudinum*, *Halodule wrightii*, and *Ruppia maritima*. They documented active growth (growth determined by addition of new leaf material after clipping) of plants collected from Redfish Bay, TX (salinity at collection site not indicated). In their study, salinity was gradually increased in temperature and light-controlled indoor tanks from ca. 30 psu up to ca. 75 psu over a 55 day period. *S. filiforme* demonstrated active growth between 30 and 40 psu and then stopped adding new leaf material. McMahan (1968) documented the presence of green leaf tissue as well as condition of roots after six weeks of exposure to salinities of 35, 44, and 52.5 psu. Plants used in the lab study were collected from Laguna Madre, TX. Salinity of the collection site was not reported, but the range of salinity for field sampling sites in the gulf passes where *S. filiforme* commonly occurs was 31-33 psu. Based on his results McMahan (1968) concluded that survival was greater at 35 than 44 psu and plants died at 52.5 psu within 21 days of exposure. Lirman and Cropper (2003) found *S. filiforme* to have an even narrower range of tolerance to high salinity. In their study plants collected from Key Biscayne, FL (salinity ca. 33 psu) grown at salinities ranging from 5 to 45 psu at 5 psu intervals exhibited optimum growth at 25 psu (0.34 cm/day) with dramatic decreases in growth on either side of this optimum. Leaf extension rates at the extreme high and low salinities were 0.12 cm/day (45 psu) and 0.08 cm/day (5 psu), respectively. No mortality was reported for the 2-week exposure period. McMillan (1974) subjected *Cymodocea* (name change to *Syringodium*) plants collected from Redfish Bay, TX to salinities of 5, 10, 13, 18, 23, 37, 50, 60 psu for 3 months. Plants lost all green tissue at 5 psu, retained some green tissue at 10 psu and survived between 10-50 psu for 2 weeks, but mortality began to occur at 60 psu after 2 weeks.

There was little reference to experimental studies assessing the lower salinity tolerance of *Syringodium filiforme*. As indicated above, McMillan (1974) documented mortality (loss of all green tissue) for plants at 5 psu, and while plants survived for 2 weeks at 10 psu they had lost most of their chlorophyll. Lirman and Cropper (2003) found that growth was sharply reduced at salinities below 25 psu (see above) but did not indicate mortality at salinities as low as 5 psu for a two-week period. Although not an experimental determination of the effects of low salinity in the laboratory, Hanisak (2002) documented a severe decline in *S. filiforme* populations in the northern Banana River, FL between 1993 and 1995 associated with heavy rainfall and persistently low salinity. Following a year of high and stable salinities of 26-32 psu a heavy rainfall event reduced salinities to 13.5-19.8 psu. These low salinities persisted for the second year of the study due to the long residence time of water in the region. Associated with the sharp and persistent decrease in salinity was the decline in shoot density and biomass of the three species of seagrass that occurred in the region *(Halodule wrightii, Syringodium filiforme, and Halophila engelmannii*). By the end of the second year *H. wrightii* had begun to recover, but after eight years *S. filiforme* still had not (Hanisak 2002). Provancha and Scheidt (2000) also noted that in the Banana River *Ruppia maritima* expansion occurred over periods of reduced salinity that corresponded to decreases in *H. wrightii* and *S. filiforme* cover between 1985 and 1996.

Halophila decipiens

Halophila decipiens is an annual tropical species (den Hartog 1970) that repopulates from seed each year. *H. decipiens* is considered a deep water species and occurs on the continental shelf (at about 20 m) adjacent to the Indian River Lagoon, in the Gulf of Mexico, the West Indies and Indo-Pacific (den Hartog 1970). Within the Indian River Lagoon system, it occurs in the southern half of the Lagoon in relatively high salinity areas often in deeper areas (> 2m) (Morris et al. 2000). *H. decipiens* is likely associated with greater depths due to an intolerance of high irradiance (Dawes et al. 1989; Durako et al. 2003). Although *H. decipiens* often occurs in deep water depths (ca. 20 m) and has reduced photosynthetic performance at high irradiance (Durako et al. 2003), South Florida Water Management District staff have observed this species in water < 2 m deep in the Pecks Lake area of the SIRL, near Coral Cove Park in close proximity to Jupiter Inlet, and at Boy Scout Island between St. Lucie Inlet and the Stuart Causeway in the SIRL (Rebecca Robbins, SFWMD, personal communication). In the associated estuaries of the SIRL *H. decipiens* was not reported as being present in the lower St. Lucie Estuary (URS Greiner Woodward and Clyde 1999), it was the second most prominent seagrass in annual surveys (2000-2003) conducted in the Lake Worth Lagoon by Barnes Ferland and Applied Technology (2004), and was not reported to occur in great abundance in the Loxahatchee River Estuary (WildPine Ecological Laboratory 2004)

Only one study could be found relating experimental manipulations of salinity and the effects on *H. decipiens*. Dawes et al. (1989) collected *H. decipiens* from Anclote Key, FL in 20 m of water. Salinity at the site of collection ranged from 31-33 psu over a five year period. Plants were brought to the lab and acclimated for three days to salinities of 5, 15, 25, and 35 psu. Rates of photosynthesis were measured on excised leaves. Plants died at 5 psu and positive O_2 evolution occurred only at 35 psu indicating that *H. decipiens* was intolerant of salinities < 35 psu.

Halophila engelmannii

Halophila engelmannii occurs in Florida, the Bahamas, Texas and the West Indies (den Hartog 1970). The northern Indian River Lagoon is considered the distributional limit for *H. engelmannii* along the east coast of Florida (Phillips 1960). *H. engelmannii* is patchily distributed throughout the IRL, but is not common south of the Sebastian Inlet area (Dawes et al. 1995). In the SIRL and associated estuaries it has been documented in the Loxahatchee River Estuary, the Lake Worth Lagoon, and the lower St. Lucie Estuary, but in low abundance (WildPine Ecological Laboratory 2004, Barnes Ferland and Applied Technology 2004, and URS Greiner Woodward Clyde 1999, respectively),

Distributional studies have documented *Halophila engelmannii* across a wide range of salinities. According to Phillips (1960) *H. engelmannii* inhabits Florida waters ranging in salinity from 5 to 35 psu. In Apalachee Bay, FL (northeastern Gulf of Mexico), Zimmerman and Livingston (1976) noted the occurrence of *H. engelmannii* in monthly samples over a 15-month sampling period at salinities ranging from 17-36 psu (measured at time of sampling). In the final month of sampling, salinity was reduced to 11 psu due to a heavy rainfall event. While *H. engelmannii* was present at the lower salinity, potential impacts of the reduced salinity event on the distribution and abundance were not evaluated. Along the Texas coast Adair et al. (1994) found *H. engelmannii* at stations ranging in depth from 35 to 110 cm with salinities of 30-40 psu in a single summer sampling event.

In laboratory studies, flowering of *Halophila engelmannii* did not occur at salinities of 10 and 18, but when plants were moved to higher salinities of 27 and 35 psu seed production occurred (McMillan 1976). Flowering of field populations occurred in Texas estuaries in April and May at salinities of 25 and 36 psu (McMillan 1976) suggesting that although plants may be able to tolerate salinities below 25 psu they may not be reproductively active.

Dawes et al. (1987) measured rates of photosynthesis and respiration of *H. engelmannii* plants collected from oceanic and estuarine source populations. Plants were exposed to salinities of 5, 15, 25, and 35 psu. The estuarine population showed greater photosynthesis at 15 and 25 psu while the oceanic population had greater rates of photosynthesis at 25 and 35 psu suggesting plants from different regions may be acclimated to local conditions.

Fewer studies have addressed the upper salinity tolerance for *H. engelmannii*, but one study indicated that active growth continued to occur as salinities were increased from 28.8 up to 70 psu (McMillan and Moseley 1967), and McMillan (1974) exposed *Halophila* plants to salinities of 23, 37, 50, and 60 psu for 13 weeks and reported survival of plants at 23 and

37 psu over the experimental time period with coloration loss and mortality occurring at 50 and 60 psu.

Halophila johnsonii

Halophila johnsonii has only been identified from the east coast of Florida from Sebastian Inlet south to Key Biscayne, FL (Eiseman and McMillan 1980; Kenworthy 1993). In the IRL the overall geographic range is from Sebastian Inlet to Jupiter Inlet, where it has been documented across a wide range of environmental conditions (Kenworthy 1993; Virnstein et al. 1997).

Eiseman and McMillan (1980) reported occurrence in salinities ranging from 24.3 to 43 psu. Initial measurements of rates of photosynthesis at short-term (3 day) exposures to salinities of 5, 15, 25, 35 psu indicated that *H. johnsonii* was tolerant of all but 5 psu (based on occurrence of positive O_2 evolution) (Dawes et al. 1989). Rates of photosynthesis, however, were greater at 25 and 35 psu than at 15 psu. Torquemada et al. (2005) further examined survival, growth, and rates of photosynthesis of *H. johnsonii* across salinities ranging from 0 to 60 psu at 10 psu intervals for 15 day durations. The lowest mortality (40%) and maximum growth rates (0.3 leaves per plant per day) were obtained at 30 psu with photosynthetic efficiency increasing as salinity increased to an optimum of 40 psu followed by a decrease at the highest salinities tested. Mortality was 100% for salinities of 0 and 60 psu. High rates of mortality (ca. 90%) and low rates of growth (< 0.1 leaves per plant per day) occurred at 10 psu while moderate mortality (50-60%) and growth (0.1-0.2 leaves per plant per day) occurred at 20, 40, and 50 psu.

Ruppia maritima

Ruppia maritima has a world-wide distribution occurring wetlands, marshes, and estuarine systems across a wide range of salinities. It is the least common species of seagrass in the Indian River Lagoon (Dawes et al. 1995), but can be locally abundant in the Banana River, Mosquito Lagoon, and north and central regions of the Indian River Lagoon (IRL) proper (Morris et al. 2000; Provancha and Scheidt 2000). It is not commonly reported in the southern portion of the IRL (SIRL) (Morris et al. 2000), but is found in the associated estuaries of the SIRL. It has been documented in the upper areas of the northwest fork of the

Loxahatchee River (WildPine Ecological Laboratory 2004) and in the middle estuary and north fork of the St. Lucie Estuary (Woodward-Clyde 1998), but was not listed as present in the Lake Worth Lagoon (Barnes Ferland and Applied Technology 2004).

