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Vegetation Evaluation in Kings Bay/Crystal River

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INTRODUCTION

Kings Bay/Crystal River is a tidally influenced system located on the west coast of peninsular Florida about 115 km north of Tampa (Figure 1, Table 1). Crystal River is an 11 km long, spring-fed river that originates in the City of Crystal River in Citrus County. At its origin, at least 30 freshwater springs deliver a combined discharge of 26 m^3/s (920 ft^3/s, Rosenau et al. 1977) into a large, open area called Kings Bay.

With an average of 70,000 visitors per year (SWFWMD 1989), Kings Bay/Crystal River is a popular destination for boaters, anglers, wildlife enthusiasts, and sport divers. One of the most common attractions is the West Indian manatee (*Trichechus manatus*), which retreats from the Gulf of Mexico to the relatively warm waters of Kings Bay during September through April. During this time, boat traffic and diving activities is significantly increased as people observe the manatees feeding on the abundant aquatic vegetation present in the bay. Sport divers are also attracted year-round to the second largest spring vent in the bay (Kings Spring), which discharges, on average, 1.2 m^3/s (42 ft^3/s, Rosenau et al. 1977). The cavernous interior of this vent and the bay's historical reputation for clear water and a sandy bottom make this a recreationally and economically important area.

Kings Bay/Crystal River has been designated as an Outstanding Florida Water (OFW). In accordance with the Surface Water Improvement and Management (SWIM) Act of 1987 (Chapter 97-97, Laws of Florida), the Southwest Florida Water Management District (SWFWMD) is charged with management of Kings Bay/Crystal River. Management activities include but are not limited to: (1) the preservation and enhancement of environmentally sensitive areas, (2) reversal of environmental degradation, (3) optimization of water quality and other habitat values and (4) the promotion of designated uses such that the area's ecosystem and economic functions are balanced and maintained (SWFWMD, 2000).

As early as the late 1980s, public concern over water quality issues, sediment conditions and a proliferation of undesirable aquatic plant and algal species in Kings Bay/Crystal River has been actively voiced (Citrus County Chronicle 1985a, 1985b, 1986). The most significant issue continues to be an apparent decline in water clarity. While the water of Kings Bay may be quite clear compared to many of Florida's inland water bodies, there is a popular opinion that it has declined quite significantly from what it was in the past. Reduced water clarity lessens the attraction of the bay and negatively impacts local economic opportunities and especially diving activities. Moreover, the public's perception of the bay's water quality is negatively effected.

Prior to March 1992, the City of Crystal River discharged treated wastewater (2.84×10^6 L/d) into Cedar Cove, a 16 ha area along the northern most shoreline of Kings Bay. The perceived decline in water clarity and a concomitant proliferation of a problem filamentous algae (*Lyngbya* sp.) were originally attributed to the discharge of this treated wastewater (Nearhoof 1989, Romie 1990). As a consequence, the city of Crystal River diverted treated municipal effluent from Cedar Cove in an attempt to improve water quality (Romie 1990) and to reestablish the natural vegetation in Kings Bay/Crystal River. Subsequently, the Coastal Rivers Basin Board of the SWFWMD entered into an agreement with the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) in August 1992 to establish a volunteer water quality monitoring program (Florida LAKEWATCH) in Kings Bay/Crystal River. At that time, the primary purpose of the program was to assess the impact of the wastewater removal on water quality and the abundance of aquatic macrophytes.

It was determined, as a result of the above agreement, that an elimination of the wastewater discharge significantly lowered total phosphorus (TP) and total nitrogen (TN) concentrations in Cedar Cove, but TP and TN concentrations were not significantly reduced in the southern portions of Kings Bay (Bishop and Canfield 1995). Bishop (1995) determined that a reduction in the frequency of occurrence of *Hydrilla verticillata* and *Lyngbya* sp. after the removal of the wastewater from Cedar Cove could be attributed to the "Storm of the Century" on March 13, 1993, and not the removal of the wastewater effluent. This interpretation of the data was further supported by Mataraza et al. (1999) who analyzed a long-term data set on submerged aquatic macrophytes in Kings Bay/Crystal River in relation to three major storm events. These investigators concluded that the percent occurrence of most species declined immediately after the storm events. There is still debate, however, as to whether the reduction in vegetation was the result of physical uprooting or an increase in salinity.

Additional work in Kings Bay (Canfield unpublished data) led to the suggestion that algae in the water column may be the primary factor affecting reduced visibility in Kings Bay/Crystal River, and it was hypothesized that back canals in southern Kings Bay were the source of the algae. As a consequence, a project was initiated July 1996 to further investigate the relationship between microscopic algae and decreased water clarity. The findings from this 1996 study suggest that the water clarity in Kings Bay/Crystal River is determined primarily by the concentration of suspended solids that are dominated by microscopic algae (Hoyer et al. 1997; Munson 1999). However, the hypothesis that the back canals were the main source of the solids was not supported by the data. Mean concentrations of suspended solids, chlorophyll and nutrients in the back canals were not significantly different from those in the bay. In fact, the total volume of water in the canals located in the southeast corner of Kings Bay/Crystal River is only about 25% of the volume of the bay southeast of Banana Island. Thus, concentrations of solids, chlorophyll, or nutrients in the canals would have to be six times as high as that in the bay to affect a one-fold increase in concentrations assuming complete flushing of the canals into the southeast bay. Additional results presented in the reports referenced above suggests that long-term variation in aquatic plant biomass in Kings Bay/Crystal River could be responsible, in part, for reported fluctuations in water clarity. When aquatic plant abundance was high in Kings Bay/Crystal River then water clarity was high. Accordingly, when aquatic plant abundance was low, so was water clarity.

The primary objective of this project was to examine the factors that affect water clarity in Kings Bay/Crystal River and specifically to characterize the relationship between aquatic vegetation and water clarity. Towards this end, we monitored water clarity, water chemistry and aquatic macrophyte abundance concurrently in Kings Bay/Crystal River. The project allowed for an evaluation of the potential impact of storm surges and increased salinities on aquatic macrophyte abundance in Kings

Bay/Crystal River.

METHODS

Overview of Study System: The watershed of Kings Bay/Crystal River located in a subtropical climate (Latitude 28°53', Longitude 82°35') is about 54 km^2 (Glace and Radcliffe 1981). The Crystal River and Kings Bay area are classified as a shelf embayment, or a broad, shallow depression developed by dissolution of limestone bedrock (Hine and Belknap 1986). The system lies in the Chassahowitzka Coastal Strip subdivision of the Big Bend Karst division of the Ocala Uplift District (Brooks 1981). The Bay area is primarily composed of limestone extending from the Ocala formation. A thin veneer of sedimentary deposits dominated by quartz sand (Jones & Upcurch 1994) typically covers areas in which the limestone is not exposed.

Average depths in Crystal River range from 3 m to 5 m (City of Crystal River, 1988) and monthly tidal fluctuations from the Gulf vary from about 0.7 m at the mouth of the river to about 0.3 m in the bay under normal climatic conditions (Rosenau et al. 1977). Kings Bay is approximately 2 x 1 km wide, with a surface area of about 1.91 km^2. The bay is shallow, typically ranging from 1 m to 3 m in depth (Romie 1990, Jones & Upchurch 1994). The 30 known springs and sinks which discharge into Kings Bay represents the fourth largest, first magnitude spring group in Florida (Rosenau et al. 1977). The springs maintain a relatively constant temperature of 25° C. Mean total phosphorus (TP) concentration of the spring discharges range from 22 µg/L to 55 µg/L and total nitrogen (TN) concentrations range from 190 µg/L to 620 µg/L (Romie 1990). The bay-wide annual average concentrations of TP and TN using seven open water stations from 1992 through 2000 ranged from 21 to 34 µg/L, and 195 to 322 µg/L, respectively (Florida LAKEWATCH 2000). The bay-wide annual average chlorophyll concentrations using seven open water stations from 1992 through 2000 ranged from 4 to 11 µg/L (Florida LAKEWATCH 2000).

Sampling Methods: Water clarity, water chemistry and aquatic plant biomass were measured bimonthly from August 1999 through August 2000 at 21 fixed sampling stations (Figure 1, Table 1). Terrell and Canfield (1996) originally established twenty of the stations; an additional station (#21) was added to provide a more complete and representative view of Kings Bay.

Daily average wind speed and direction were obtained from Florida Power Corporation in Crystal River, Florida (15760 W. Power Line Road, Crystal River, Florida 344288-6708). The corporation has a meteorological tower, located near the mouth of Crystal River, on which two wind meters are mounted at a height of 10 and 53 m to measure wind speed and direction.

Water clarity: Multiple approaches were used to assess water clarity in the bay. At each station, a Secchi depth was measured with a 20-cm diameter white disk. Because the water was usually clear enough to see the bottom of the Bay, horizontal Secchi distances were also recorded when possible. In addition, quantum light sensors (Li-Cor Instruments, Inc.) were employed to simultaneously collect surface and downwelling irradiance (umole m^{-2} s^{-1} of photosynthetically active radiation; i.e., PAR) with a data logger and light attenuation (K_d) at each station was determined with the following equation:

$$\text{(eq. 1)} \quad K_d = [\ln (I_0/I_z)] / z ;$$

where I_0 is incident irradiance at the water surface and I_z is light intensity at depth z (m) (Kirk, 1983).

***Water Chemistry*:** Temperature (C°), dissolved oxygen concentration (mg/L), specific conductance (μS/cm^2 at 25 C°) and salinity (ppt) were measured with a YSI Model 57 meter at the surface (ca. 0.25 m) and bottom (ca. 0,25 m above sediments) of the water column at each site. Surface water samples for nutrient analysis were collected in 250-ml, acid-cleaned Nalgene bottles that were pre-rinsed with bay water. Samples were transported on ice and subsequently frozen prior to analysis at the Department of Fisheries and Aquatic Sciences. Total phosphorus (TP) concentrations (μg/L) were determined using the procedures of Murphy and Riley (1962) with a persulfate digestion (Menzel and Corwin 1965). Total nitrogen (TN) concentrations (μg/L) were determined by oxidizing water samples with persulfate and determining nitrate-nitrogen with second derivative spectroscopy (D'Elia et al. 1977; Simal et al. 1985; Wollin 1987). A total nitrogen equivalency study of nitrogen in surface waters demonstrated that this method is a suitable substitute for the standard U.S. Environmental Protection Agency method involving the sum of nitrate-nitrogen and Kjeldahl-nitrogen as measured with an automated analyzer (Bachmann and Canfield 1996).

Additional surface water samples were collected for analyses of chlorophyll and suspended solids. For chlorophyll analysis, a known volume of water was filtered on site through a 47 mm Gelman type A-E glass fiber filter. Filters were kept cold, stored over silica gel desiccant and later frozen prior to analysis.

Chlorophyll concentrations (µg/L) were determined spectrophotometrically (Method 10200 H; APHA 1989) following pigment extraction with ethanol (Sartory and Grobbelaar 1984). The actual weight of the algal cells (TSSchl) was estimated from chlorophyll concentrations assuming a dry-weight/chlorophyll ratio of 70 (Scheffer 1998). Suspended solids were determined by filtering water on site through precombusted (550°C) and preweighed glass fiber filters. At the laboratory, filters were weighed after drying at 100°C for 1 h, yielding the weight of total suspended solids (TSS). Non-volatile suspended solids (TSSnon) were determined after combustion at 550°C for 1 h. Volatile suspended solids were determined by the difference between total and non-volatile suspended solids. The weight of volatile suspended solids accounted for by detritus (TSSdet) was computed as the difference between volatile and algal suspended solids.

***Vegetative Sampling*:** Aquatic plant biomass and species richness at each of the 21 stations were sampled on a bimonthly basis to correspond with the water chemistry sampling described above. At each station, all aquatic macrophyte species present within 0.25 m^2 quadrat were recorded. A diver subsequently removed all vegetation and the resultant sample was spun in nylon mesh bag to remove excess water and weighed to the nearest 0.1 kg.

For examination of long-term trends and model development, data collected by Bishop (1995), Terrell and Canfield (1996), Hoyer et al. (1997), Munson (1999) and Florida LAKEWATCH (2000) were combined, where possible, with data collected during this study. Bishop (1995) and Terrell and Canfield (1996) sampled nutrients, chlorophyll, water clarity (only vertical Secchi depth) and aquatic plants monthly at 20 of the 21 stations (see Figure 1) from August 1992 to August 1994. Hoyer et al. (1997) and Munson (1999) sampled nutrients, chlorophyll, water clarity (vertical Secchi depth, Horizontal Secchi distance and light extinction coefficients), specific conductance and concentrations of suspended solids from 16 stations in Kings Bay/Crystal River (Figure 2) between September 1996 and May 1998. Hoyer et al. (1997) and Munson (1999) also sampled aquatic plants at the same 20 stations that Bishop (1995) and Terrell and Canfield (1996). The water quality sampling stations, however, were primarily in the southeastern portion of Kings Bay/Crystal river and did not correspond with the aquatic plant sampling stations. Data from the Florida LAKEWATCH program (Florida LAKEWATCH 2000) was from 7 stations in Kings Bay/Crystal River (Figure 3). Nutrient, chlorophyll and water clarity (vertical Secchi depth) data were collected monthly since August 1992.

Quality Assurance and Statistical Analyses: All analytical procedures for this project were based on a Department of Fisheries and Aquatic Sciences, University of Florida, comprehensive quality assurance plan (# 910157) approved by the Florida Department of Environmental Protection. Statistical computations were performed with the JMP statistical software package (SAS Institute, Inc. 1994). For correlation analyses and model development all variables were transformed to their logarithms (base 10) to accommodate heterogeneity of variances. Statements of statistical significance imply $p \leq 0.05$. All raw water chemistry and aquatic plant data collected during this project are listed in Appendices I through IV.

RESULTS AND DISCUSSION

Factors impacting water clarity: Secchi disk recordings provide a simple way to characterize water clarity and the method has been used extensively in both freshwater and marine environments. Since 1992, over 1200 vertical Secchi depth readings have been made in Kings Bay. In approximately 75% of these cases, however, the Secchi disk was recorded as occurring on the bottom or in dense vegetation. Although these data indicate that water clarity in Kings Bay/Crystal River is generally sufficient to allow light to reach the sediments and support aquatic plant growth, it is apparent that other methods are required to assess more subtle changes in the optical characteristics of this system. Horizontal Secchi readings are likely to be a more useful measure of water clarity (e.g., Davies-Colley 1988). Moreover, Kirk (1983) suggests that a light attenuation coefficient ($K_{d;}$ eq. 1) may be the best single parameter with which to make such comparisons. Both approaches are discussed more fully below.

The primary factors that influence light transmittance in aquatic systems include algal cells (Canfield and Hodgson 1983), non-volatile suspended solids (Canfield and Bachmann 1981, Hoyer and Jones 1983), detrital suspended solids (Buiteveld 1995) and dissolved organic substances (Brezonik 1978, Canfield and Hodgson 1983). Particulate substances in the water column tend to increase the scattering of light while dissolved substances tend to increase light absorption. Generalized relationships (see Davies-Colley et al. 1993) for K_d and Secchi distance (we assume also horizontal Secchi) with suspended solids concentrations accounted for by algal cells (TSSchl), detritus (TSSdet) and non-volatile suspended solids (TSSnon) are as follows:

$$\text{(eq. 2)} \qquad K_d = a_1 + b_1 \bullet TSSchl + b_2 \bullet TSSdet + b_3 \bullet TSSnon, \text{ and}$$

$$\text{(eq. 3)} \quad \text{Secchi depth} = a_2 - b_1 \bullet \text{TSSchl} - b_2 \bullet \text{TSSdet} - b_3 \bullet \text{TSSnon};$$

where the intercepts a_1 and a_2 represent the light attenuation accounted for by color and other factors not written into the equation. Note that the concentrations of suspended solids accounted for by algal cells and detritus are not measured directly in this or most other studies. Algal solids were estimated, for our purposes here, from chlorophyll concentrations assuming a dry-weight/chlorophyll ratio of 70 (Scheffer 1998). Detrital suspended solids were estimated by subtracting the algal solids component from the volatile suspended solids.

Canfield and Hodgson (1983) reported that color accounted for a significant portion of the variance in the water clarity of Florida lakes. However, Hoyer et al. (1997) and Munson (1999) measured color at 8 open water and 11 canal stations in Kings Bay/Crystal River and found that this variable explained little of the observed variation in K_d or horizontal Secchi distance. This is not surprising considering that few of the color measurements in Kings Bay/Crystal River were greater than 5 Pt-Co units and the average for 165 Florida lakes was greater than 50 Pt-Co units (Canfield and Hodgson 1983). It is possible that color could contribute significantly to water clarity in marshes around the bay but based on these previous studies, color was not considered a significant factor determining water clarity in Kings Bay/Crystal River and was not considered further in this study.

Bishop and Canfield (1995) examined surface water collected near Kings Spring during a period of low visibility in Kings Bay and determined that suspended particles in the water column were comprised primarily of microscopic algal cells. Because horizontal Secchi distances were correlated with surface water chlorophyll concentrations, these investigators suggested that algal solids may be the primary determinant of water clarity in the Bay. In fact, minimum (10 ft) and maximum (58 ft) horizontal Secchi readings occurred on days when chlorophyll concentrations were at 20 µg/L and 1.7 µg/L, respectively. Although the source of the algae was not determined, several mechanisms might explain the occurrence of elevated chlorophyll concentrations in Kings Bay. There is anecdotal evidence, for example, to suggest that algal material resuspended from the bottom and/or dislodged from the ubiquitous vegetative community within the Bay may be responsible. Bachmann et al. (2000) suggested, however, that wind-generated surface waves are not likely to disturb bottom sediments in most bay locations and that periphyton originally associated with aquatic plants is a more plausible source. Periphyton and settled detritus associated with plants can be dislodged by wind-generated waves, power boats, swimmers, and divers during high traffic periods as well as from movements of foraging manatees, which have been known to consume up to 50 kg of vegetation per animal per day (Kochman et al. 1983; Packard 1983).

Hoyer and Jones (1983) showed that total suspended solids among 82 midwest reservoirs accounted for ca. 84% of the variance in water clarity measurements. For this study, station average total suspended solids ranged from 0.7 to 7.5 mg/L with a grand mean of 3.1 mg/L (Table 3). Combining suspended solids data from Hoyer et al. (1997) and Munson (1999) with data generated during this study shows that total suspended solids are directly related to light extinction coefficients (Figure 4) and inversely related to horizontal Secchi distances (Figure 5). However, total suspended solids statistically accounted for only 7% of the variance in light attenuation coefficients (Figure 4), while total suspended solids accounted for 37% of the variance in horizontal Secchi distance (Figure 5).

Similarly, both Hoyer et al. (1997) and Munson (1999) reported that relations between water clarity and suspended solids data were consistently more variable when water clarity was estimated with light attenuation coefficients rather than horizontal Secchi distances. Even though Kirk (1983) suggested that K_d may be the best single parameter with which to compare light attenuating properties among various water bodies, data presented here suggests that in Kings Bay/Crystal River horizontal Secchi distance is a more statistically robust measure of water clarity and more representative of what divers can see. The greater variance associated with the light attenuation coefficients may be, in part, because of difficulties associated with deploying the light meter and maintaining a constant depth and vertical orientation in shallow water when waves are present. Wave action in Kings Bay/Crystal River also changes the angle of light entering the water column, which adds variance to the measurement of light attenuation coefficients. Thus, for the remainder of this report we will use horizontal Secchi distance as the primary measure of water clarity. This will also allow for easier communication of finding to the public because they can easily understand horizontal viewing distances.

Equations 2 and 3 show that total suspended solids can be broken into three main components: (1) non-volatile solids, (2) volatile algal solids and (3) volatile detrital solids. The mean concentrations of non-volatile, algal and detrital solids in Kings Bay/Crystal River for 22 stations were 1.5, 0.5, and 1.1 mg/L, respectively (Table 3). Combining the data above with that collected by Hoyer et al. (1997) and Munson (1999) shows that non-volatile, algal and detrital solids are all inversely related to horizontal Secchi distance (Figures 6-8). Non-volatile solids and detrital solids accounted for 30% and 12% of the variance in horizontal Secchi distance, respectively (Figure 6 and 8). Algal solids accounted for the largest percentage of the variance, i.e., ca. 40% (Figure 7). Because the algal solids fraction was estimated from chlorophyll concentrations, it follows that the latter measure too is inversely related to horizontal Secchi distances. In fact, chlorophyll concentrations in the water column account for 40% of the variance in horizontal Secchi distances (Figure 9). These findings are consistent with those of previous investigators working in Kings Bay (Bishop 1995, Hoyer et al. 1997 and Munson 1999) and show that algal abundance is the primary factor determining water clarity in Kings Bay/Crystal River.

Total phosphorus, total nitrogen, and chlorophyll relations: Phosphorus and nitrogen are often primary factors determining the abundance of algal cells in waters around the world (Sakamoto 1966; Aizaki et al 1981). Thus, we examined the concentrations of total phosphorus and total nitrogen in Kings Bay/Crystal River to determine if these nutrients were related to chlorophyll, an indicator of algal biomass, and the primary determinant of water clarity in Kings Bay (see above). Total phosphorus, total nitrogen and chlorophyll concentrations over the course of this investigation averaged 28, 229, and 8 µg/L, respectively (Table 2). Because these values are similar to the long-term averages (1992 to 2000) of 26, 247, and 7 µg/L measured by Florida LAKEWATCH (2000) for total phosphorus, total nitrogen, and chlorophyll, respectively, we elected to explore the latter data set in more detail.

An examination of the Florida LAKEWATCH data for the seven stations sampled monthly from 1992 to 2000 showed that total phosphorus (Figure 10) and total nitrogen (Figure 11) were indeed positively correlated to chlorophyll levels in Kings Bay/Crystal River. This is consistent with research showing that total phosphorus and total nitrogen are significantly related to chlorophyll concentrations among Florida lakes (Canfield 1983). If, however, the annual mean data are analyzed in relation to other mean lake data collected from around the state (mean TP, TN and TChl concentrations from 296 Florida lakes with 4 years or greater of monthly data; Florida LAKEWATCH 2000) an interesting pattern emerges. All of the Kings Bay/Crystal River data fall well below the linear regression line of the total phosphorus-chlorophyll plot (Figure 12), suggesting that chlorophyll concentrations could be much higher given the current total phosphorus concentrations (see Brown et al. 2000). In contrast, the chlorophyll response to total nitrogen concentrations for all of the Kings Bay/Crystal River data fell well above the linear regression line of the total nitrogen-chlorophyll plot (Figure 13). This suggests that chlorophyll concentrations are near the maximum for the current total nitrogen concentrations and that changes in nitrogen concentrations may readily influence chlorophyll, i.e., algal concentrations, and, in turn, water clarity in Kings Bay.

The yield of chlorophyll per unit of phosphorus in fresh water bodies has been shown to be related to total nitrogen concentrations when the total nitrogen to total phosphorus ratios are less than 17 (Smith and Shapiro 1981) and especially when they are less than 10 (Sakamoto 1966). The total nitrogen to total phosphorus ratios for Kings Bay/Crystal River from 1992 to 2000 (Florida LAKEWATCH 2000) averaged 10 and over 75% of the samples were under 12. These data are consistent with the suggestion that nitrogen may be a factor limiting chlorophyll in this system. There is little evidence, however, that either total phosphorus or total nitrogen have increased/decreased in Kings Bay/Crystal River over the last decade (Figure 14; see also Dixon 1997).

Flushing Rate: Flushing rate may potentially affect chlorophyll concentrations by washout or removal of phytoplankton before the algal standing crop reaches levels determined by concentrations of limiting nutrients (Kofoid 1903; Swanson and Bachmann 1976). This effect becomes increasingly important as the rate at which cells are flushed from a system approaches the cell growth rate. Canfield and Hoyer (1988a) conducted chlorophyll bioassays on 20 Florida rivers (all with flushing rates less than 2 days) where surface water samples where collected and allowed to stand in sunlight in glass jars for 12 days. Chlorophyll concentrations were measured initially and then at days 3, 7 and 12. Initial and day 3 chlorophyll concentrations for the 20 rivers averaged 25% and 74%, respectively, of the day 12 chlorophyll concentrations. Day 7 chlorophyll concentrations averaged 99% of the day 12 chlorophyll concentrations. These data suggest that chlorophyll concentrations can approach a level determined by nutrient concentrations somewhere between 3 and 7 days. More recent work by Frazer (unpublished data) suggests that maximum chlorophyll concentrations in controlled bioassays are reached between 2-3 d in Kings Bay/Crystal River system.

Hammett et al (1996) measured the flushing characteristics of Kings Bay/Crystal River using models to simulate particle and dye movement out of Kings Bay/Crystal River. The models were calibrated with intensive measurements during the tidal cycle of June 7-8, 1990. Tidal fluctuations added an oscillatory component to the models therefore each model ran simulations for three different hydrologic conditions: low inflow, typical inflow, and low inflow with reduced friction from aquatic plants. The models suggested that mean particle residence time in Kings Bay/Crystal River was 59 hours for low inflow conditions, 50 hours for typical inflow conditions and 56 hours with low inflow reduced friction. Ninety-five percent of a simulated dye injection exited Kings Bay/Crystal River within 94 hours for low inflow conditions, 71 hours for typical inflow conditions and 94 hours for low inflow with reduced friction. These data suggest that the water in Kings Bay is completely replaced after approximately 2.1 to 3.9 days and that algal populations can potentially reach maximum biomass, as shown by bioassay data, given the ambient nutrient concentrations.

During the period of intensive field measurements (June 7-8, 1990), Hammett et al. (1996) estimated the total discharge from Kings Bay/Crystal River to be about 735 ft^3/sec. This discharge was about 25% less than the long-term average of 975 (ft^3/sec) from 1965 to 1977 reported by Yobbi and Knochenmus (1989). Hammett et al. (1996) attributed the lower discharge to below normal rainfall in north central Florida during the time of their study. Rainfall in both 1999 and 2000 was also below normal suggesting that water discharge of Kings Bay/Crystal River may also be low with a resultant decrease in flushing rate. Recent elevations in salinity (Figure 15) are consistent with this scenario and suggest that the flushing rate of the bay may presently be closer to 4 days than 2 days. Thus, the flushing rate at this time appears to be slow enough for chlorophyll concentrations to reach maximum levels determined by ambient nutrient concentrations and possibly decreasing water clarity. However, if higher rainfall or unusual tidal fluctuations change flushing rate in Kings Bay/Crystal River to 2 days or less, there may be potential impacts on chlorophyll concentrations. Under these circumstances chlorophyll concentrations may not develop to the level determined by ambient nutrient concentrations and water clarity may increase. Therefore, over time the flushing rate of Kings Bay/Crystal River may be a significant factor impacting water clarity.