Ruppia maritima occurs across a wide range of salinities, but it is often restricted to regions of lower salinity. Phillips' (1960) early survey of seagrasses in Florida indicated *R. maritima* beds occurring at sites with salinities ranging from freshwater to ca. 33 psu. Most populations, however, were restricted to areas with a salinity of < 25 psu. In Texas estuaries Adair et al. (1994) also documented *R. maritima* presence across a wide range of salinities in a single summer sampling event, but it was more abundant in the 10-30 psu range than the higher 30-40 psu range measured at their sample sites. Similarly, Pulich (1985) found that *R. maritima* persisted throughout the year at sites in south Texas estuaries where salinity ranged from 25-32 psu. In the northeastern Gulf of Mexico (Apalachee Bay, FL) Zimmerman and Livingston (1976) found *R. maritima* November through April in monthly samples over a 15-month sampling period at corresponding measured salinities ranging from 16-24 psu. *R. maritima* did not occur in samples collected May through October in that study. In northeast Florida Bay *R. maritima* is often more abundant at intermediate and upper stations along an estuarine gradient with an annual mean salinity range of ca. 15-25 psu (Montague et al. 1989; Montague and Ley 1993). Provancha and Scheidt (2000) indicated that *R. maritima* was common in the Banana River in the mid 1980s at salinities ranging from ca. 15 to 30 with a mean of ca. 20-25, and in the Mosquito Lagoon with salinities ranging from ca. 20 to 40 psu with mean of ca. 25-30 psu. They also noted that in the Banana River *R. maritima* expansion occurred over periods of reduced salinity that corresponded to decreases in *Halodule wrightii* and *Syringodium filiforme* cover between 1985 and 1996.

Mayer and Low (1970) subjected seeds collected from a wetland lake in Utah to salinities from 0 to 27 psu at 3 psu increments and examined germination rates of seeds and subsequent growth (as biomass) and survival of plants. Germination, growth, and survival were all greatest at 0 psu (85% germination, 0.33 g total dry weight, and 100% survival, respectively) and decreased as salinity increased. Survival rates were not significantly different, however, among 0 to 12 psu treatments for 2-week old plants. Koch and Dawes (1991b) also investigated the effects of salinity on germination of *R. maritima* seeds using seeds collected from Florida (Weeki Wachee) and North Carolina (Pamlico Sound). Seeds collected from Florida did not germinate at 30 psu, but did at 0 and 15 psu (range of salinities tested was 0, 15, and 30 psu), while those from North Carolina did. Overall, seeds collected from North Carolina also had a higher and more rapid germination rate than those collected from Florida indicating that populations from different sources may vary in their response to environmental conditions. Kahn and Durako (2005) attempted to germinate *R. maritima* seeds at salinities ranging from 0 to 70 psu. Germination rates were low across all treatments, but general trends indicated successful germination at 0, 10, and 20 psu. Plants may occur in the field at salinities > 20 psu, but based on these germination studies periods of reduced salinity may be necessary for seed germination to occur.

Berns (2003) cultured *R. maritima* plants collected from an estuary in Florida Bay (Madeira Bay) under salinities ranging from 0-60 psu in 10 psu increments and monitored leaf color and growth (measured as development of new nodes and blades, blade length measurements, and weight of new plant material). Leaf discoloration was greatest at 60 psu, intermediate in 0, 10, and 50 psu treatments, and no change in leaf color was noted in 20, 30, or 40 psu treatments. The optimal range for growth was between 0 and 40 psu with maximum growth occurring at 20 psu. Leaf growth rates ranged from 0.25 cm/day at 60 psu to 4.5 cm /day at 20 psu. All growth parameters decreased significantly as treatment salinities varied from 20 psu, but higher growth rates occurred in salinities of 30 psu and lower than at salinities of 40-60 psu.

Berns' (2003) results are similar to an earlier study by McMillan and Moseley (1967) in which they determined growth as the addition of new leaf material after clipping of plants (plants collected from Redfish Bay, TX, salinity at collection site not indicated). Plants were subjected to a gradual increase in salinity in temperature and light-controlled indoor tanks from ca. 30 psu up to ca. 75 psu over a 55 day period. *R. maritima* demonstrated active growth between ca 30 and 50 psu and then stopped adding new leaf material.

Koch and Dawes (1991a) examined the effects of salinity on growth and photosynthetic rates of *R. maritima* seedlings cultured from seeds collected from North Carolina (NC) and Florida (FL). Seedlings were grown at 10, 20, and 30 psu (22^{o}C, irradiance of 102 μE/m^{2}/sec, 12-hour photoperiod) for two months. Total plant biomass did not differ among salinities, but plants cultured from NC seeds had a significantly greater biomass than those cultured from seeds collected from FL (due to greater leaf and root biomass as rhizome biomass was similar between the two populations). Photosynthetic rates (based on P-I curves) did not differ among salinity treatments for the NC population, but for the FL population rates of photosynthesis were greater at 30 psu than at 20 or 10 psu.

Bird et al. (1993) examined growth of the underground portion of *R. maritima* by measuring rhizome and root growth. Plants were collected from Beaufort, NC (salinity of collection site not specified), sterilized, and grown in various growth media. Their results indicated the greatest rhizome growth for plants cultured in vitro at 0 and 5 psu (addition of ca. 8 to 16 new nodes over 4 weeks), intermediate growth at 10 psu (ca. 9-12 nodes over 4 weeks), and lowest growth at 15 and 20 psu (ca. 3-9 nodes over 4 weeks). The greatest root production (number of new roots formed) occurred at 5 and 10 psu (3 to 6 new roots produced over 3 weeks).

La Peyre and Rowe (2003) examined growth responses (relative growth rate as [ln (final biomass) – ln (initial biomass)]/time) of *R. maritima* under constant salinity (control at 10 psu) and pulsed salinity events to determine how variability in salinity might affect plant growth. Pulsed events included increased salinity events: pulsed from 10 to 20 psu and then to 30 psu (two step), pulsed to 20 psu and held there (one step), pulsed to 20 psu and then lowered again to 10 psu. Decreased salinity events were also tested: pulsed from 10 to 0 psu and held at 0 psu, and pulsed from 10 to 0 psu and back up to 10 psu. Growth was greatest under constant salinity (ca. 0.03 g/day). After three weeks at low salinity plants showed decreased growth rates (ca. 0.015 g/day) even when salinity was returned to ambient. Increasing salinity one step did not affect growth significantly (although it was lower than the control) (ca. 0.025 g/day), but increasing it two steps significantly decreased growth (ca. 0.01 g/day).

Chesnes (2002) also examined the role of salinity fluctuations on *R. maritima* by assessing the loss of photosynthetic material (% of green tissue), and plant morphometrics under various manipulations of salinity amplitude (0, 7 or 14% of a mean salinity of 18 psu with 4 day wave period), wave periodicity (0, 4, and 8 day periods with salinity fluctuating from 0 – 36 psu around a mean of 18 psu), fluctuations around different mean salinities (9% amplitude around mean of 9 psu [min 0, max 18 psu] and 27 psu [min 18, max 36 psu] over a 8 day period), and rapidness of change in salinity (stable, square, or pyramid wave types fluctuating from 4 to 32 psu around a mean of 18 psu over an 8 day period). *R. maritima* survived all salinity fluctuation treatments, but increasing frequency of salinity change did have a negative impact by resulting in lower % of green leaf tissue and a reduced over all number of leaves.

Physiological responses to salinity may occur in the form of variation of leaf ultrastructure (Jagels and Barnabas 1989). Plants collected from a site with a salinity of 28 psu (range 20-28) showed deeply invaginated plasmalemma with numerous mitochondria while plants collected from sites of 18 psu (range 6-22) and 5 psu (range 4-12) did not. These physiological responses to salinity may also alter photosynthetic rates (Lazar and Dawes 1991, Murphy et al. 2003).

Lazar and Dawes (1991) examined the photosynthetic response of excised *R. maritima* leaves exposed to a combination of temperature (10, 20 and 30^{o}C) and salinity (0, 17.5, 35 psu) treatments (acclimated to each salinity for 3 days prior to making measurements). Plants were collected from two sites with different salinity conditions in Tampa Bay, FL. One site was located near the mouth of the bay where salinity ranged from 30-34 psu with an average of 30.7 psu over a 12 month period, and the other site (55 km from the mouth of the bay) ranged in salinity from 22-29 psu with a mean 25.7. Regardless of collection site, both populations held at 10 or 20^{o}C and 0 psu showed little to no photosynthetic responses, while those held in 17.5 and 35 psu had similar photosynthetic responses ranging from the production of < 2,000 to > 8,000 µl O^2/gdwt/h depending on month plants were collected. Both populations also showed low photosynthetic rates in August and September (ca. 0 to 4,000 µl O^2/gdwt/h) when field plants were showing blade damage and die back. High rates of photosynthesis occurred in plants collected in fall and winter at both 17.5 and 35 psu and 20 and 30^{o}C (ca. 4,000 to 10,000 µl O^2/gdwt/h).

Murphy et al. (2003) exposed cultured plants (one-year old clonal cultures from Madeira Bay, Florida Bay held at 20 psu) to 0, 10, 20, and 40 psu and measured photosynthetic performance (quantum yield, Fv/Fm). The increases and reductions of external ion concentration were initially stressful for *R. maritima* (Fv/Fm dropped in 0, 10, and 40 psu treatments initially to ca. 0.70 – 0.73 vs. 0.78 for 20 psu), but physiological adjustment occurred after several days. By 48 hours, quantum yields were similar across 0, 10 and 20 psu but were lower at 40 psu.