Aquatic plant abundance and chlorophyll concentrations: Plant biomass data collected bimonthly in Kings Bay/Crystal River between October 1997 and June 2000 were supplemented with similar data collected in Kings Bay from March 1993 through August 1994 (Terrell and Canfield 1996) and July 1996 through October 1997 (Hoyer et al. 1997) to gain additional insight into the relationship with surface water chlorophyll concentrations. The highest mean plant biomass in the Kings Bay/Crystal River, 6.5 kg/m^2 wet weight, was observed from March 1993 to August 1994 (Figure 14). During the same time interval, chlorophyll concentrations averaged 5.9 µg/L with a range of 3.1-10.3 µg/L and exceeded 10 µg/L only one time. During July 1996 to October 1997 and October 1997 to June 2000, mean plant biomass values were lower; i.e., 2.6 kg/m^2 and 3.0 kg/m^2, respectively. Mean chlorophyll concentrations were, however, higher than previously observed, i.e., 7.3 µg/L and 7.1 mg/L, respectively. The chlorophyll concentrations during the latter plant sampling intervals also exceeded 10 µg/L on several occasions (Figure 14). These data are only bay-wide averages but suggest there may be an inverse relation between chlorophyll concentrations and aquatic plant biomass.

To examine the relation between aquatic plant biomass and chlorophyll in more detail we merged the long-term Florida LAKEWATCH chlorophyll data with the aquatic plant biomass data collected during all three studies mentioned above, by similar station location. Chlorophyll data from Florida LAKEWATCH stations 1, 2, 3, 4, 5, and 7 (Figure 3) were matched by year and month with aquatic plant biomass data from stations 1, 19, 8.2, 13, 17, and 5 (Figure 1), respectively. When aquatic plant biomass equaled or exceeded 5 kg/m^2, chlorophyll concentrations never exceeded 7.1 (µg/L) which is the average chlorophyll value for this database (Figure 16). When chlorophyll and aquatic plant data were logarithmically transformed for linear regression analysis, aquatic plant biomass data accounted for 11% of the variance in chlorophyll concentrations among individual sites (Figure 17). Since chlorophyll is a proxy for algal abundance and because algal suspended solids are a primary factor determining water clarity in Kings Bay/Crystal River (Figure 7), aquatic plant abundance may also be related to the water clarity in this system.

Several mechanisms can explain the apparent inverse relationship between plant biomass and chlorophyll in the water column: (1) aquatic plants and their associated epiphytic algae compete for nutrients that might otherwise be assimilated by phytoplankton, (2) aquatic plants dampen wave energy and cause phytoplankton to settle and (3) aquatic plants stabilize sediments and lessen the likelihood of resuspension of benthic microalgae. Two of these mechanisms are wind driven, and suggest that wind speed should be examined as a possible factor determining water clarity in Kings Bay/Crystal River.

Data collected as part of this effort and that of Hoyer et al. (1997) demonstrate that the average daily wind speed at the mouth of Kings Bay Crystal River is directly related to chlorophyll concentrations and total suspended solids in the water column (Figures 18 and 19, respectively). Chlorophyll concentrations rarely exceed 10 µg/L until average daily wind speeds exceed 5 km/h (Figure 18). Moreover, chlorophyll concentrations above 20 µg/L do not generally occur until wind speeds are in excess of 10 km/h. Similarly, total suspended solids rarely exceed 5 mg/L until average daily wind speeds exceed 5 to 10 km/hr and extreme values only occur at the higher wind speeds (Figure 19). Bachmann et al.

(2000) suggest that very few wind events would create waves capable of resuspending bottom sediments in all but a few shallow areas around the shoreline and the islands of Kings Bay. Therefore, the increase in chlorophyll and suspended solids with an increase in average daily wind speed is most likely the consequence of previously settled algae and detritus being dislodged from the surfaces of aquatic vegetation, and also periphyton that grows attached to aquatic vegetation. Even though chlorophyll and suspended solids increased in Kings Bay/Crystal River with wind in the presence of aquatic macrophytes there is still evidence that chlorophyll concentrations were less during times of high aquatic plant biomass (Figure 14). In a similar study of two macrophyte dominated lakes in central Florida, Lamb (2000) reported similar increases in suspended solids and chlorophyll concentrations with increases in average daily wind velocities. She suggested, as we do here, that the increases in chlorophyll were the result of settled phytoplankton and periphyton associated with aquatic plants in the two systems. Lamb's (2000) data indicate also that water column chlorophyll concentrations were inversely related to the occurrence of macrophytes consistent with the findings in this investigation.

As daily average wind speed increases in Kings Bay/Crystal River so do the concentrations of chlorophyll and suspended solids. The relationship is complicated, however, by the fact that wind velocity changes throughout the day with some studies showing low wind speeds at night and higher speeds in afternoon hours (Canfield and Hoyer 1988b). Moreover, there are accounts from lakes in the northeast United States that demonstrate increases in suspended solids concentrations in relation to boat traffic (see, e.g., Wright and Wagner 1991), which also is generally low at night and high in afternoon hours. Simple recreational activities like swimming, canoeing, and tubing (floating on inflatable inner tubes) was substantial enough to cause increases in suspended solids concentrations in Rainbow River, Florida (Mumma 1996) and such activities may have similar effects in Kings Bay. Clearly, the potential influence of recreational activities on water clarity needs to be examined in this system.

Aquatic plant abundance and salinity: The aquatic plant biomass in Kings Bay/Crystal River was drastically reduced in March 1993 following the "Storm of the Century" (Terrell and Canfield 1996). The reduction in aquatic plant biomass was attributed to a presumed increase in salinity associated with storm surge. Reductions in aquatic plant biomass were also documented after the occurrences of hurricane "Elena" (September 1985) and tropical storm "Josephine" (October of 1996) (Mataraza et al. 1999). These observations have lead to the hypothesis that increased salinity in Kings Bay, as a consequence of episodic storm events, is a major factor influencing the abundance and distribution of aquatic vegetation in Kings Bay. More subtle variations in salinity that likely occur in association with longer-term weather patterns that affect rainfall, ground-water supply and spring discharge may also be important in the ecology of this system.

Bishop (1995) measured specific conductance ($\mu S/cm^2$ @25C°) in surface waters of 17 stations one week after the "Storm of the Century." and values ranged from 700 to 4,200 $\mu S/cm^2$@25C° (see also Romie 1990). Specific conductance and salinity in Kings Bay/Crystal River are highly correlated (Figure 20). The values reported by Bishop (1995) are equivalent to a salinity range of 0.3 to 2.3 ppt. Annual average specific conductance and salinity in surface water over the course of this study ranged from 226 to 9,681 $\mu S/cm^2$@25C° and 0.1 to 5.7 ppt, respectively (Table 2). Bottom measures of specific conductance and salinity were, as expected, higher and ranged from 236 to 13,011 $\mu S/cm^2$@25C° and 0.1 to 7.6 ppt, respectively (Table 2). During this study, annual average total plant biomass averaged 3.5 kg wet wt m^{-2} with a range of 0.2 to 6.5 kg wet wt m^{-2} (Table 4). Vascular plant biomass and filamentous algae biomass averaged 2.4 and 1.1 kg wet wt m^{-2}, respectively (as noted above, these values are less than those reported by Terrell and Canfield (1996) in 1993 and 1994. Both surface and bottom water salinity were inversely related to total plant weight (Figure 21), vascular plant biomass (Figure 22), and filamentous algae biomass (Figure 23). Moreover, there is a trend of increasing specific conductance in Kings Bay over the last decade (Figure 15) that may be, in large part, related to an observed decline in aquatic vegetation and resultant high chlorophyll concentrations.

Aquatic plant species and salinity: Ten species of submersed aquatic plants were identified in the 390 quadrat samples from Kings Bay/Crystal River taken between July 1999 and July 2000 (Figure 24). Submerged aquatic vegetation is ubiquitous in Kings Bay and less than two percent of the quadrats lacked vegetation. The four most dominant plants/algae in Kings Bay/Crystal River were *Myriophyllum spicatum, Hydrilla verticillata, Lyngbya sp., and Vallisneria americana*, occurring in 90, 85, 64, and 59 of the quadrat samples, respectively.

The distribution of individual aquatic plant species within lakes and the presence or absence of individual plant species among lakes has repeatedly been related to salinity and/or specific conductance (e.g., Hutchinson 1975; Hoyer et al. 1996). This appears to be the case in Kings Bay (see Figure 25). *Myriophyllum spicatum,* and *Vallisneria americana*, for example, occur in locations with a higher mean specific conductance than either *Hydrilla verticillata* or *Lyngbya* sp. These data suggest that elevated salinities in Kings Bay/Crystal River may favor the expansion of *Myriophyllum spicatum,* and *Vallisneria americana* over *Hydrilla verticillata* and *Lyngbya.* Indeed, *Hydrilla verticillata* and *Myriophyllum spicatum* exhibited different recovery patterns in Kings Bay/Crystal River after major storm events (Mataraza et al 1999). *Myriophyllum spicatum* recolonized quickly after the storms when salinities were elevated but then declined as *Hydrilla* began to increase in abundance. Thus, changes in salinity of Kings Bay/Crystal River seem to impact both the biomass and species composition of submerged aquatic vegetation.

Summary

The empirical relationship established between horizontal Secchi distance and chlorophyll (a proxy measure of suspended algal solids) implicates the latter as a primary determinant of water clarity in Kings Bay/Crystal River. There is sufficient phosphorus in Kings Bay/Crystal River for chlorophyll concentrations to exceed those that are currently being observed, however, chlorophyll concentrations appear to be near the maximum that would be predicted from existing nitrogen concentrations. Both total phosphorus and total nitrogen concentrations in Kings Bay/Crystal River are directly related to chlorophyll concentrations but account for only a small percentage of the variance in chlorophyll concentrations. This suggests that other factors are likely influencing chlorophyll concentrations within Kings Bay/Crystal River.

Long-term monitoring of vegetation abundance and water chemistry suggest further that fluctuations in aquatic plant biomass are inversely related to chlorophyll concentrations, i.e., algal solids in the water column. Therefore, fluctuations in the aquatic plant biomass in Kings Bay/Crystal River could be responsible, in part, for reported fluctuations in water clarity. When aquatic plant biomass was highest in Kings Bay/Crystal River water clarity was improved.

Several studies have documented direct relations between aquatic plant abundance and water clarity in freshwater bodies around the world. Two of three major mechanisms posited here to explain the direct relation between aquatic plant biomass and water clarity are strongly influenced by wind. Aquatic plants dampen wave action in the water column and, as a consequence, decrease wind resuspension of sediments and associated nutrients, and allow open water algal cells to settle (in this case, often on the plants themselves). Data presented herein demonstrate that wind speed is directly related to the total amount of suspended solids in the water column and inversely related to the water clarity in Kings Bay/Crystal River. We suggest based on our findings that wind can and does resuspend detrital material and periphyton associated with aquatic plants, but not necessarily the bay bottom (see Bachmann et al. 2000). Other factors such as recreational activities and grazing by large herbivores in the Bay also likely dislodge detrital and algal solids associated with aquatic vegetation and may, at times, be an important determinant of water clarity in the systems. Although this study was not intended to address these other factors, they merit further study.

Data from previous investigations in the Kings Bay/Crystal River system suggest that major storm events influence the abundance of aquatic plants in Kings Bay/Crystal River. Storm surges likely increase the salinity in Kings Bay/Crystal River and, as a consequence, reduce the abundance of submerged aquatic vegetation. Findings presented here indicate that more subtle changes in specific conductance (possible related to long-term climatic cycles) can also influence the abundance and species composition of aquatic vegetation in this system. A qualitative inspection of data collected over the past decade suggests that water in Kings Bay has become more saline and vegetative biomass has declined. This change, in light of the data generated here, may be, in large part, responsible for the reported reduction in water clarity in Kings Bay over the same time frame.

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Table 1. Latitude and Longitude of sampling stations in Kings Bay/Crystal River.

Kings Bay/Crystal River plant sampling stations set up by Bishop (1995) with the addition of station 21 for this study.