Koch et al. (2006) exposed in tact cores of *R. maritima* (cores collected from north-central Florida Bay in October) to gradual increases in salinity from 35 to 70 psu at a rate of ca. 1.0 psu per day over a one month period to mimic changes in salinity due to evaporation in tropical climates. There were no significant differences in the number of shoots produced across all salinity treatments, and overall few new shoots were produced (3-9 shoots). The experiment was conducted October-November, however, during a time when *R. maritima* begins to senesce in the field. None of the salinity treatments resulted in total shoot mortality, although an increased percentage of shoot loss occurred especially beyond 55 psu. Consistent with the growth measurements, photosynthetic efficiency did not differ among salinity treatments (Fv/Fm ca. 0.70 – 0.75 for all treatments).

Caulerpa prolifera

Caulerpa prolifera is a common marine alga that occurs throughout the Indian River Lagoon system and its associated estuaries. It has been documented as the dominant vegetation in the northern portion of the Indian River Lagoon in the past with periodic declines in populations speculated to be driven by herbivory of an ascoglossan (White and Snodgrass 1990). While it is not a species of seagrass it does provide habitat and stabilization of the sediment (Kehl 1990) much like seagrasses do. We could not locate any published studies specifically quantifying the distribution and abundance of *Caulerpa prolifera* either regionally or locally with respect to salinity. It is, however, included in the seagrass monitoring programs for St. Johns and South Florida Water Management Districts. Initial examination of these data suggest that *C. prolifera* occurs within the IRL system at salinities ranging from ca. 18 to 35 psu (Robert Virnstein, SJRWMD, personal communication).

We found a single published experimental study with respect to salinity manipulation and performance of *C. prolifera*. Khalaefa and Shaalan (1979) monitored growth (% dry weight) and survival of *C. prolifera* (note subspecies not specified and source of plants not provided) at combinations of three temperatures (10, 20, and 30^{o}C) and seven salinities (15, 20, 25, 30, 35, 40, 45 psu). Results indicated a significant interaction between temperature and salinity on *C. prolifera* growth. At 10^{o}C, growth increased gradually with increasing salinity reaching a maximum at 30 psu (22.53 %), while growth at 40 and 45 psu decreased (21.26 and 20.01%, respectively). At 20°C, maximum growth rates occurred at 35 psu (26.10%) and the algae died at 15 psu. At 30°C, mortality occurred at 15 and 20 psu, but plants survived at higher salinities with a maximum growth rate occurring at a salinity of 40 psu (21.63%).

ONGOING STUDIES

The following is a synopsis of the responses received from investigators that replied to a query on current and pending research related to the effects of salinity on the target species. Specific communications are provided in Appendix III (copies of email requests and mailed requests with seagrass survey and questionnaire) and Appendix IV (copies of seagrass survey responses and email responses).

- Dr. Penny Hall is co-PI with Dr. Mike Durako on the CERP Monitoring and Assessment Plan for the South Florida Fisheries Assessment Program. The objectives of the habitat assessment program are to develop basic understanding of the relationships among salinity, water quality, and seagrass species distributions in South Florida. She provided me with a summary of the 2005 annual report for the South Florida Fisheries Habitat Assessment Program and Dr. Durkao provided me with reprints and information from lab studies that he and his students have been conducting to assess the physiological effects of altered salinity on SAV. The results of the finished studies have been included in the review, and unpublished information is provided below.
- Dr. Mike Durako at the University of North Carolina, Wilmington currently has a Ph.D. student (Amanda Kahn) who is looking at the effect of salinity and CDOM (chromophoric dissolved organic matter) on *Halophila johnsonii* in both field and mesocosm investigations. The mesocosm experiments have three salinity treatments: 10, 20 and 30 psu. Plant material for mesocosm studies was collected from Jupiter Inlet. There are three field sampling areas, each with paired inlet/riverine sites: Ft. Pierce Inlet/ Taylor Creek (north), Jupiter Inlet/Loxahatchee River (central) and Haulover Inlet/ Oleta River (south). Each station is sampled at high and low tide to capture a range of salinity and CDOM. The anticipated end date for this project is summer 2007.

- Dr. Robert Virnstein, along with Lori Morris and Lauren Hall, at St. Johns River Water Management District have their on-going seagrass transect and water quality monitoring programs that provide data on seagrass distributions and associated salinities in the Indian River Lagoon. These data, however, are not specifically analyzed for relationships between salinity and the distribution and abundance of target species. Dr. Virnstein, however, provided a brief assessment of ranges of salinity at which the target species occur in their transects (see attached correspondence in Appendix IV)
- Dr. Rick Bartleson responded for Dr. Steve Bortone of the Sanibel-Captiva Conservation Foundation. They have an ongoing monitoring program in place for estuaries in southwest Florida that can provide distributional data for target species along with salinity information, but no experimental studies are in progress. (See Appendix IV for summary of correspondence)
- Dr. Silvia Macia of Barry University in Miami, FL currently does not have any on going monitoring or experimental work that is related to seagrass and salinity distributions. She provided input on her past experience with salinity and seagrass by responding to the survey. (see attached correspondence in Appendix IV)
- Dr. Marguarite Koch provided pre-prints of a manuscript to be published in Aquatic Botany on the effects of hyper-salinity on *Thalassia testudinum, Halodule wrightii,* and *Ruppia maritima*. Results of her study have been included in the literature review.
- Dr. Tom Chesnes provided a copy of his dissertation, as no peer-reviewed publications from his dissertation are available at this time. The results of his research looking at the effects of fluctuating salinity on *Halodule wrightii*, *Thalassia testudinum*, and *Ruppia maritima* have been included in the review.
- Dr. Christopher Madden provided a copy of a previous salinity review conducted by Battelle, Inc., and along with Amanda McDonald provided information on the development of a seagrass model for Florida Bay.
- Dr. Jud Kenworthy does not currently have any research or monitoring programs directly related to salinity and seagrass.

- Dr. Mary Collins does not currently have any research or monitoring programs directly related to salinity and seagrass
- Dr. Brad Robbins of Mote Marine Lab has a SFWMD funded project assessing the influence of salinity changes on juvenile fish and seagrass (*Halodule wrightii*, *Syringodium filiforme* and *Thalassia testudinum*) in the Caloosahatchee Estuary. The on-going project is entering its 3rd year. The monitoring program samples seagrass every 5-6 weeks for canopy height and biomass. Growth rates for *T. testudinum* are also made. No effect of timing of salinity pulses has been detected for *T. testudinum* growth rates, but results may be confounded by temperature. Additional work is being done with *Vallisneria americana* (not one of the target species for the SIRL) germination and seedling growth under different salinity, light, and temperature regimes.
- Dr. Elizabeth Irlandi has unpublished studies examining the interactive effects of salinity and nutrients on competitive interactions between *Thalassia testudinum* and *Halodule wrightii* in mesocosm experiments. *T. testudinum* plants were 1 year old plants grown from seeds collected along the shores of Key Biscayne and *H. wrightii* plants were collected from the Indian River Lagoon. Completion of data analysis and manuscript writing is anticipated by the end of 2007. Preliminary studies have also been done to assess the effects of salinity (10, 15, 20, 25, 30 psu) on growth of *Halophila engelmannii*, *Caulerpa prolifera*, and *Syringodium filiforme* in aquaria. These were preliminary studies conducted by students and need follow up. A facility is being refurbished in conjunction with the Brevard County Environmentally Endangered Lands Program that will allow continued investigation of the effects of salinity on SAV in the IRL. Facility should be operational by mid to end of 2007.

SUMMARY/RECOMMENDATIONS

There are limited experimental studies on the effects of salinity stress on several of the target species (e.g., *Halophila decipiens, H. engelmannii, Caulerpa prolifera*). In addition, much of the experimental work that has been done has manipulated static salinity as a single variable. Inclusion of interactions between salinity and other environmental factors is necessary to fully understand the effects of water management on SAV populations. Conclusions relating SAV distribution and abundance in the field to salinity are confounded with changes in other environmental parameters that co-vary with salinity. For example, significant relationships have been identified between salinity and light attenuation in both the Indian River Lagoon (Hanisak 2001) and Charlotte Harbor (Tomasko and Hall 1999). While salinity does not directly affect light, freshwater from runoff and canal discharge adds nutrients that can fuel blooms of phytoplankton, epiphytes, and/or macroalgae. These other primary producers can limit the amount of light reaching benthic seagrass leaves. Suspended solids (increased turbidity) and dissolved organic acids (e.g., tannins that color the water) are often present in freshwater runoff and canal discharge that reduce light levels. In addition, low salinity events associated with precipitation often correspond with elevated summer temperatures and interactions between salinity and temperature may significantly influence submerged aquatic vegetation.

Studies also need to incorporate appropriate mean and variance scales in salinity over the appropriate temporal scales to best simulate water delivery (either natural estuarine or managed) schedules. Variability in salinity may be more of a factor than salinity itself. Durations of exposure to salinity manipulations need to be on the appropriate time scale as those experienced in the field. Short term reductions in salinity can be tolerated by some species, but salinity stress may make them more vulnerable to other environmental variables such as reduced light or high temperatures. While studies of salinity tolerance to static salinity conditions may be a first cut they will be less useful in predicting responses of plants in the field.

When conducting laboratory studies, previous history of collected plants also may be of importance. Populations occurring in a region of variable salinity may be better adapted to changes in salinity than those that have been growing in a stable salinity environment. Time of collection for plants used in laboratory studies may also influence how well plants perform in the lab. Plants collected during dormant vs. active growing periods may respond differently to the disturbance of transplantation and subsequently to experimental treatments.

The addition of multi species studies is also appropriate given the high diversity of SAV species that occur in the IRL. Interactions between co-occurring species under different water management scenarios of altered salinity, temperature, light, etc. are needed to elucidate potential changes in species distributions.