	Latitude			Longitude		
Station	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
1	28	54	18	82	38	23
2	28	54	21	82	36	56
3	28	53	48	82	36	31
4	28	53	54	82	36	7
5	28	54	25	82	37	55
6	28	53	55	82	35	46
7	28	53	18	82	36	19
8.1	28	53	37	82	36	14
8.2	28	53	24	82	36	12
9	28	53	42	82	35	57
10	28	53	40	82	35	31
11	28	53	10	82	35	54
12	28	53	17	82	35	54
13	28	53	17	82	35	21
14	28	53	10	82	35	22
15	28	52	56	82	36	21
16	28	52	47	82	36	6
17	28	52	50	82	35	41
18	28	52	57	82	35	34
19	28	53	48	82	35	51
20	28	53	47	82	35	9
21	28	53	8	82	35	55

Florida LAKEWATCH long-term water quality monitoring stations in Kings Bay/Crystal River

	Latitude			Longitude		
Station	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds

1	28	54	18	82	38	23
2	28	53	48	82	35	51
3	28	53	24	82	36	12
4	28	53	54	82	36	7
5	28	52	50	82	35	41
6	28	52	56	82	36	4
7	28	54	25	82	37	55

Table 2. Annual average water chemistry values for Kings Bay/Crystal River from July 1999 to July 2000.

Station	Number of Samples	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Chlorophyll (µg/L)	Surface Temperature (C)	Surface Dissolved O2 (mg/L)	Surface Conductivity (µS/cm@25°C)	Bottom Conductivity (µS/cm@25°C)	Surface Salinity (ppt)	Bottom Salinity (ppt)
1	7	33	266	5	24.8	6.1	9681	13011	5.7	7.6
2	7	28	223	7	24.9	8.1	3973	4593	2.1	2.5
3	7	31	256	11	24.8	7	3149	3000	1.5	1.7
4	7	36	236	6	22.7	2.9	418	403	0.2	0.2
5	7	35	290	8	25.1	6.3	7943	7837	4.5	4.5
6	7	28	231	6	23.1	4.1	390	384	0.2	0.2
7	7	29	249	9	24.8	7.8	2756	2761	1.4	1.5
8.1	7	29	223	8	24	6.3	1719	1923	0.9	1.1
8.2	7	28	213	7	24.9	6.7	2522	3033	1.3	1.7
9	7	23	224	5	23.5	5.8	854	929	0.4	0.5
10	7	26	272	11	23.6	6.4	226	236	0.1	0.1
11	7	27	231	9	24.8	8.2	2842	2836	1.5	1.5
12	7	26	236	8	25	7.7	2626	2623	1.4	1.4
13	7	24	210	4	24.7	6.5	382	416	0.2	0.2
14	7	23	183	7	25.2	6.6	393	421	0.2	0.2
15	7	25	229	7	24.7	8.5	3330	3407	1.7	1.7
16	7	25	221	8	22.7	7.5	3123	3166	1.6	1.7
17	7	29	194	6	24.7	5.6	2570	3542	1.3	1.9
18	7	28	186	8	25	7	1836	2147	0.9	1.1
19	7	27	250	6	23.4	5	671	844	0.3	0.5
20	7	28	187	6	24.7	6.6	282	274	0.1	0.1
21	7	29	220	13	25.1	8.8	2863	2923	1.5	1.5
Mean		28	229	8	24.4	6.6	2479	2759	1.3	1.5
Standard Dev.		3	28	2	0.8	1.4	2391	2915	1.4	1.7

Table 3. Annual average suspended solids, water clarity, and wind velocity values for Kings Bay/Crystal River from July 1999 to July 2000.

Station	Number of Samples	Total Suspended Solids (mg/L)	Volatile Solids (mg/L)	Non-volatile Solids (mg/L)	Algal Solids (mg/L)	Detrital Solids (mg/L)	Horizontal Secchi (m)	Extinction Coefficient (m-1)	Wind Speed (km/hr)
1	7	7.5	3.5	4	0.4	3.1	1.7	2.02	13.7
2	7	4.3	2	2.3	0.5	1.5	2.6	1.91	13.7
3	7	6.9	2.9	4.1	0.8	2.1	1.7	1.51	13.7
4	7	3.4	1.8	1.6	0.4	1.4	5	2.02	13.7
5	7	7.3	3.4	3.8	0.6	2.9	1.4	1.78	13.7
6	7	0.7	0.5	0.2	0.4	0.1	4.7	0.88	13.7
7	7	3.7	1.9	1.8	0.7	1.3	2.3	0.86	13.7
8.1	7	2.2	1.3	1	0.6	0.7	2.6	1.18	13.7
8.2	7	3.4	1.5	1.9	0.5	1	2.5	1.07	13.7
9	7	1.4	0.9	0.6	0.4	0.5	3.7	0.87	13.7
10	7	1.5	1.2	0.4	0.8	0.4	4.2	1.42	13.7
11	7	4	2	1.9	0.6	1.4	2.5	0.63	13.7
12	7	2.9	1.7	1.2	0.6	1.1	2.2	0.63	13.7
13	7	1.1	0.6	0.5	0.3	0.4	6.5	1.05	13.7
14	7	1.3	0.9	0.4	0.5	0.4	4.5	0.65	13.7
15	7	2.6	1.5	1.1	0.5	1	2.6	1.29	13.7
16	7	2.5	1.4	1.1	0.6	0.8	2.9	0.88	13.7
17	7	1.9	1.2	0.7	0.4	0.8	3.7	0.94	13.7
18	7	2.7	1.6	1.2	0.5	1	3.6	0.59	13.7
19	7	1.5	0.8	0.7	0.4	0.4	3.9	0.85	13.7
20	7	1.6	1	0.6	0.4	0.6	5.9	1.73	13.7
21	7	4.5	2.6	1.9	0.9	1.6	1.8	0.99	13.7
Mean		3.1	1.6	1.5	0.5	1.1	3.3	1.17	13.7
Standard Dev.		2	0.8	1.2	0.2	0.8	1.4	0.47	0

Table 4. Annual average aquatic plant biomass, surface water salinity and bottom water salinity for each station sampled in Kings Bay/Crystal River between July 1999 and July 2000.

Station	Total Plant Weight (kg/m2)	Vascular Weight (kg/m2)	Filamentous Algae weight (kg/m2)	Salinity @ Surface (ppt)	Salinity @ Bottom (ppt)
1.0	0.2	0.2	0	5.7	7.6
2.0	2.1	1.9	0.7	2.1	2.5
3.0	2.9	2.8	0.1	1.5	1.7
4.0	1.9	1.1	0.8	0.2	0.2
5.0	1.5	1.5	0	4.5	4.5
6.0	5.5	2.4	3.1	0.2	0.2
7.0	2.7	2.4	0.5	1.4	1.5
8.1	3.3	3.2	0.1	0.9	1.1
8.2	2.5	2.5	0	1.3	1.7
9.0	4.9	3.1	1.8	0.4	0.5
10.0	4.8	1.3	3.5	0.1	0.1
11.0	4.1	4	0.1	1.5	1.5
12.0	1.7	1.7	0	1.4	1.4
13.0	5.7	0.3	5.4	0.2	0.2
14.0	4.7	4.7	0.1	0.2	0.2
15.0	5.9	5.6	0.3	1.7	1.7
16.0	5.3	4.4	0.8	1.6	1.7
17.0	1.6	1.1	0.5	1.3	1.9
18.0	1.5	0.7	0.8	0.9	1.1
19.0	6.5	2.5	4	0.3	0.5
20.0	2.7	1	1.7	0.1	0.1
21.0	5.3	4.7	0.6	1.5	1.5
Avg.	3.5	2.4	1.1	1.3	1.5
Min	0.2	0.2	0.0	0.1	0.1
Max	6.5	5.6	5.4	5.7	7.6
STD	1.8	1.5	1.5	1.4	1.7

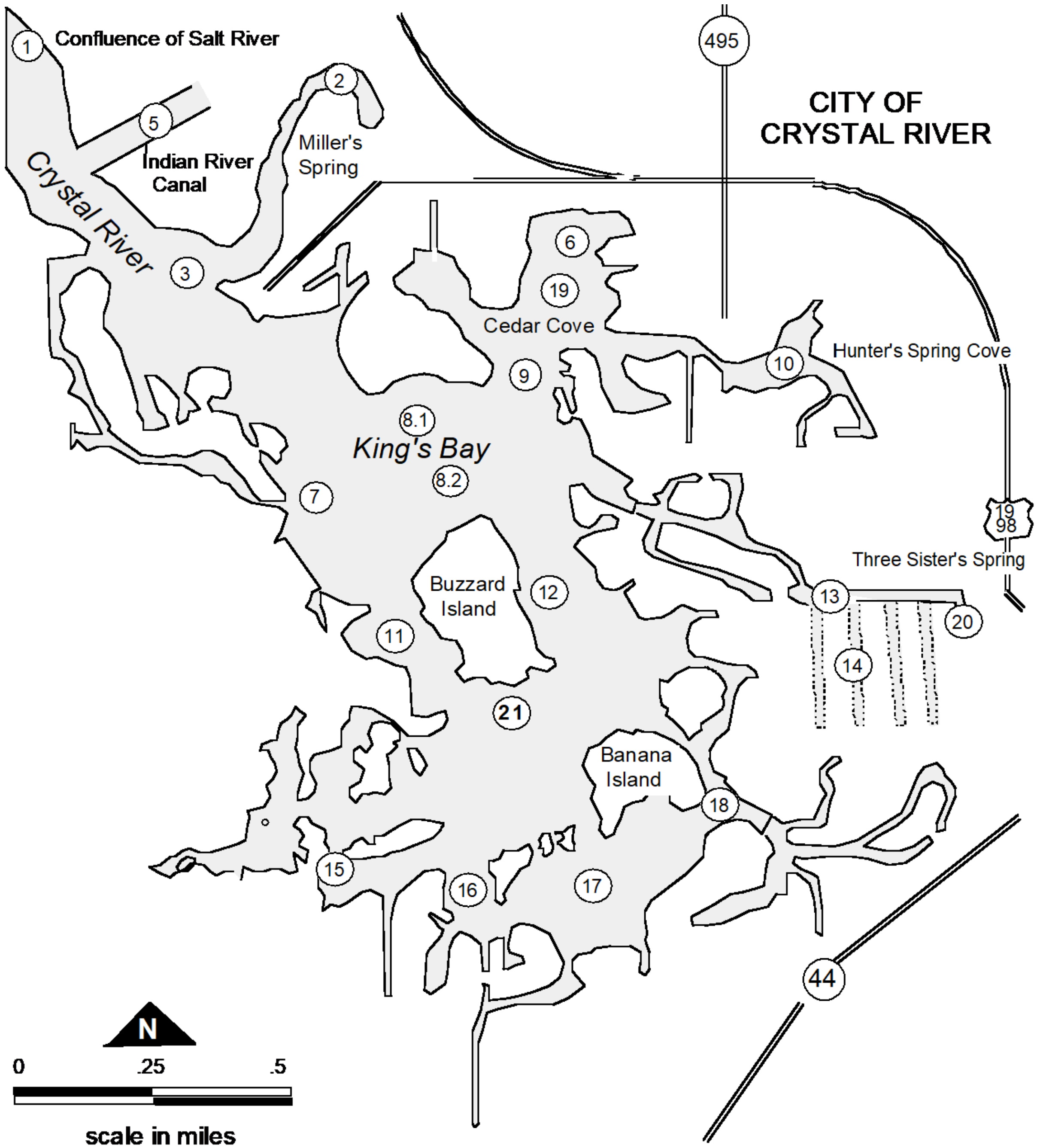

1
Confluence of Salt River
2
5
495
CITY OF
CRYSTAL RIVER
Miller's
Spring
Indian River
Canal
Crystal River
3
6
19
Cedar Cove
9
10
Hunter's Spring Cove
8.1
King's Bay
8.2
7
19
98
Three Sister's Spring
Buzzard
Island
12
13
20
11
14
21
Banana
Island
18
15
16
17
44
N
0
.25
.5
scale in miles

Figure 1. Submersed aquatic macrophyte sampling stations established by Terrell and Canfield (1996) with the addition of station 21 in bold used during this study.