Appendix I –References Cited

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Author	Date	Target Species Included	Lab/Field	Type of Study	Salinity Range in Field or Lab	Duration of Exposure/Study	Co-Effects	Measurement Variable(s)	Optimum Salinity Reported	Location
Adair et al.	1994	H. wrightii, H. engelmannii, R. maritima, T. testudinum	Field	Sampling/monitoring program	10-40 psu	samples collected July-Aug	N/A	species composition and biomass	T. testudinum and H. engelmannii found only 30-40 psu; R. maritima mostly 10-30 psu, and H. wrightii mostly 30-40 psu	Texas
Berns	2003	R. maritima, T. testudinum	Lab	Experimental	0-60 psu (increments of 10)	one, seven, and 28 day periods	N/A	leaf discoloration, growth rates, photosynthetic characteristics (P_{max}, respiration, alpha, I_k)	T. testudinum - 20-40 psu; R. maritima optimum 0- 40 psu with max growth at 20 psu	R. maritima from Maderia Bay, FL; T. testudinum grown from fruits from Biscayne Bay, FL
Bird, et al.	1993	R. maritima	Lab	Experimental	0-20 psu (increments of 5)	three 4wk experiments	effect of carbon source on root production	number of nodes produced on rhizome, number of roots	rhizome growth greatest at 0 and 5 psu, intermediate at 10 and lowest at 15 and 20; root production greatest at 5 and 10 psu	original plants collected from Beaufort, NC and sterilized for in vitro growth in media
Chesnes	2002	H. wrightii, R. maritima, T. testudinum	Lab	Experimental	10-30 psu; variable means, amplitudes, rates of change, and periods	8 to 22 days depending on experiment	N/A	% of green leaf, rhizome and leaf length, number of leaves	most did better with low amplitude, low frequency, sloping changes in salinity, and with fluctuations around high salinity	plants collected from Little Madeira Bay, north Florida Bay
Dawes et al.	1987	H. engelmannii	Lab	Experimental	5-35 psu	3 day exposure to lab salinities	previous history of plants	photosynthesis	estuarine populations 15-25 psu; oceanic populations 25-35 psu	plants from Indian Bluff Island and Homosassa River Bay, FL in Sept and December
Dawes et al.	1989	H. decipiens, H. johnsonii	Lab	Experimental	5, 15, 25, 35 psu	acclimated for 3 days at target salinities	temperature	photosynthesis via P - I curves and oxygen evolution	positive O_2 evolution for H. decipiens occurred only at 35 psu ; H. johnsonii positive at 15, 25, and 35 with rate of O_2 production increasing as temperature increased from 10 to 30 ^oC	H. johnsonii collected from IRL near Fort Pierce - 24 to 38 psu; H. decipiens collected from Anclote Key - 31-33 psu
Doering & Chamberlain	2000	T. testudinum	Lab	Experimental	6, 12,18, 25, 35 psu	43 days	N/A	number of shoots, number of blades/shoot, blade length, growth via marking	No. of blades and shoots similar between 12-35, length and growth greatest 18-35, biomass increased as salinity increased	Plants collected from Caloosahatchee River Estuary, FL
Doering et al.	2002	H. wrightii	Field and Lab	Field collections, experiments, and modeling	Lab: 3, 6, 12, 18, 25 Field: < 5 to > 25 psu	Lab: 3-10 week - Field: monthly 1986-89, 1994-95	N/A	growth and production based on change in number of blades	mortality at < 6, greater growth above 12 psu, higher blade densities in field above 12	Caloosahatchee River Estuary, FL
Dunton	1996	H. wrightii	Field	Sampling/monitoring program w/ in situ photosynthesis	Guadalupe 5-25 psu; Laguna Madre 35-55 psu	5 years - seasonal sampling	salinity, temperature, light all co-varying in field, but not manipulated	biomass, chlorphyll content, in situ photosynethesis	variable - none specified	Guadalupe Estuary & Laguna Madre, TX
Eiseman & McMillan	1980	H. johnsonii	Field	Sampling/monitoring	up to -43 psu	collections made from various locations all year	N/A	plant occurrence	none reported	Atlantic coast of Florida
Fong & Harwell	1994	H. wrightii, S. filiforme, T. testudinum	Model	Modeling using existing field and lab data	22-40 psu	2yr simulation with seasonal changes in forcing functions	temperature, light, nutrients	biomass produced	T. testudinum - high light, low water column nutrients with stable salinity and temperature; H. wrightii - fluctuating salinities and higher nutrients; S. filforme - oceanic influence, litlle variability in salinity & low nutrients	Model for subtropical-tropical seagrass systems
Fourqurean et al.	2003	H. wrightii, H. decipiens, R. maritima, S. filiforme, T. testudinum	Model	Modeling using field data	Variable - included ranges measured in field - mean 28.5 psu, min 0.2, max 63, median 30.5	Monitoring data from 9yrs used	nutrients, sediment depth, light	Braun-Blanquet density	Rm-Hw beds dominate 11-18 psu, Hw only 15-35; dense Tt ca 22-35; sparse Tt25-35; Hd and Sf ca. 35 psu	Florida Bay, FL
Gilbert & Clark	1981	S. filiforme, H. engelmannii, H. wrightii	Field	Sampling/monitoring program	Field ranges from ca 21 to 28 psu	16 mos of monthly sampling	air temperature also measured in field at time of sampling	dry weight (g/m^2)	peak biomass in Sept corresponding to salinity of 29 psu and temp of 28^oC min biomass in in Feb @ 24 psu and 23^oC	Northern Indian River, FL
Greenwalt-Boswell et al.	2006	H. wrightii, T. testudinum, S. filiforme	Field	Sampling/monitoring program	Range ca. 15 to 36 psu; means 21 to 33 psu	6 yrs annual seagrass samples; monthly salinity for wet/dry averages	N/A	Braun-Blanquet % cover score and frequency of occurrence in surveyed quadrats	occurrence at mean wet season salinity: Sf-28.9, Tt-24.6,Hw21.2; dry season salinity Sf-34.7, Tt-33.4, Hw-31.6 psu	Charlotte Harbor Estuaries, FL
Hanisak	2002	H. wrightii, H. engelmanni, S. filiforme	Field	Descriptive occurrence	26-32 psu yr1, 13.5-19.8 psu yr2	2yr	N/A	cover, shoot density, biomass	Optimum not specified but biomass reduced in times of reduced salinity	Indian River Lagoon
Irlandi et al.	2002	T. testudinum	Field	Sampling/monitoring program w/ insitu measurements of growth/production	0-30 psu	2 yrs with winter/summer	N/A	in situ measurements of growth/production and biomass	greater growth and production on eastern side of bay at 30-35 psu than western side with ca. 20-25 psu	Biscayne Bay, FL
Jagels & Barnabus	1989	R. maritima	Field	Descriptive occurrence	20-28, 6-22, 4-12 psu ranges at field sites	Plants collected once in Sept. Salinity measured Sept - Oct	N/A	leaf ultrastructure	N/A	Hog Bay, ME
Kahn & Durako	2005	R. maritima	Lab	Experimental	0,4,6,10,16,20,26,28 psu	3-5 mos.	ammonium	germination of seeds	low germination rates in all treatments - no optimum determined	seeds collected from Garfield Bight, north central Florida Bay
Kahn & Durako	2006	T. testudinum	Lab	Experimental	0-70 psu(increments of 10)	14 weeks	ammonium	morphometrics (leaf length, width), mortality (no green tissue), photosynthesis via PAM fluorometry	30-40 psu	seedlings collected from Tavernier Key, FL at ca. 35 psu
Khaleafa & Shaalan	1979	C. prolifera	Lab	Experimental	15, 20, 25, 30, 35, 40, 45 psu	3 weeks	temperature (10, 20, 30^oC)	% dry weight	30 psu at 10^oC; 35 psu at 20^oC; 40 psu at 30^oC	origin of plants not indicated in text
Koch & Dawes	1991a	R. maritima	Lab	Experimental	10, 20, 30 psu	2 months	temperature, photoperiod considered separately for NC and FL populations	biomass (leaf and root), photosynthetic response (P vs. I curves)	no effect on biomass, FL population increased photosynthesis at 30 psu	Seeds collected from Pamlico Sound, NC (6-30 psu); Weeki Wachee R FL (2-14 psu)