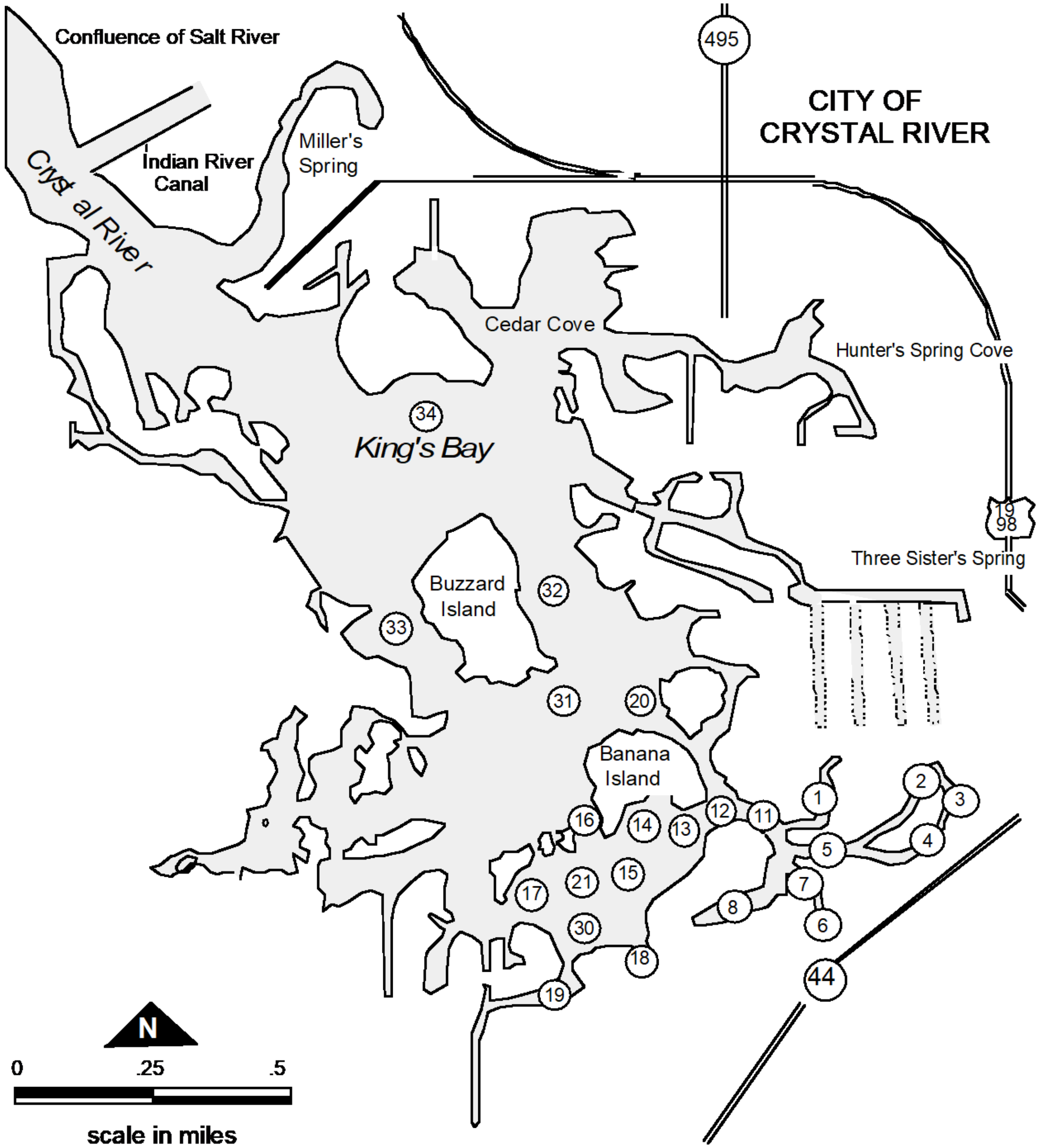


Figure 2. Water chemistry stations in Kings Bay/Crystal River, Florida sampled by Munson (1999).

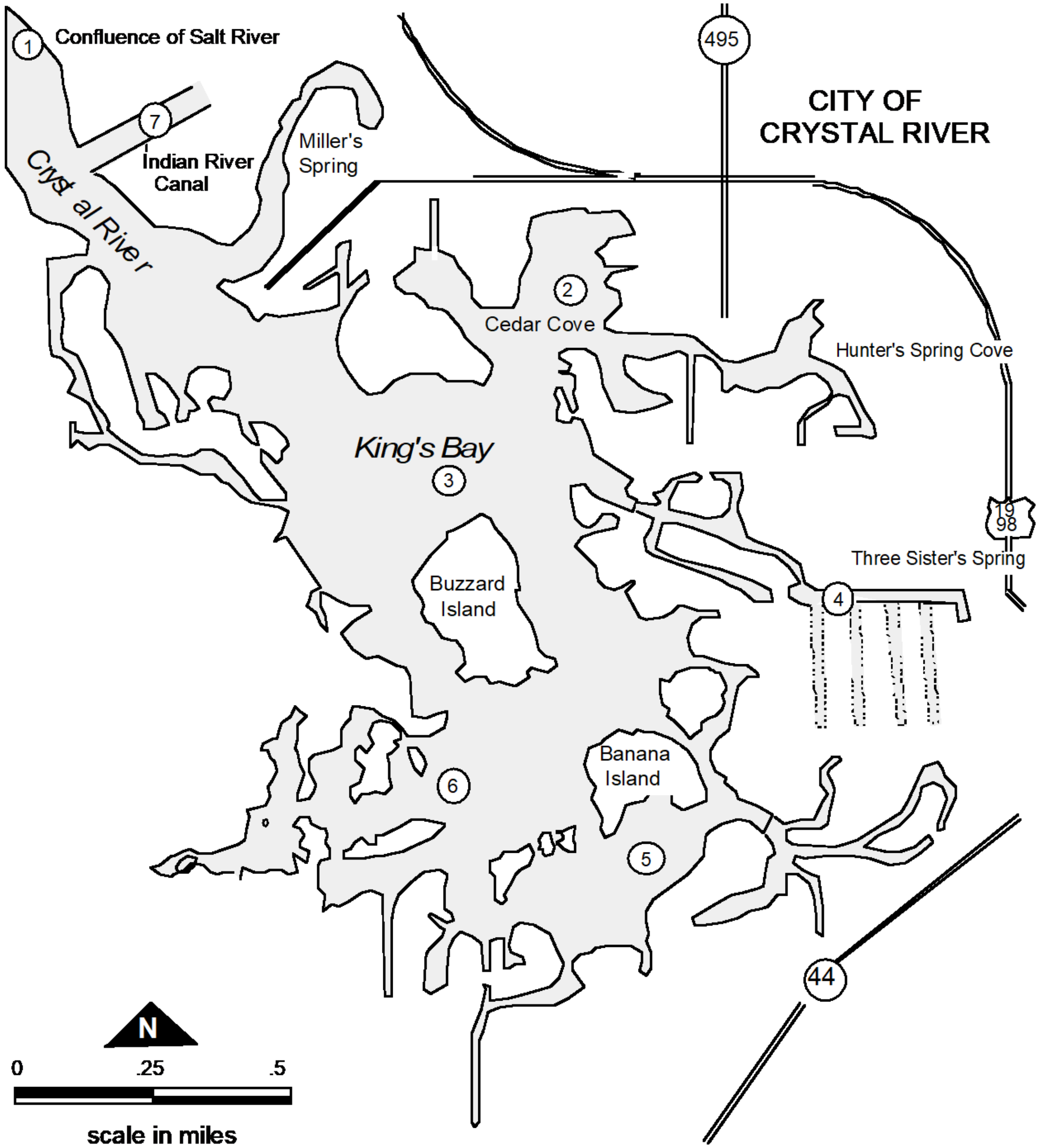
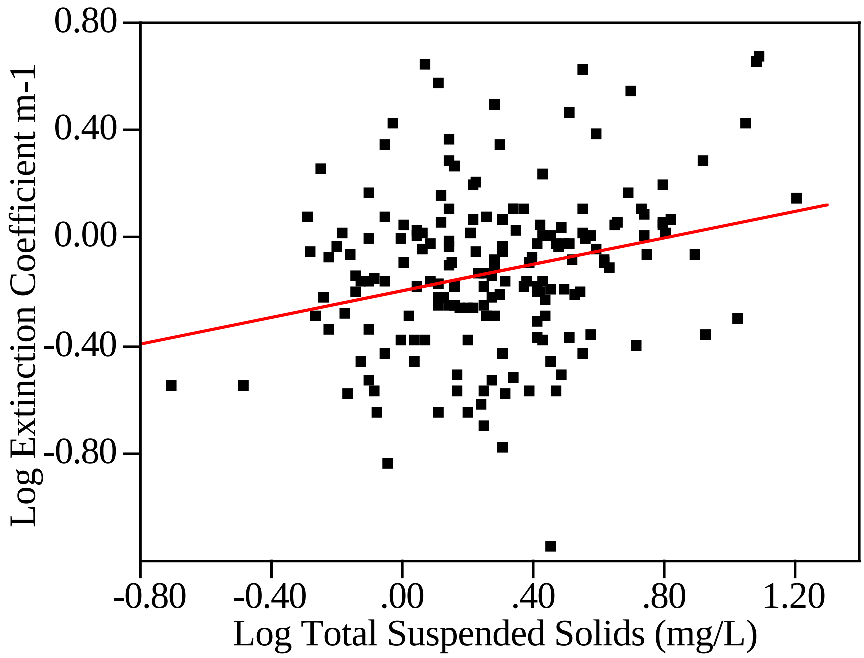


Figure 3. Long-term water chemistry monitoring stations established by Terrell and Canfield (1996) and sampled by Florida LAKEWATCH volunteers.



Linear Fit
Log Extinction Coefficient m-1 = -0.195629 + 0.2479022 Log Total Suspended Solids (mg/L)

Summary of Fit

RSquare	0.069071
RSquare Adj	0.063811
Root Mean Square Error	0.292312
Mean of Response	-0.12425
Observations (or Sum Wgts)	179

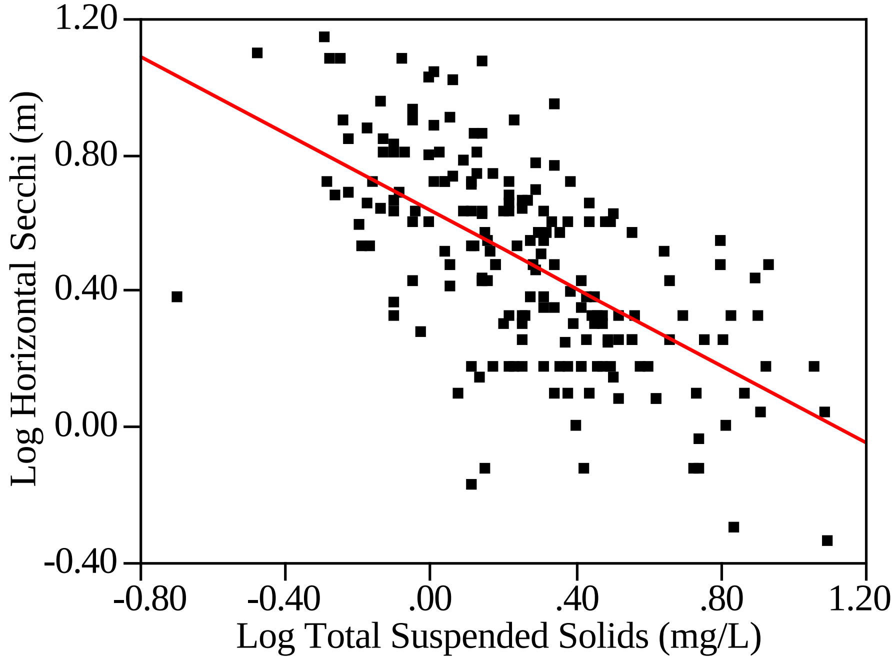
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1.122129	1.12213	13.1326
Error	177	15.123960	0.08545	**Prob > F**
C. Total	178	16.246089		0.0004

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.195629	0.029417	-6.65	<.0001
Log Total Suspended Solids (mg/L)	0.2479022	0.068408	3.62	0.0004

Figure 4. Relation between total suspended solids (mg/L) and extinction coefficient (m^{-1}) for Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Horizontal Secchi (m) = 0.6354175 - 0.5679266 Log Total Suspended Solids (mg/L)

Summary of Fit

RSquare	0.373615
RSquare Adj	0.370301
Root Mean Square Error	0.237037
Mean of Response	0.48035
Observations (or Sum Wgts)	191

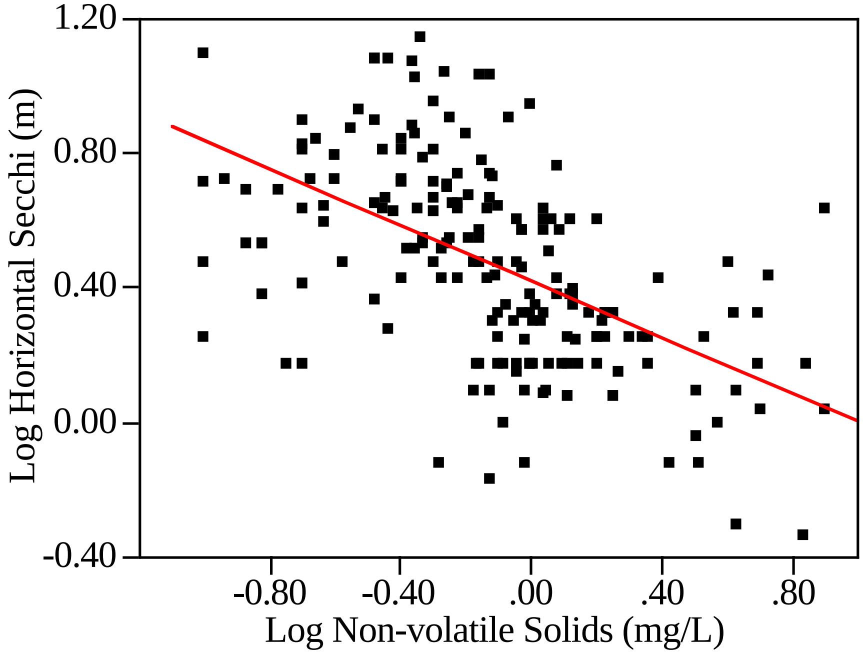
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	6.334008	6.33401	112.7315
Error	189	10.619284	0.05619	**Prob > F**
C. Total	190	16.953292		<.0001

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.6354175	0.022527	28.21	<.0001
Log Total Suspended Solids (mg/L)	-0.567927	0.05349	-10.62	<.0001

Figure 5. Relation between total suspended solids (mg/L) and horizontal Secchi distance (m) for Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Horizontal Secchi (m) = 0.4221718 - 0.4173048 Log Non-volatile Solids (mg/L)

Summary of Fit

RSquare	0.304143
RSquare Adj	0.300382
Root Mean Square Error	0.251674
Mean of Response	0.472638
Observations (or Sum Wgts)	187

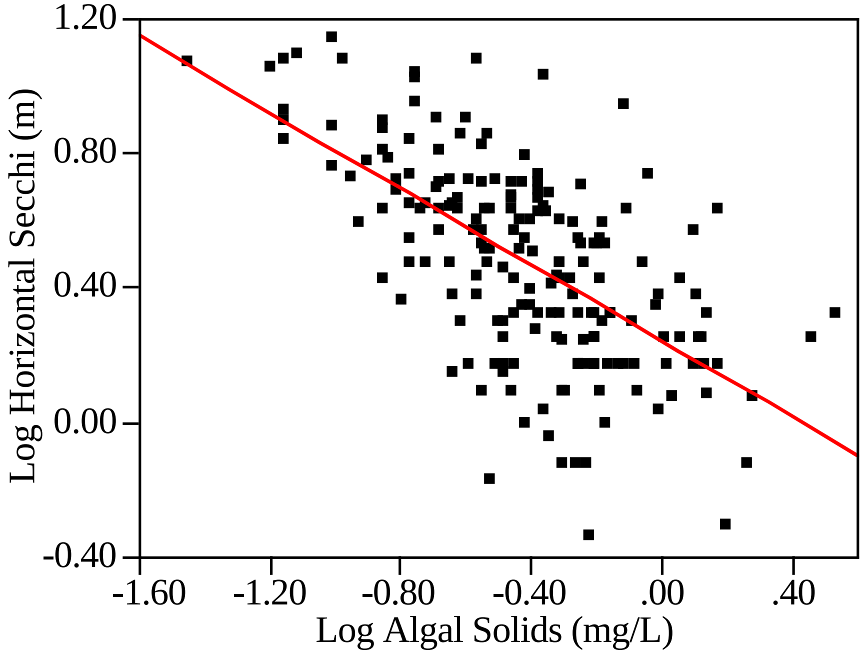
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	5.121604	5.12160	80.8593
Error	185	11.717851	0.06334	**Prob > F**
C. Total	186	16.839455		<.0001

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.4221718	0.019241	21.94	<.0001
Log Non-volatile Solids (mg/L)	-0.417305	0.046408	-8.99	<.0001

Figure 6. Relation between Non-volatile solids (mg/L) and horizontal Secchi distance (m) for Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Horizontal Secchi (m) = 0.2421452 - 0.5666199 Log Algal Solids (mg/L)

Summary of Fit

RSquare	0.396764
RSquare Adj	0.393622
Root Mean Square Error	0.231952
Mean of Response	0.477975
Observations (or Sum Wgts)	194

Analysis of Variance

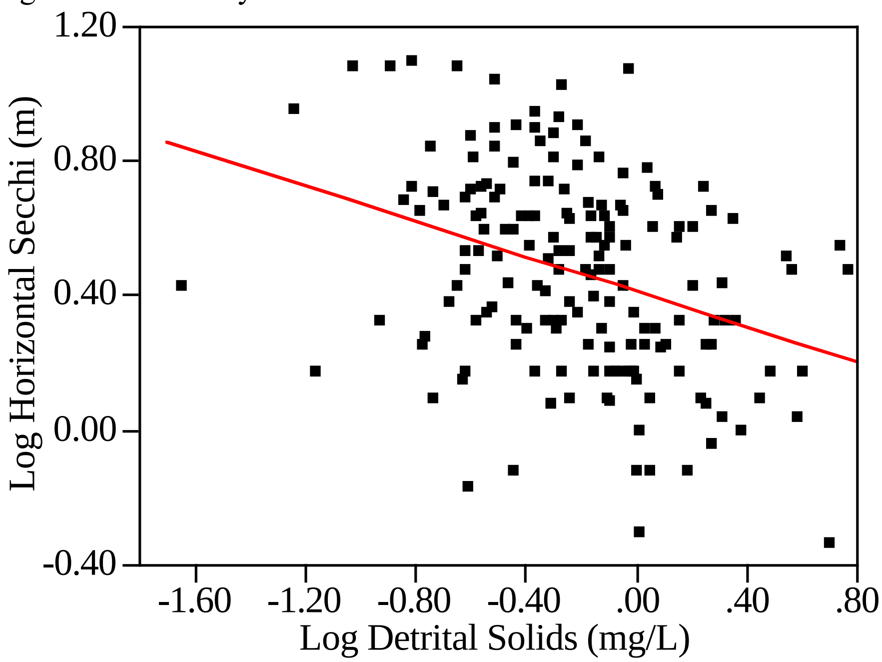
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	6.794256	6.79426	126.2833
Error	192	10.329926	0.05380	**Prob > F**
C. Total	193	17.124181		<.0001

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.2421452	0.026791	9.04	<.0001

Term	Estimate	Std Error	t Ratio	Prob>|t|
Log Algal Solids (mg/L)	-0.56662	0.050422	-11.24	<.0001

Figure 7. Relation between algal solids (mg/L) and horizontal Secchi distance (m) for Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Horizontal Secchi (m) = 0.4141344 - 0.2611639 Log Detrital Solids (mg/L)

Summary of Fit

RSquare	0.121266
RSquare Adj	0.116097
Root Mean Square Error	0.279583
Mean of Response	0.468275
Observations (or Sum Wgts)	172

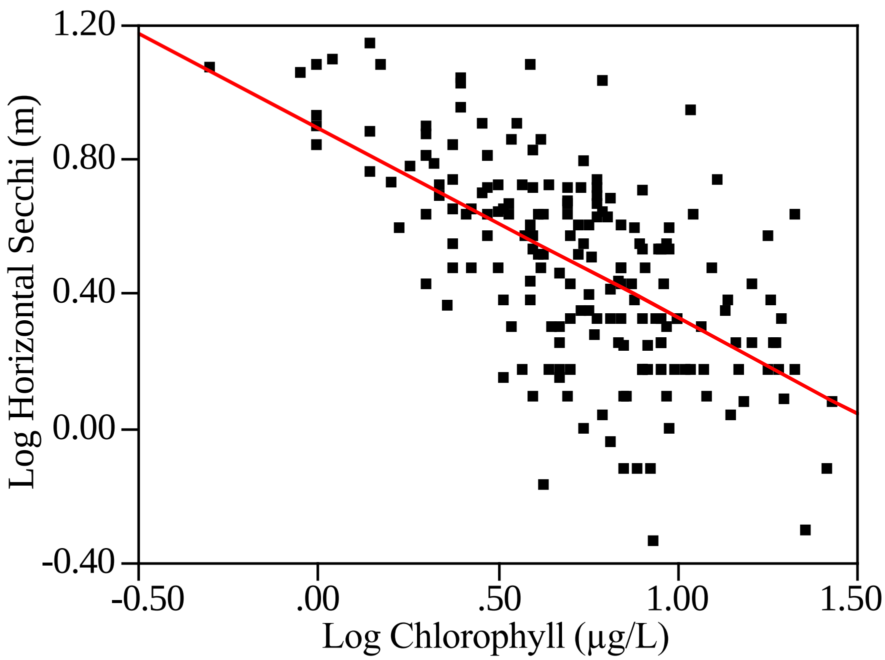
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.833792	1.83379	23.4601
Error	170	13.288305	0.07817	**Prob > F**
C. Total	171	15.122097		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.4141344	0.024071	17.20	<.0001
Log Detrital Solids (mg/L)	-0.261164	0.05392	-4.84	<.0001

Figure 8. Relation between detrital solids (mg/L) and horizontal Secchi distance (m) for Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Horizontal Secchi (m) = 0.8965356 - 0.5666199 Log Chlorophyll (µg/L)

Summary of Fit

RSquare	0.396764
RSquare Adj	0.393622
Root Mean Square Error	0.231952
Mean of Response	0.477975
Observations (or Sum Wgts)	194

Analysis of Variance

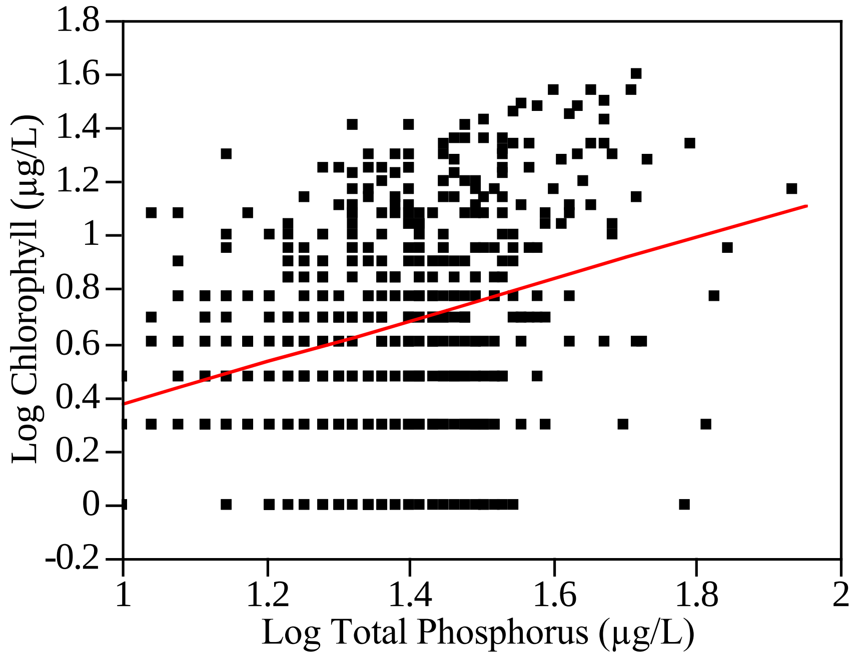
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6.794256	6.79426	126.2833
Error	192	10.329926	0.05380	**Prob > F**

Source	DF	Sum of Squares	Mean Square	F Ratio
C. Total	193	17.124181		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8965356	0.0408	21.97	<.0001
Log Chlorophyll (µg/L)	-0.56662	0.050422	-11.24	<.0001

Figure 9. Relation between chlorophyll concentration (µg/L) and horizontal Secchi distance (m) for Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Chlorophyll (µg/L) = -0.397848 + 0.7750953 Log Total Phosphorus (µg/L)

Summary of Fit

RSquare	0.09956
RSquare Adj	0.097943
Root Mean Square Error	0.355227
Mean of Response	0.6649
Observations (or Sum Wgts)	559

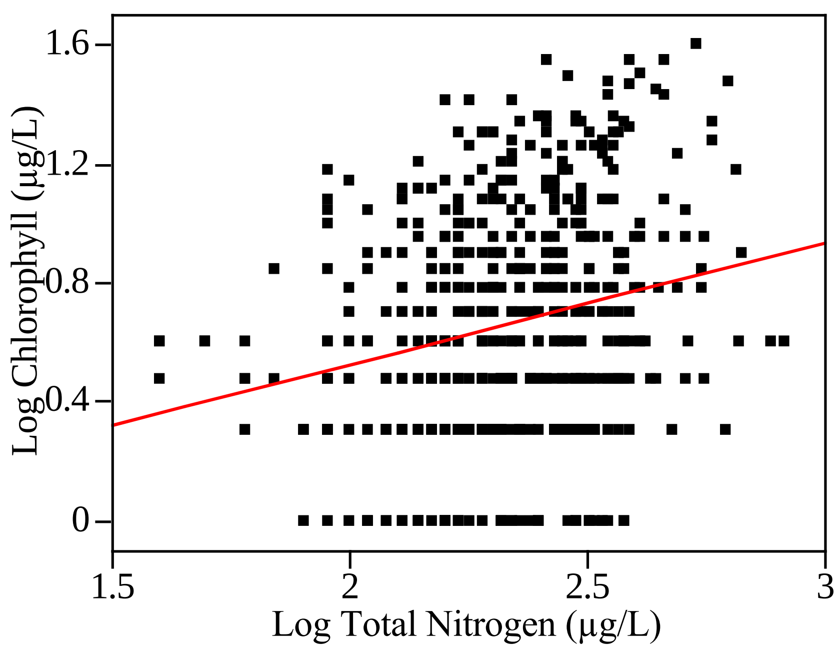
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	7.771333	7.77133	61.5863
Error	557	70.285696	0.12619	**Prob > F**
C. Total	558	78.057029		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.397848	0.136253	-2.92	0.0036
Log Total Phosphorus (µg/L)	0.7750953	0.098767	7.85	<.0001

Figure 10. Relation between chlorophyll (µg/L) and total phosphorus (µg/L) in open water stations of Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Chlorophyll (µg/L) = -0.296071 + 0.4113878 Log Total Nitrogen (µg/L)