Koch & Dawes	1991b	R. maritima	Lab	Experimental	0,15,30 psu	70 days	none manipulated simultaneously, but temperature also investigated	seed germination	FL seeds did not germinate at 30 psu, germination at 0 and 15 for both FL and NC	Seeds collected from Pamlico Sound, NC (6-30 psu); Weeki Wachee R FL (2-14 psu)
Koch & Erskine	2001	T. testudinum	Lab	Experimental	controls @ 36 psu, high salinity treatments @ 55-60 psu	up to 28 day exposures	sulfides, temperature, salinity	leaf elongation, leaf O_2 production	none reported	Plants collected from Florida Bay, FL
Koch et al.	2006	T. testudinum, H.wrightii, R. maritima	Lab	Experimental	35-70 psu	pulsed events with rapid increase (T. testudinum only), and slower increases over time over 30 day exposures	N/A	shoot decline, growth rates (leaf marking for Tt, new shoots produced for Hw and Rm), photosynthetic performance (O_2 evolution, floresence)	Gradual increase in psu - R. maritima and H. wrightii survived all salinities with only slight decreases in growth and photosynthesis at 70 psu, T testudinum declined at 60 psu. Rapid increase 45 psu for T. testudinum (only spp	Plants collected from Whipray Basin to Garfield Bight in north-central Florida Bay
La Peyre & Rowe	2003	R. maritima	Lab	Experimental	0-30 psu - constant and pulsed up or down @ 10 psu increments	9wks	N/A	relative growth as [ln(final biomass or height) - ln(initial biomass or height)]/time	greater growth under constant salinity of 10 psu, than when pulsed up or down 10 psu	plants collected from Lake Pontchartrain, LA in May
Lazar & Dawes	1991	R. maritima	Field and lab	Experimental	0, 17.5, 35 psu in lab; 30-34 mean 30.7 psu site 1 & range 22-29, mean 25.7 psu site 2 in field	12 month field sampling and 3 day acclimation to salinity	temperature	organic constitutents of plants from field, photosynthetic response of blades in lab	10 or 20^{o}C and 0 psu showed little to no photosynthesis; 17.5 and 35 psu and 20 or 30^{o}C photosynthetis higher	Tampa Bay, FL
Lirman & Cropper	2003	H. wrightii, S. filiforme, T. testudinum	Field and Lab (and model)	Field collections, experiments, and modeling	5 to 45 psu - pulsed	14 day pulses in lab, one-time field collections in June	N/A	leaf elongation rates in lab study, occurrence at field sites	T. testudinum - 30-40 psu; S. filiforme - 25 psu; H. wrightii similar across all salinities tested but peaked at 35 and least at 45 psu	Biscayne Bay, FL
Madden & McDonald	2006	T. testudinum, H. wrightii	Model	Modeling using existing field and mesocosm data	variable under different model scenarios	variable under different model scenarios	scenario runs with multiple stressors - sulfide, nutrients	biomass as g C per m^2	T. testudinum performs better under stable and hypersaline conditions (> 40 psu), while H. wrightii is more tolerant of salinity < 40 psu	Model for specific basins in Florida Bay
Mayer & Low	1970	R. maritima	Lab	Experimental	0-27 psu for germination, plant growth, and mortality	2 week exposure for seed germination, 28 days for plant growth	age of plants	seed germination, plant growth as biomass, mortality	seed germination, plant growth, and survival all greatest at 0 psu, and decreased as salinity increased	seeds collected in March from East Lake, Utah, plants from germinated seeds
McMahan	1968	Diplanthera (H.) wrightii, S. filiforme	Field and Lab	Sampling/monitoring program and lab experiments	Field : S.filiforme - 31-33 psu; H. wrightii 45-52 psu - Lab: H.w. 3.5 to 87.5 psu, S.f. 35-52.5 psu	Field - monthly to quarterly samples, Lab - up to 6 wk exposure	N/A	assessment of green leaf material and condition of rhizome	S. filifmorme - 35 psu; H. wrightii - 44 psu	Laguna Madre, TX
McMillan	1974	genus names only provided- Halodule, Thalassia, Cymodocea (Syringodium), Halophila	Review and results of unpublished lab studies	Preliminary experiments	Halodule and Halophila 23, 37, 50, 60 psu; Thalassia and Cymodocea 5, 10, 13, 18, 23, 37, 50, 60 psu	Halodule and Halophila - 13 weeks; Thalassia and Cymodocea 3 months	N/A	leaf coloration and survival	Halodule and Halophila survived 13 wks at 23 and 37 psu, Thalassia and Cymodocea plants survived 2 weeks between 10-50 psu	Plants collected from Redfish Bay, Texas
McMillan	1976	H. engelmanni, T. testudinum, S. fliliforme, R. maritima, H. wrightii	Field and Lab	Sampling/monitoring program and lab experiments	H.e. 10, 18, 27, 35 psu; H.w. 6, 13, 27,38, 51, 64 psu; R.m. T.t. S.f. 35 psu	1 year	temperature	flower production	H. engelmannii-27-35 psu @22-24^{o}C; H. wrightii in field at 26-36 psu; other species did not flower enough to make conclusions	Redfish Bay, TX
McMillan & Moseley	1967	Diplanthera (H.) wrightii, H. engelmanni, R. maritima, S. filiforme, T. testudinum	Lab	Experimental	gradual increase in salinity from 28.8 to 70 psu	increases gradual over 55 days (ca. rate of < 1 psu per day)	N/A	plant growth as increase in leaf length after clipping	R. maritima active growth 30-50 psu; S. filiforme between 30-40 psu;	Redfish Bay, TX
Montague et al.	1989	H. wrightii, R. maritima, T. testudinum	Field	Descriptive occurrence	field ranges from ca. 10-31 psu	March '86 to Aug '86 - monthly samples; bimonthly samples Nov '86-Sept'87	many environmental variables measured at sampling, none manipulated (e.g., oxygen, turbidity, temperature, nutrients, depth, seidment thickness, etc)	plant biomass	T. testudinum biomass greater at outer stations with more stable salinity; H. wrightii and R. maritima biomass greater at intermediate and upper stations with lower more variable salinity.	Northeast Florida Bay, FL
Montague & Ley	1993	H. wrightii, T. testudinum, R. maritima	Field	Sampling/monitoring program	mean among stations 11.4 -33.1 psu	1yr 7 mos with 12 sampling times	N/A	plant biomass	R. maritima ca. 15-25 psu, H. wrightii ca. 20-32 psu, T. testudinum ca 25-30 psu	Northeast Florida Bay, FL
Murphy et al.	2003	R. maritima	Lab	Experimental	20 psu acclimated plants exposed to 0, 10, 20, 40 psu	2 days	N/A	photosynthesis via leaf flouresence and osmolality	10-20 psu had greatest quantum yields	1 yr old clone cultures from plants collected from Madeira Bay in Florida Bay
Quammen and Onuf	1993	H. wrightii, S. filiforme, T. testudinum	Review and Field	Descriptive occurrence- change over time from past to current	Over 30 year period with general reduction in salinity over time	Surveys over two 2yr periods, and one 1yr period	Field data - water depth, water temperature, and secchi depth also	species composition and dominant contributor to vegetative cover	As salinity in lagoon is being moderated H. wrightii is being replaced by S.f. and T. t.	Laguna Madre, TX
Tomasko & Hall	1999	T. testudinum	Field	Sampling/monitoring program	0-35 psu	bimonthly samples for 1.3 yr	co varying water quality parameters in field with salinity - temperature, light	productivity	25-35 psu and 25-30^{o}C	Charlotte Harbor, FL
Torquemada et al.	2005	H. johnsonii	Lab	Experimental	0-60 psu (increments of 10)	15 days	temperature and pH	mortality of plants, growth (no of new leaves per plant per day), photosynthesis	30 psu	plants collected from Haulover Park in northern Biscayne Bay, FL
Zieman	1975	T. testudinum	Field	Sampling/monitoring program and growth measurements	Ranged from ca. 10 to 40 psu at all sites during study	Measurements made every 2-3 wks over ca. 1.5 yr	temperature measured at time of sampling	leaf growth, leaf length, production, standing crop, denstiy,	30 psu	Biscayne Bay, FL
Zieman et al.	1989	H. wrightii, S. filiforme, T. testudinum	Field	Sampling/monitoring program	salinities not reported, but correspond to general trends	one time sampling in summer 1984	water depth, sediment depth	standing crop and production	none reported	Florida Bay, FL
Zieman et al.	1999	T. testudinum	Field	Sampling/monitoring program	Summer 25-55 psu- Mean for all sites ranged 30-47 psu	2-6 Xs per year for ca. 7 years	temperature also measured at time of sampling	shoot density, standing crop, leaf morphology, prodution	hyper salinity (> 35 psu) along with high temperature detrimental to T. testudinum	Florida Bay, FL
Zimmerman & Livingston	1976	H. wrightii, H. engelmanni, R. maritima, S. filiforme, T. testudinum	Field	Sampling/monitoring program	16 - 36 psu with one occurrence of extremely low salinity of 6 psu	15 months- monthly samples	temperature, water color, turbidity, and water depth measured at time of sampling	dry weight	optima not provided, just ranges at which each species occurred	Apalachee Bay, FL

Appendix III – Seagrass Surveys and Questionnaire

Below are copies of correspondences, a survey to obtain professional opinion and guidance on the effects of salinity on the target species, and a shorter questionnaire requesting information related to ongoing research activities. The longer survey was emailed on June 27, 2006 and again on August 8, 2006. The questionnaire was mailed in mid August 2006. Responses are provided in Appendix IV.

First email request made June 27, 2006.

Elizabeth Irlandi

From: "Elizabeth Irlandi" <irlandi@fit.edu>
To: "Macia, Silvia" <SMacia@mail.barry.edu>; "Lauren Hall" <lhall@sjrwmd.com>; "Carlson, Paul" <Paul.Carlson@MyFWC.com>; "Lori Morris" <LMorris@sjrwmd.com>; "Robert Virnstein" <Robert_Virnstein@district.sjrwmd.state.fl.us>; "Rick Alleman" <ralleman@sfwmd.gov>; "Steve Bortone" <sbortone@sccf.org>; "Tom Chesnes" <THOMAS_CHESNES@pba.edu>; "Mary Collins" <mec@ufl.edu>; <pdoering@sfwmd.gov>; "Mike Durako" <durakom@uncw.edu>; "Mark Fonseca" <mark.fonseca@noaa.gov>; <jim.fourqurean@fiu.edu>; <jud.Kenworthy@noaa.gov>; <mkoch@fau.edu>; <cmadden@sfwmd.gov>; <robbins@mote.org>
Sent: Tuesday, June 27, 2006 11:44 AM
Attach: seagrass survey questionnaire.xls
Subject: seagrass salinity review

The Marine Benthic Ecology Laboratory in the Department of Marine and Environmental Systems at the Florida Institute of Technology has been contracted by the South Florida Water Management District to conduct a review of published and unpublished studies related to salinity effects on eight species of submerged aquatic vegetation that occur in central and south Florida estuaries. As part of that contract the District has charged us with contacting scientists to identify unpublished and ongoing monitoring and research activities related to salinity for the species of concern. I have included a portion of the Statement of Work from the District explaining the contract and associated tasks below. A short questionnaire has also been attached. This same information will be sent to you via U.S. mail. Email reply is preferred, but if you prefer you can complete the hard copy and return it to me via mail.

I can truly appreciate your busy schedule, but if you could take a few minutes of your time to respond to the questionnaire it would be greatly appreciated. A copy of the completed literature review and survey will be provided to you upon completion.

Thank you for your time and consideration.

Sincerely,

Elizabeth Irlandi, Ph.D.
Associate Professor, Oceanography
Department of Marine and Environmental Systems
Florida Institute of Technology
150 West University Boulevard
Melbourne, FL 32901
321-674-7454

Second email request made August 8, 2006.