Summary of Fit

RSquare	0.052835
RSquare Adj	0.051131
Root Mean Square Error	0.363838

Mean of Response	0.663842
Observations (or Sum Wgts)	558

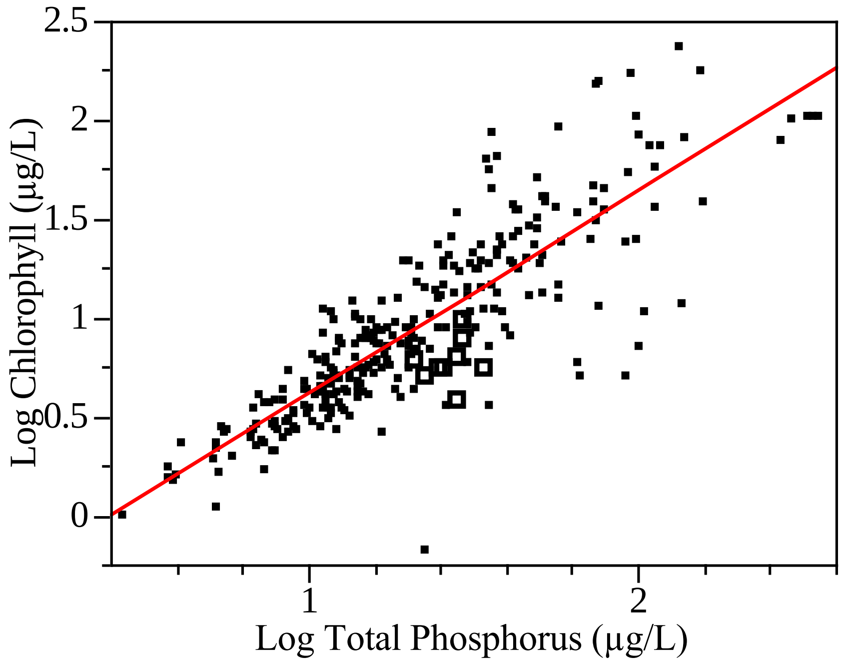
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4.105658	4.10566	31.0146
Error	556	73.602206	0.13238	**Prob > F**
C. Total	557	77.707864		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.296071	0.173052	-1.71	0.0877
Log Total Nitrogen (µg/L)	0.4113878	0.07387	5.57	<.0001

Figure 11. Relation between chlorophyll (µg/L) and total nitrogen (µg/L) in open water stations of Kings Bay/Crystal River with linear regression summary statistics.



Linear Fit

Log Chlorophyll (µg/L) = -0.405593 + 1.0287825 Log Total Phosphorus (µg/L)

Summary of Fit

RSquare	0.724072

RSquare Adj	0.723136
Root Mean Square Error	0.241238
Mean of Response	0.953723
Observations (or Sum Wgts)	297

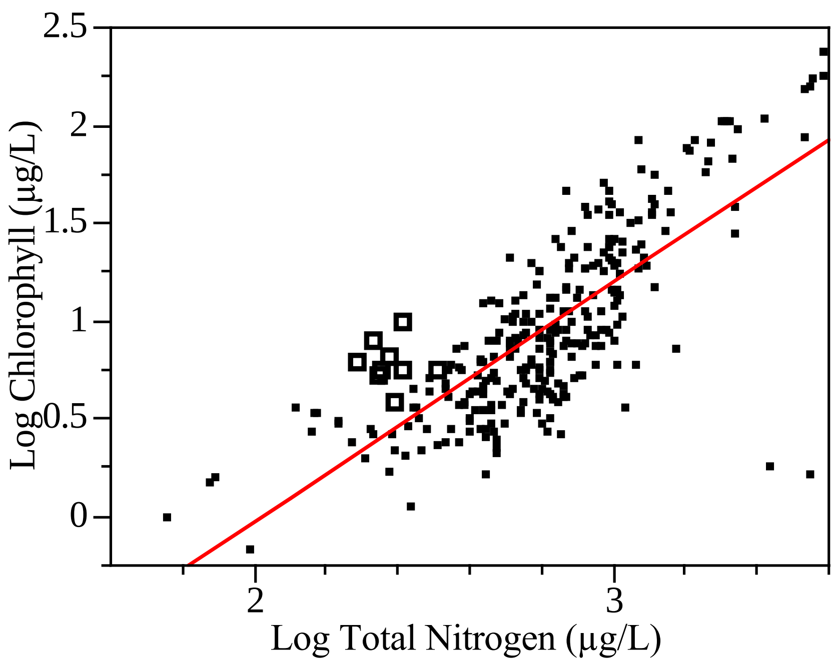
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	45.050292	45.0503	774.1188
Error	295	17.167695	0.0582	**Prob > F**
C. Total	296	62.217987		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.405593	0.050822	-7.98	<.0001
Log Total Phosphorus (µg/L)	1.0287825	0.036976	27.82	<.0001

Figure 12. Relation between whole lake average total phosphorus (µg/L) and chlorophyll (µg/L) for 297 Florida LAKEWATCH lakes sampled monthly for a minimum of four years. The large squares overlaid on the plot are Florida LAKEWATCH annual average values for Kings Bay/Crystal River from 1992 to 2000.



Linear Fit
Log Chlorophyll (µg/L) = -2.476341 + 1.2236297 Log Total Nitrogen (µg/L)

Summary of Fit

RSquare	0.587243
RSquare Adj	0.585844
Root Mean Square Error	0.295049
Mean of Response	0.953723
Observations (or Sum Wgts)	297

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	36.537105	36.5371	419.7070
Error	295	25.680882	0.0871	**Prob > F**
C. Total	296	62.217987		<.0001

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-2.476341	0.168301	-14.71	<.0001
Log Total Nitrogen (µg/L)	1.2236297	0.059728	20.49	<.0001

Figure 13. Relation between whole-lake average total nitrogen (µg/L) and chlorophyll (µg/L) for 297 Florida LAKEWATCH lakes sampled monthly for a minimum of four years. The large squares overlaid on the plot are Florida LAKEWATCH annual average values for Kings Bay/Crystal River from 1992 to 2000.

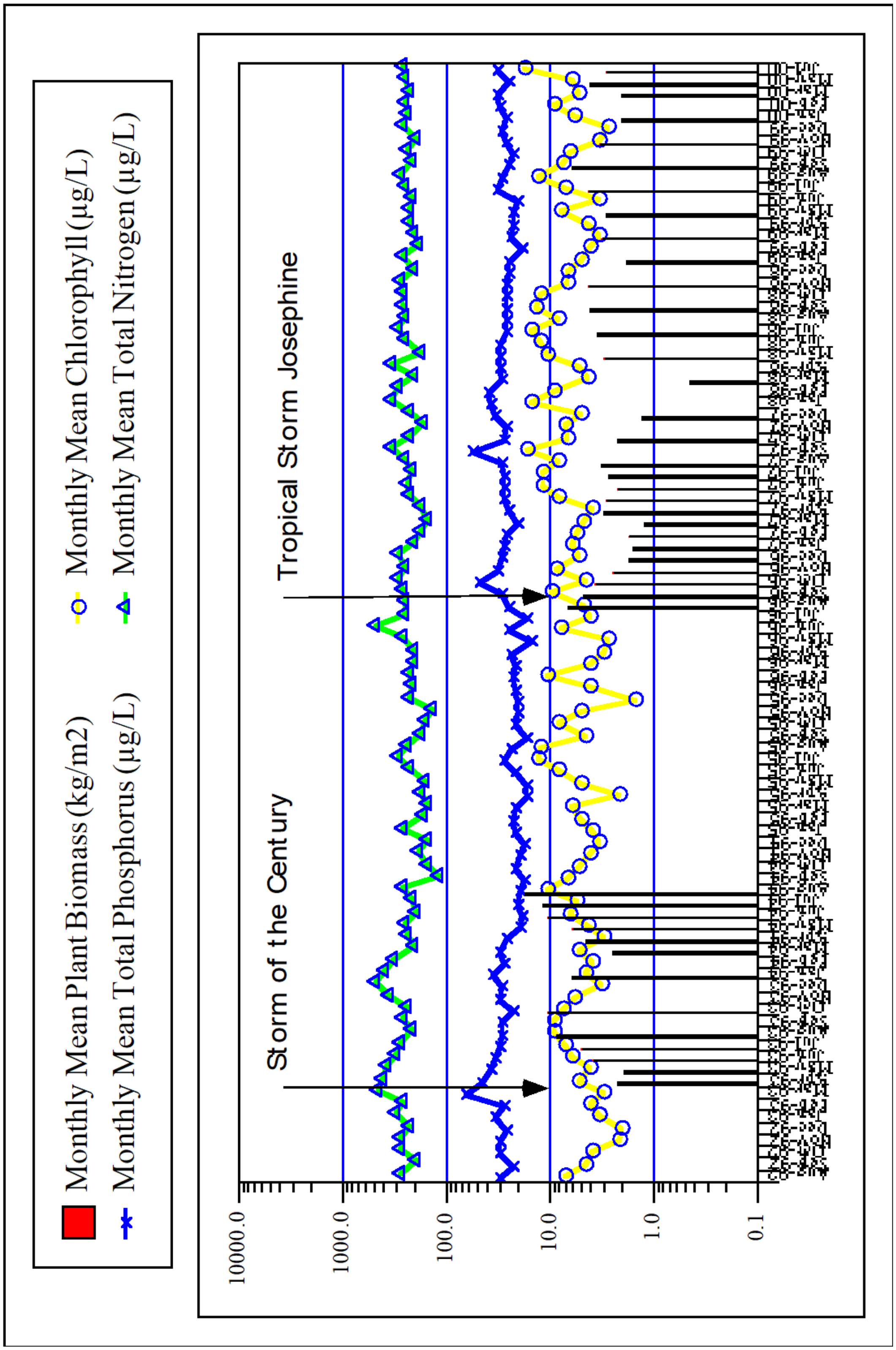


Figure 14. Long term total phosphorus (µg/L), total nitrogen (µg/L), chlorophyll (µg/L), and aquatic plant biomass (kg/m^2) data for Kings Bay/Crystal River.

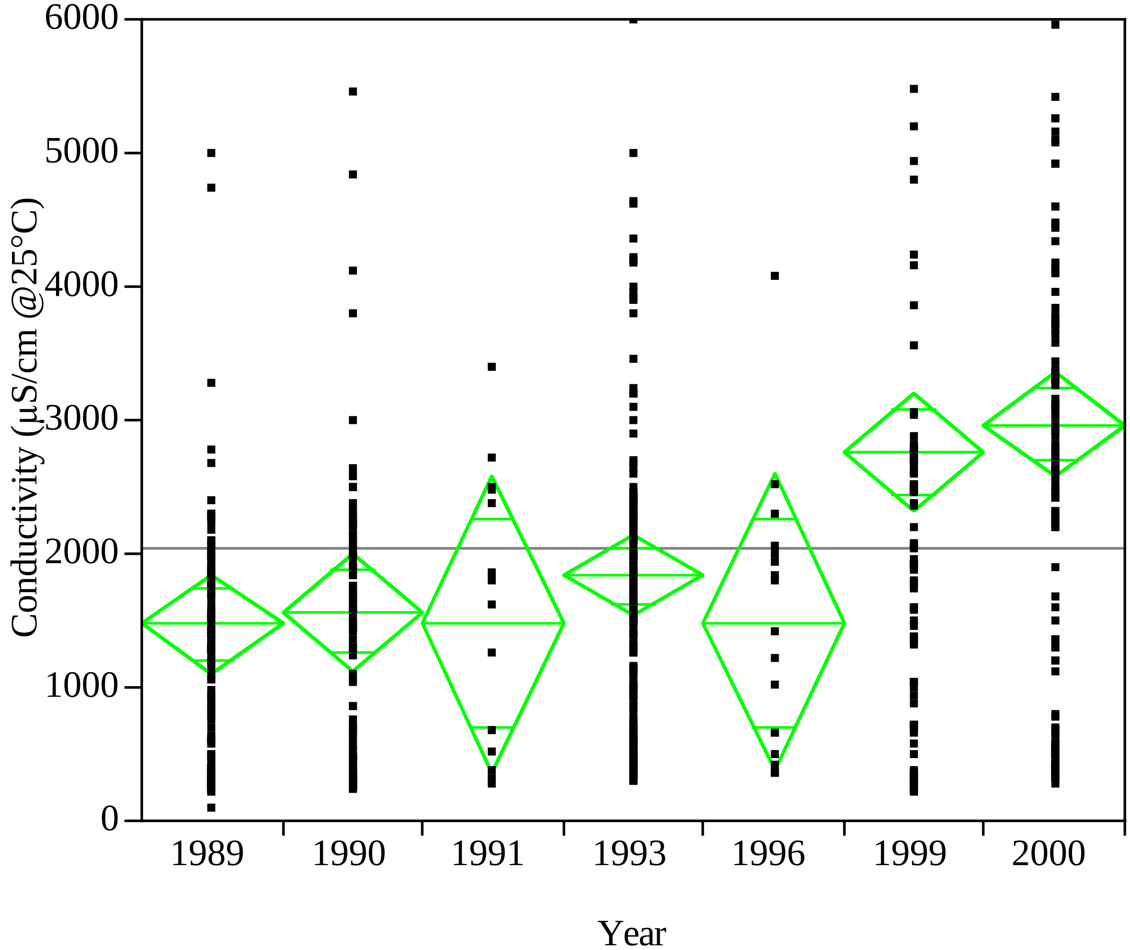


Figure 15. Long-term average surface water conductivity data for the same 17 stations in Kings Bay/Crystal River. Data are from Romie (1990), Bishop (1995) and this study. Several values in 1989, 1990, 1993, 1999 and 2000 are higher than 6,000 (µS/cm @25°C) and are not plotted on this figure due to the scale of the plot but they are included in the calculation of the mean. The bar in the middle of the diamond represents the mean of all values for that year and the tip of the diamond represent the 95% confidence intervals for that year. The overlap lines are between the mean and 95% confidence interval and for groups with equal sample sizes overlap marks can indicate significant differences between years.