Elizabeth Irlandi

From: "Elizabeth Irlandi" <irlandi@fit.edu>
To: "Lauren Hall" <lhall@sjrwmd.com>; "Carlson, Paul" <Paul.Carlson@MyFWC.com>; "Lori Morris" <LMorris@sjrwmd.com>; "Robert Virnstein" <Robert_Virnstein@district.sjrwmd.state.fl.us>; "Rick Alleman" <ralleman@sfwmd.gov>; "Tom Chesnes" <THOMAS_CHESNES@pba.edu>; "Mary Collins" <mec@ufl.edu>; <pdoering@sfwmd.gov>; "Mark Fonseca" <mark.fonseca@noaa.gov>; <jim.fourqurean@fiu.edu>; <jud.Kenworthy@noaa.gov>; <mkoch@fau.edu>; <cmadden@sfwmd.gov>; <robbins@mote.org>; <penny.hall@myFWC.com>
Sent: Tuesday, August 08, 2006 3:01 PM
Attach: STATEMENT OF WORK.doc; seagrass survey questionnaire.xls
Subject: Seagrass Salinity Review take 2

FOR THOSE OF YOU THAT HAVE ALREADY REPLIED....THANK YOU VERY MUCH :)

The Marine Benthic Ecology Laboratory in the Department of Marine and Environmental Systems at the Florida Institute of Technology has been contracted by the South Florida Water Management District to conduct a review of published and unpublished studies related to salinity effects on eight species of submerged aquatic vegetation that occur in central and south Florida estuaries. As part of that contract the District has charged us with contacting scientists to identify unpublished and ongoing monitoring and research activities related to salinity for the species of concern. I have included a portion of the Statement of Work from the District explaining the contract and associated tasks below. A short questionnaire has also been attached. Email reply is preferred, but if you want you can complete a hard copy and return it to me via mail.

I can truly appreciate your busy schedule, but if you could take a few minutes of your time to respond to the questionnaire it would be greatly appreciated. A copy of the completed literature review and survey will be provided to you upon completion.

Thank you for your time and consideration.

Sincerely,
Elizabeth Irlandi, Ph.D.
Associate Professor, Oceanography
Department of Marine and Environmental Systems
Florida Institute of Technology
150 West University Boulevard
Melbourne, FL 32901
321-674-7454

Seagrass survey included in email requests.

Please answer the following questions for all or any of the species of submerged aquatic vegetation listed below.
State the species for which your answers apply. Copy and paste questions and provide your answers if you are responding for more than one species.

Species	*Halodule wrightii*	*Syringodium filiforme*	*Thalassia testudinum*	*Halophila johnsonii*	*Halophila decipiens*	*Halophila engelmannii*
	Ruppia maritima	*Caulerpa prolifera*				

Species? ______________________

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for
a) prolonged exposures (weeks to months) and low ______________ high ______________
b) short-term acute exposures (hours to days) low ______________ high ______________

2) Are you basing your values on (check all that apply)
a) casual field observations ______________
b) documented and quantified field observations ______________
c) controlled laboratory studies ______________
d) other - specify ______________

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?
(check all that apply) low salinity high salinity
a) Mortality? ______________
b) Physiological stress? ______________
c) Reduced growth? ______________
d) Changes to morphology? ______________
e) Senescence? ______________
f) Other ______________

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species? If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

6) We are conducting a literature review and have identified much of the published information related to salinity tolerances for the species listed. It would be helpful, however, if you could include any references for both peer-reviewed publications and gray-literature reports that document your research and observations related to salinity tolerances for the indicated species. If gray-literature is not available on line, please include a copy of the report or email a .pdf to **irlandi@fit.edu.**

General letter and portion of statement of work mailed out mid August.

Florida Institute of Technology

College of Engineering
Department of Marine and Environmental Systems
Science • Engineering • Management

Date

Name
Organization
Address

Dear _______________:

The Marine Benthic Ecology Laboratory in the Department of Marine and Environmental Systems at the Florida Institute of Technology has been contracted by the South Florida Water Management District to conduct a review of published and unpublished studies related to salinity effects on eight species of submerged aquatic vegetation that occur in central and south Florida estuaries. As part of that contract the District has charged us with contacting scientists to identify unpublished and ongoing monitoring and research activities related to salinity for the species of concern. I have included a portion of the Statement of Work from the District explaining the contract and associated task. A short questionnaire has also been included. If you have replied via email, thank you very much, and please disregard this request. If you prefer, however, you can complete the hard copy and return it to me via mail. A return date of September 22nd would be greatly appreciated!

I can truly sympathize with your busy schedule, but if you could take a few minutes of your time to respond to the questionnaire I would be most great full. A copy of the completed literature review and survey will be provided to you upon completion.

Thank you for your time and consideration.

Sincerely,

Elizabeth Irlandi

Elizabeth Irlandi, Ph.D.
Associate Professor, Oceanography
Phone: 321-674-7454
Email: irlandi@fit.edu

150 West University Boulevard, Melbourne, FL 32901-6975 • (321) 674-8096 • Fax (321) 674-7212 • E mail dmes@marine.fit.edu

MARINE & ENVIRONMENTAL SYSTEMS

Our mission is to integrate oceanography, ocean engineering, environmental science, meteorology and related academic concentrations into interdisciplinary knowledge-based optimal solutions to vital contemporary issues through education, research and service.

STATEMENT OF WORK

Literature Review of Salinity Effects on Submerged Aquatic Vegetation (SAV) found in the Southern Indian River Lagoon and Adjacent Estuaries

INTRODUCTION

As directed by the Monitoring and Assessment Plan (MAP) of the Comprehensive Everglades Restoration Plan (CERP), the South Florida Water Management District (District) and its partners are:

1) establishing pre-CERP baseline, including variability, of SAV (submerged aquatic vegetation) in the Southern Indian River Lagoon (SIRL), St. Lucie Estuary, Loxahatchee Estuary, and Lake Worth Lagoon;
2) assessing the response of CERP implementation on SAV in the referenced estuaries; and,
3) conducting scientific investigations designed to increase understanding of SAV and to help establish cause-and-effect relationships for SAV health.

Mapping and monitoring efforts have identified the following key SAV species in the referenced estuaries:

1) *Halodule wrightii*
2) *Syringodium filiforme*
3) *Thalassia testudinum*
4) *Halophila johnsonii*
5) *Halophila decipiens*
6) *Halophila engelmanni*
7) *Ruppia maritima*
8) *Caulerpa prolifera* (although not a seagrass, *Caulerpa prolifera* is often abundant in the SIRL).

The District plans to develop tools to help predict impacts to SAV parameters due to changes in water management, in the referenced estuaries and associated watersheds. The predictive tool(s) will rely on field data, laboratory studies, and available literature information. As part of the predictive tool development process, a current literature review of salinity effects on the SAV species is needed.

The literature review will focus on the species listed above. The District will provide the selected contractor with previous literature review reports completed for the St. Lucie Estuary, Biscayne Bay, and Florida Bay. The St. Lucie Estuary literature review was completed approximately 10 years ago and needs to be updated. **The Biscayne and Florida Bay reviews are more recent but did not include all of the species listed above and focused on hypersaline conditions not low salinity conditions which affect the estuaries that are the focus of this study**.

OBJECTIVES:

This project will provide the District with a review and synopsis of literature (published and gray) and on-going research related to salinity effects on key SAV species found in the Southern Indian River Lagoon, St. Lucie Estuary, Loxahatchee Estuary, and Lake Worth Lagoon. This project will help identify data that can be used for developing ecological models for these waterbodies. Additionally, this project will identify data gaps that need to be filled in order to develop SAV models for the referenced estuaries. The synopsis will be delivered in report form.

Task. The Contractor will document ongoing research activities that address salinity effects on the key SAV species. The purpose of this effort is to identify ongoing monitoring and research projects related to the literature review goals. Ongoing efforts should be summarized to clearly explain the work being done, the goals of the work, and expected completion date. Additionally, through this effort the Contractor may identify published or gray literature not found in Task 1.

Questionnaire

Respondent Name:________________________

1) Do you currently have any ongoing research or monitoring programs that would provide information regarding the effects of salinity on the distribution of target species listed?

2) If so, please summarize the goals and objectives of the ongoing study.

3) What species are included in the study?

4) What is the expected date of completion for the study?

Appendix IV: Responses to survey and questionnaire

Species *Halodule wrightii* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	13	high	45
b) short-term acute exposures (hours to days)	low	3	high	60

2) Are you basing your values on (check all that apply)

a) casual field observations	x	
b) documented and quantified field observations		x
c) controlled laboratory studies		
d) other - specify		

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	x	
b) Physiological stress?	x	x
c) Reduced growth?	x	x
d) Changes to morphology?		
e) Senescence?	x	
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?	x	x
c) Reduced growth?	x	x
d) Changes to morphology?		
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.
Transect monitoring continues since 1994 (and for each species below)

Species *Syringodium filiforme* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	21	high	40
b) short-term acute exposures (hours to days)	low	12	high	50

2) Are you basing your values on (check all that apply)

a) casual field observations	x	
b) documented and quantified field observations		x
c) controlled laboratory studies		
d) other - specify		

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	x	
b) Physiological stress?	x	x
c) Reduced growth?	x	x
d) Changes to morphology?		
e) Senescence?	x	
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	maybe, <5 psu	
b) Physiological stress?	x	x
c) Reduced growth?	x	x
d) Changes to morphology?		
e) Senescence?	maybe	
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species *Thalassia testudinum* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	17	high	>40
b) short-term acute exposures (hours to days)	low	8	high	50?

2) Are you basing your values on (check all that apply)

a) casual field observations x

b) documented and quantified field observations x

c) controlled laboratory studies

d) other - specify

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	x	
b) Physiological stress?	x	x
c) Reduced growth?	x	x
d) Changes to morphology?		
e) Senescence?	x	
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?	x	x
c) Reduced growth?	x	x
d) Changes to morphology?		
e) Senescence?	maybe	
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species *Halophila johnsonii* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	15	high	none known
b) short-term acute exposures (hours to days)	low	<5	high	none known

2) Are you basing your values on (check all that apply)

a) casual field observations	x
b) documented and quantified field observations	
c) controlled laboratory studies	
d) other - specify	

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	x	?
b) Physiological stress?	x	?probably
c) Reduced growth?	x	?probably
d) Changes to morphology?	?	?
e) Senescence?	x	?
f) Other		?

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	maybe	?
b) Physiological stress?	x	likely
c) Reduced growth?	x	likely
d) Changes to morphology?	?	?
e) Senescence?	maybe	?
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species *Halophila decipiens* **Bob Virnstein**

NOTE: I don't have enough observations on this species to even guess. Winter doesn't count, since it's an annual.

Species?

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

	low		high
a) prolonged exposures (weeks to months) and	low	>20	high
b) short-term acute exposures (hours to days)	low	?	high

2) Are you basing your values on (check all that apply)

a) casual field observations x

b) documented and quantified field observations

c) controlled laboratory studies

d) other - specify

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	maybe	
b) Physiological stress?	likely	
c) Reduced growth?	likely	
d) Changes to morphology?		
e) Senescence?		
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species? If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species *Halophila engelmannii* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	<20	high	any?
b) short-term acute exposures (hours to days)	low	<15	high	none?

2) Are you basing your values on (check all that apply)

a) casual field observations x

b) documented and quantified field observations

c) controlled laboratory studies

d) other - specify

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	likely	
b) Physiological stress?	probably	
c) Reduced growth?	probably	
d) Changes to morphology?		
e) Senescence?		
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity	Can't guess
a) Mortality?			
b) Physiological stress?			
c) Reduced growth?			
d) Changes to morphology?			
e) Senescence?			
f) Other			

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species *Ruppia maritima* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	0	high	>60
b) short-term acute exposures (hours to days)	low	0	high	>50

2) Are you basing your values on (check all that apply)

a) casual field observations x

b) documented and quantified field observations

c) controlled laboratory studies

d) other - specify

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity	Can't guess, but less than other species
a) Mortality?			
b) Physiological stress?			
c) Reduced growth?			
d) Changes to morphology?			
e) Senescence?			
f) Other			

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity	Can't guess, but less than other species
a) Mortality?			
b) Physiological stress?			
c) Reduced growth?			
d) Changes to morphology?			
e) Senescence?			
f) Other			

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species *Caulerpa prolifera* **Bob Virnstein**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	20	high	?
b) short-term acute exposures (hours to days)	low		high	

2) Are you basing your values on (check all that apply)

a) casual field observations	x
b) documented and quantified field observations	x
c) controlled laboratory studies	
d) other - specify	

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	x	
b) Physiological stress?	x	
c) Reduced growth?	x	
d) Changes to morphology?		
e) Senescence?		
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

Species? *Thalassia testudinum* **Silvia Macia**

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	25	high	38
b) short-term acute exposures (hours to days)	low	5	high	40

2) Are you basing your values on (check all that apply)

a) casual field observations X

b) documented and quantified field observations X

c) controlled laboratory studies

d) other - specify

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?	X	X
c) Reduced growth?	X	X
d) Changes to morphology?	X	
e) Senescence?	X	X
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

No.

Species	*Halodule wrightii*	*Syringodium filiforme*	**CHESNES** ***Thalassia testudinum***	*Halophila johnsonii*	*Halophila decipiens*	*Halophila engelmanni*
	Ruppia maritma	*Caulerpa prolifera*				

Species?

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low		high	
b) short-term accute exposures (hours to days)	low	**0-9 (see note 1)**	high	**36 (see note 2)**

2) Are you basing your values on (check all that apply)

a) casual field observations

b) documented and quantified field observations

c) controlled laboratory studies

d) other - specify **mesocosm experiments focusing on salinity fluctuation**

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		
e) Senescence?		
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	**X**	
b) Physiological stress?	**X**	
c) Reduced growth?	**X**	
d) Changes to morphology?	**X**	
e) Senescence?	**X**	
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?

If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

6) We are conducting a literature review and have identified much of the published information related to salinity tolerances for the species listed. It would be helpful, however, if you could include any references for both peer-reviewed publications and gray-literature reports that document your research and observations related to salinity tolerances for the indicated species. If gray-literature is not available on line, please include a copy of the report or email a .pdf to **irlandi@fit.edu.**

Note 1- Low salinity survival is based on an experiment with exposure to salinity fluctuating between 0 and 9‰ over 27 days
***Thalassia* survived this treatment, although there was much defoliation. When fluctuation occurred over a wider range (0-36), there was no survival ove**

Note 2- The highest salinity used in these experiments was 36 ‰, in the field *Thalassia* has been documented to tolerate higher salinities.

Species	*Halodule wrightii*	*Syringodium filiforme*	*Thalassia testudinum*	*Halophila johnsonii*	*Halophila decipiens*	*Halophila engelmanni*
	Ruppia maritma	*Caulerpa prolifera*				

Species? ______

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low		high	
b) short-term accute exposures (hours to days)	low	**0 (see note 1)**	high	**36**

2) Are you basing your values on (check all that apply)

a) casual field observations ______

b) documented and quantified field observations ______

c) controlled laboratory studies ______

d) other - specify **mesocosm experiments focusing on salinity fluctuation**

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		

e) Senescence?		
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?	X	
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

6) We are conducting a literature review and have identified much of the published information related to salinity tolerances for the species listed. It would be helpful, however, if you could include any references for both peer-reviewed publications and gray-literature reports that document your research and observations related to salinity tolerances for the indicated species.
If gray-literature is not available on line, please include a copy of the report or email a .pdf to **irlandi@fit.edu.**

Note 1- *Ruppia was* extremely resilient to fuctuations in salinity. In this experiment, salinity fluctuated between 0 and 36 ‰ over four day and eight day
This experiment spanned 24 days.
There were no significant changes in morphology between the *Ruppia* exposed to the eight day fluctuation period and the control kept at constant 18‰
Plants exposed to the four day period (w/ more frequent fluctuation) showed minor changes in morphology, although survival was still high.

Species	***Halodule wrightii***	*Syringodium filiforme*	*Thalassia testudinum*	*Halophila johnsonii*	*Halophila decipiens*	*Halophila engelmanni*
	Ruppia maritma	*Caulerpa prolifera*				

Species?

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for

a) prolonged exposures (weeks to months) and	low	high

b) short-term accute exposures (hours to days) low **0 (see note 1)** high **36**

2) Are you basing your values on (check all that apply)

a) casual field observations

b) documented and quantified field observations

c) controlled laboratory studies

d) other - specify **mesocosm experiments focusing on salinity fluctuation**

3) Based on your observations and/or experimental research what are the consequences of **prolonged exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?		
b) Physiological stress?		
c) Reduced growth?		
d) Changes to morphology?		
e) Senescence?		
f) Other		

4) Based on your observations and/or experimental research what are the consequences of **short-term exposures** to low and/or high salinity?

(check all that apply)	low salinity	high salinity
a) Mortality?	**X**	
b) Physiological stress?	**X**	
c) Reduced growth?	**X**	
d) Changes to morphology?	**X**	
e) Senescence?		
f) Other		

5) Are you currently involved in any ongoing monitoring or experimental studies related to high and/or low salinity tolerance for this species?
If so provide a summary of the work including **project objectives** and **anticipated date of completion**.

6) We are conducting a literature review and have identified much of the published information related to salinity tolerances for the species listed. It would be helpful, however, if you could include any references for both peer-reviewed publications and gray-literature reports that document your research and observations related to salinity tolerances for the indicated species. If gray-literature is not available on line, please include a copy of the report or email a .pdf to **irlandi@fit.edu.**

Note 1: This is based on a fluctuation experiment with salinity ranging from 0 to 36 ‰, over 4 and 8 day periods, spanning 24 days. There was significant mortality of Halodule, however some plants did survive. Key differences in morphology between survivng experimental and cont include a reduction in the number of shoots, the number of leaves per shoot, and leaf length.

Additional Reply from Bob Virnstein

From: Robert Virnstein
To: Elizabeth Irlandi
Sent: Thursday, August 10, 2006 4:33 PM
Subject: RE: Seagrass Salinity Review take 3

Beth,
I should have completed my spreadsheet by changing/updating my numbers for *Caulerpa*:

18 psu prolonged
13 psu for short-term.

Although I have called them "guesses," my numbers are based on 30 years of field observations in the IRL.
And some of what I marked as "casual field observations" do have some "documented field observations" to back them up. For example, we have checked some transect data against WQ monitoring network data. So some of the "guessing" come in the form of interpolating limited (monthly) WQ data with limited (semi-annual) seagrass monitoring. For example, we know that if we observed *Halodule* at 13 psu, and then it rained like crazy for a week, that the *Halodule* experienced salinities lower than 13 psu, even if the next monthly WQ sampling measures salinity above 13 psu. I'll match my guesses against a few periodic measurements at a few sites.

Reply from Marguerite Koch

From: Marguerite Koch
To: 'Elizabeth Irlandi'
Sent: Saturday, September 09, 2006 10:05 AM
Subject: RE: Seagrass Salinity Review take 2

Hi Beth!
Even though it seems like it, I have not been ignoring your emails etc. I am awaiting the proofs of our hypersalinity manuscript-I will forward it asap-when is your report due?
Hope all is well with you and your family-things are busy as always here.
Warm regards,
Marguerite

Marguerite S. Koch-Rose, Ph.D.
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http://www.fau.edu/divdept/biology/people/mrose.htm

Reply from Rick Bartleson for Steve Bortone

Elizabeth Irlandi

From: <rbartleson@sccf.org>
To: "Elizabeth Irlandi" <irlandi@fit.edu>
Cc: <sbortone@sccf.org>
Sent: Friday, June 30, 2006 5:25 PM
Subject: Re: salinity tolerances questions

Beth,

Here are the max and min salinities we have for the last 4 years for the seagrasses, and about the last 7 years for Val. Let me know if you need more detail. Good luck and happy 4th!

Rick

---

1) Given your professional experience what is the lowest and highest salinity this species can tolerate for short or long term exposures.
b) documented and quantified field observations

I can't answer this question since I haven't done experiments on salinity tolerance. Instead, these are the documented observations and field measurements from our data on plant occurrence and salinities from our data. Higher and lower values for these sites may be found in SFWMD's DBHYDRO database.

We have found H. wrightii (or beaudettei), R. maritima and T. testudinum in Sanibel waters where we measured salinity of 40 ppt.
At our (district) sites in and near the Caloosahatchee salinities we recorded where T. testudinum occurred ranged from 35.7to 8.06 ppt. Salinities at Ruppia sites ranged from 35.7 to 0.16 ppt. Salinites at Halodule sites ranged from 35.7 to 0.18 ppt. Salinities where Vallisneria was present ranged from 24 to 0 ppt. Syringodium has not been recorded in the SFWMD sampling quadrats, but I have recorded salinities from 35 to 40 in where it was present near Sanibel. Halophila englemanni and H. decipiens are also growing near Sanibel growing at and H decipiens also was growing at the outermost river site at a salinity of 28.6 this spring.

Reply from Jud Kenworthy

Elizabeth Irlandi

From: "Jud Kenworthy" <Jud.Kenworthy@noaa.gov>
To: "Elizabeth Irlandi" <irlandi@fit.edu>
Sent: Thursday, September 28, 2006 1:28 PM
Attach: jud.kenworthy.vcf
Subject: Re: one last try before I call :)

Beth, I should apologize for being delinquent, but I don't have a good excuse, other than being so busy I haven't taken the time to reply to you questionaire, which by the way, is a very good effort.

Ok, so what have I done. For salinity directly, nothing, but indirectly, well I should advise you to contact some other folks if you haven't gotten a reply yet, Mike Durako and Bob Virnstein for sure. they are definitely doing work. Mike especially, and he will be closely networked with ongoing work by others because he has a graduate student doing a thesis related to this.

Reply from Chris Madden

----- Original Message -----
From: Madden, Christopher
To: Elizabeth Irlandi
Sent: Tuesday, September 05, 2006 5:09 PM
Subject: RE: Seagrass Salinity Review take 2

Hi Beth-

You may already have this but the best contribution I can make is to send you the literature/data review that I had contracted about two years ago through Battelle. It is pretty good although it does not assess all of the species you mention. It is a start though.

If you would like an electronic copy please let me know.

Regards

chris

Christopher J. Madden, Ph.D.
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Reply from Mary Collins

Elizabeth Irlandi

From: "Collins,Mary E" <mec@ufl.edu>
To: "Elizabeth Irlandi" <irlandi@fit.edu>
Sent: Thursday, September 28, 2006 10:40 AM
Subject: RE: one last try before we start phone tag

Elizabeth:

I had passed this email on to my colleague Dr. Rex Ellis, but I guess he did not response. Dr. Ellis is working in the area of subaqueous soils. The answer is no. We are not studying salinity effects on SAV. We are monitoring a number of other soil factors on SAV.

Sorry about the delay for such a short response.

Mary

Mary E. Collins, Ph.D.
Professor
President, Soil Science Society of America
Undergraduate and Honors Coordinator
Soil and Water Science Department
2169 McCarty Hall
PO Box 110290
University of Florida
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352-392-3902 (fax)

Reply from Mike Durako

Elizabeth Irlandi

From: "Durako, Michael" <durakom@uncw.edu>
To: "Elizabeth Irlandi" <irlandi@fit.edu>
Sent: Wednesday, June 28, 2006 10:50 AM
Attach: Kahn&DurakoBMS2005.pdf; Kahn&DurakoJEMBE335(2006).pdf; Murphy et al AQBOT2003.pdf; TourquemadaetalMarBio2005.pdf
Subject: RE: seagrass salinity review

Beth:

Attached are some pdfs of some of the salinity-tolerance work that we've done here. I have a PhD student who is looking at salinity/CDOM effects on Halophila johnsonii in both the field and in mesocosms. This work should be completed sometime next summer.

mjd

Michael J. Durako, Professor
Department of Biology and Marine Biology
Center for Marine Science
The University of North Carolina Wilmington
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Wilmington, NC 28409
910-962-2373/FAX 910-962-2410
durakom@uncw.edu
http://people.uncw.edu/durakom/index.htm

Additional reply from Amanda Kahn for Mike Durako

Elizabeth Irlandi

From: "Kahn, Amanda Elizabeth" <aek8122@uncw.edu>
To: <irlandi@fit.edu>
Cc: "Durako, Michael" <durakom@uncw.edu>
Sent: Monday, September 25, 2006 4:03 PM
Subject: H.johnsonii salinity study

Beth,
I am Mike's student who is working on the H.j. studies. The mesocosm experiments have 3 salinity treatments: 10, 20 and 30. Plant material was collected from Jupiter Inlet. There are 3 field sampling areas, each with paired inlet/riverine sites: Ft. Pierce Inlet/ Taylor Creek (North), Jupiter Inlet/Loxahatchee river (central) and Haulover Inlet/ Oleta River (South). Each station is sampled at high and low tide to capture a range of salinity and CDOM.

If there are any other questions, please let me know. ~AK

Amanda Kahn
UNCW Center for Marine Science
Marine Botany Lab
Office: 910-962-2374
aek8122@uncw.edu

Reply from Penny Hall

Elizabeth Irlandi

From: "Hall, Penny" <Penny.Hall@MyFWC.com>
To: "Elizabeth Irlandi" <irlandi@fit.edu>
Sent: Thursday, September 28, 2006 10:47 AM
Attach: Final 2005 FHAP SF Annual Report.doc
Subject: RE: one last try before I resort to phone tag :)

Dear Beth -

I'm so sorry I haven't responded to your request. I have your letter on my desk in my to-do pile along with about 25 other things that are late...

I don't have any experimental studies re: salinity effects on seagrass distribution and abundance, but Mike Durako does. You probably already know that. However, we are monitoring the status and trends of South Florida seagrass communities as part of CERP MAP. I'm going to attach the text from the annual report I just completed. I think it will give you the information you need for your report.

If you need anything else let me know.

Hope you're doing well.

Take care,
Penny

Margaret O. Hall, Ph.D.
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Email: Penny.Hall@MyFWC.com

Reply from Tom Chesnes

Elizabeth Irlandi

From: "THOMAS CHESNES" <THOMAS_CHESNES@pba.edu>
To: "Elizabeth Irlandi" <irlandi@FIT.EDU>
Sent: Thursday, August 31, 2006 8:58 AM
Attach: seagrass survey questionnaire.xls
Subject: RE: Seagrass Salinity Review take 2

Hi Elizabeth-

Attached is the completed seagrass survey.

The information is reported in my dissertation:
Chesnes, T.C. 2002. Responses of subtropical seagrasses to fluctuations in salinity within an experimental facility. PhD Dissertation, University of Florida, pp 207.

I am currently working on papers to submit from it. I have a digital (pdf) copy of the dissertation, however it is a rather large file (8 MB). I can send it, if you wish.

Please do not hesitate to contact me if you have any questions.

Take care,
Tom

****

Thomas C. Chesnes, PhD
Assistant Professor of Biology
Palm Beach Atlantic University
PO Box 24708
West Palm Beach, FL 33416-4708
561.803.2394

Reply from Brad Robbins

Elizabeth Irlandi

From: "Brad Robbins" <robbins@mote.org>
To: "Elizabeth Irlandi" <irlandi@fit.edu>
Sent: Friday, October 06, 2006 10:08 AM
Attach: robbins.vcf
Subject: Re: one last try before I call :)

Beth,
I can only hope that I'm the last to respond to your request.

Yes. I'm looking at the influence of salinty changes on juvenile fish and seagrass (Halodule, Syringodium & Thalassia) in the Caloosahatchee Estuary. This is a SFWMD-funded study that is entering its 3rd year. I also have similar data from the same sites for the year proceeding Year 1 of the current project (also a SFWMD-funded project). These are more monitoring than experimental. We sample the seagrass every 5-6 weeks measuring canopy height and biomass. I've also measured growth rates in Thalassia but didn't find an effect (related to timing of salinity pulses and confounded by temperature).

An Eckerd College student who I mentor has recently completed a salinity/light/temperature study on Vallisneria americana germination. She was measuring germination success at 3 salinities (0, 5, 10), two light levels (light/dark) and 2 temperatures (24 & 30oC).

Two summer interns conducted research on the influence of salinity on the buoyancy of Vallisneria seed pods this past summer. Four treatments (0,5,7, & 10 psu).

We're about to begin a new study looking at salinity/light/temperature on seedling growth this fall.

Cheers, Brad

Respondent Name: Peter Doering (via Beth Orlando)

1) Do you currently have any ongoing research or monitoring programs that would provide information regarding the effects of salinity on the distribution of target species listed?

At the moment I do not have any ongoing research or monitoring programs in the SIRL, St. Lucie Estuary, Loxahatchee Estuary, or the Lake Woorth Lagoon. However, we have 2 different ongoing studies within the Caloosahatchee River Estuary.

2) If so, please summarize the goals and objectives of the ongoing study.

The first study uses hydroacoustic technology to monitor the SAV distribution/changes at 8 stations within the Caloosahatchee River Estuary (2 freshwater, 2 brackish, 2 marine). Hydroacoustic sampling has been conducted 3 times a year (Sept, Mar, Jun) since 1996. There is one paper out on this and another in the works. The published paper is:

Sabol, Bruce, R.E. Melton, Jr., R. Chamberlain, Pl Doering and K. Haunert. 2002. Evaluation of a digital Echo Sounder Syst4em for detection of submersed aquatic vegetation. Estuaries. 25(1): 133-141.

The second study involves the physical monthly monitoring of the SAV at 3 stations in the upper CRE. This study started in 1998 by Steve Bortone in Sannibel. His group did it 98-99, then Peters group took it over from 2000-2003. We contracted it out to Steve Bortones group in 2004 and they have been doing it ever since.

3) What species are included in the study?

The hydroacoustic study includes *Vallisneria americana*, *Ruppia maritima, Thalassia testudinum and Halodule wrightii.*

The monthly monitoring includes *Vallisneria americana and Ruppia maritima*

4) What is the expected date of completion for the study?

The hydroacoustic monitoring has no completion date. It will be done as long as we are funded to do it. The monthly monitoring was a 3 year contract starting in 2004. Whether or not it will be refunded after the 3 years I'm not sure.