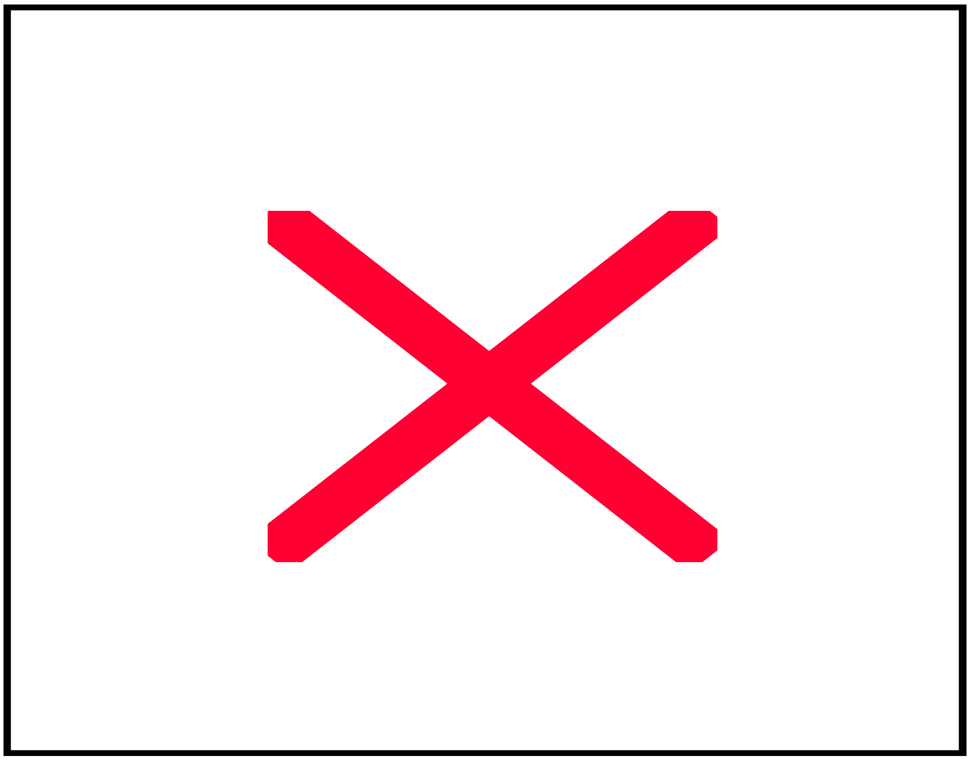
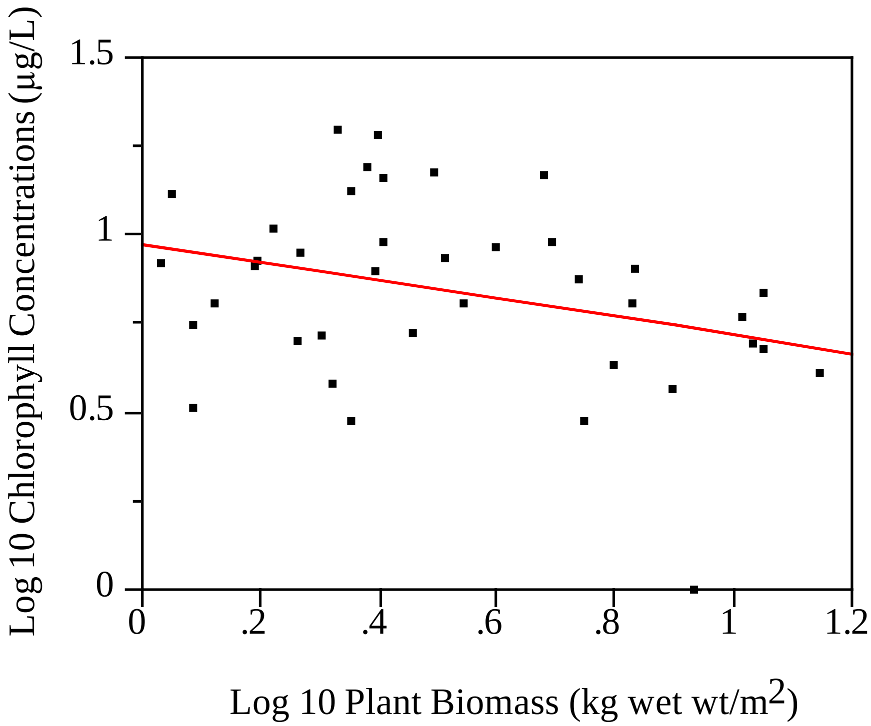


Figure 16. Relation between monthly aquatic plant biomass data from individual stations (Terrell and Canfield (1996), Hoyer et al (1997) and this study) and corresponding monthly chlorophyll



concentrations (Florida LAKEWATCH 2000). Aquatic plant stations 1, 19, 8.2, 13, 17, and 5 corresponded to water quality stations 1, 2, 3, 4, 5, and 7, respectively (see Figure 1 and Figure 3).

<u>Linear Fit</u>

Log Mean Chlorophyll (µg/L) = 0.9746793 - 0.2574437 Log Mean Total Plant Biomass (kg/m2)

Summary of Fit

RSquare	0.107813
RSquare Adj	0.084334
Root Mean Square Error	0.24537
Mean of Response	0.844541
Observations (or Sum Wgts)	40

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	0.2764641	0.276464	4.5919
Error	38	2.2878405	0.060206	**Prob > F**
C. Total	39	2.5643046		0.0386

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.9746793	0.072065	13.53	<.0001
Log Mean Total Plant Biomass (kg/m2)	-0.257444	0.120139	-2.14	0.0386

Figure 17. Relation between logarithmically transformed monthly aquatic plant biomass data from individual stations (Terrell and Canfield (1996), Hoyer et al (1997) and this study) and corresponding monthly logarithmically transformed chlorophyll concentrations (Florida LAKEWATCH 2000), with linear regression summary statistics. Aquatic plant stations 1, 19, 8.2, 13, 17, and 5 corresponded to water quality stations 1, 2, 3, 4, 5, and 7, respectively (see Figure 1 and Figure 3).

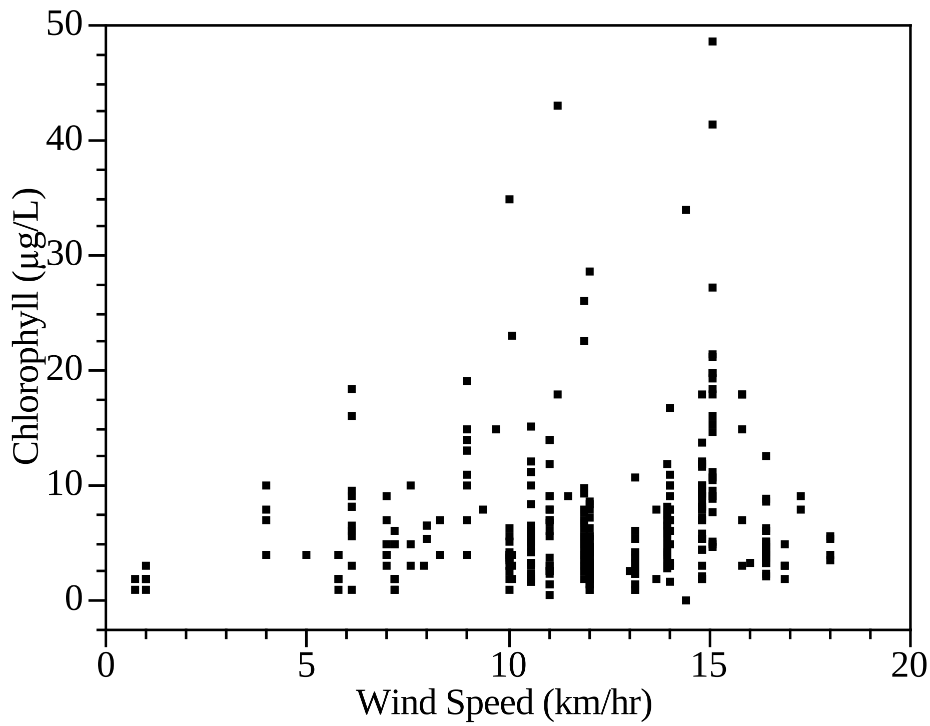


Figure 18. Relation between average daily wind speed (km/hr) measured at the mouth of Crystal River by Florida Power Corporation in Crystal River, Florida and chlorophyll concentration (µg/L) in Kings Bay/Crystal River.

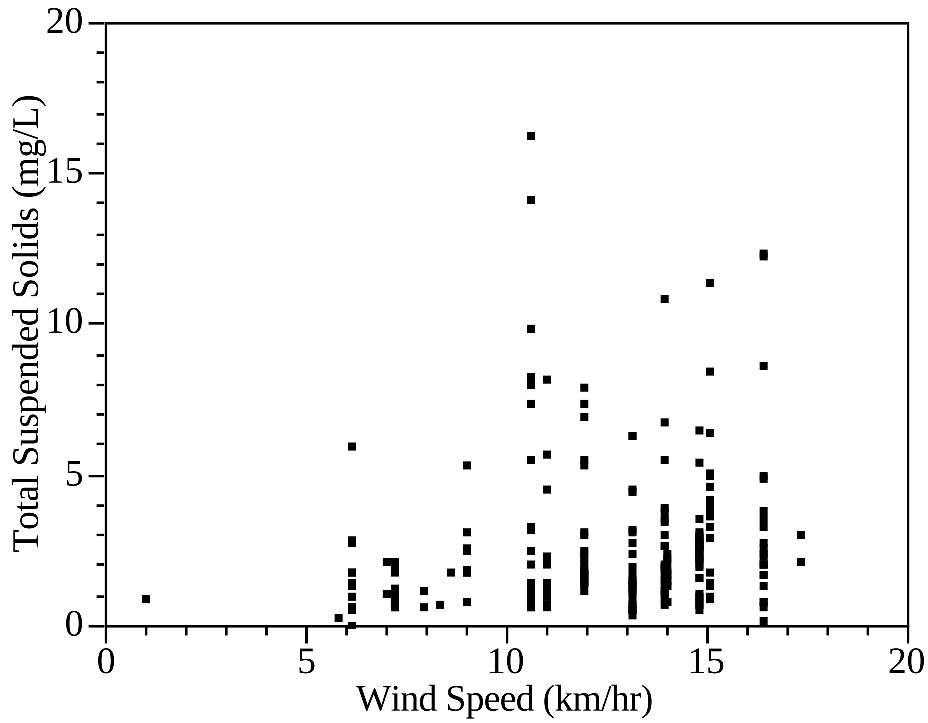
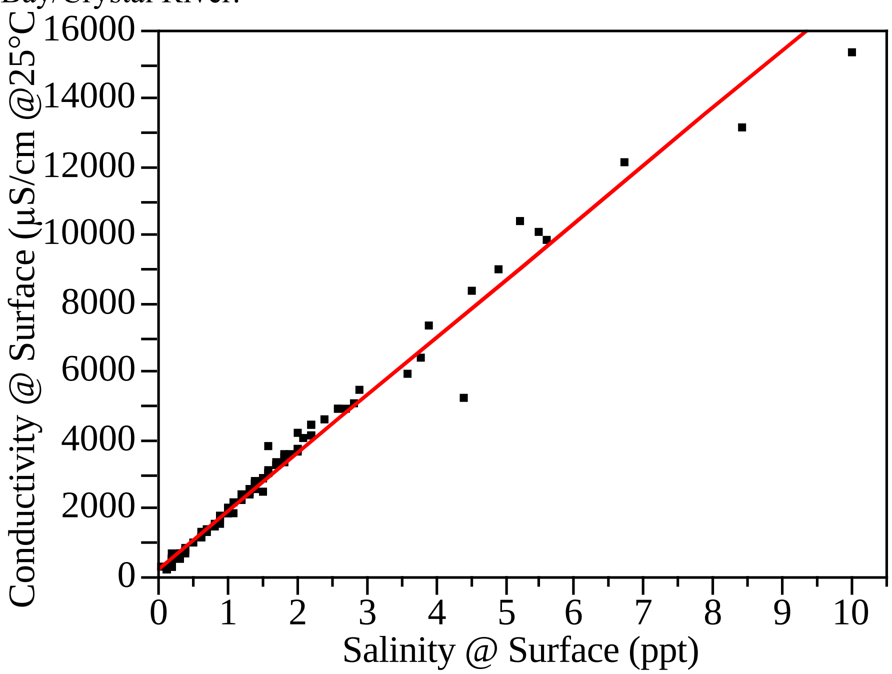


Figure 19. Relation between average daily wind speed (km/hr) measured at the mouth of Crystal River by Florida Power Corporation in Crystal River, Florida and concentration of total suspended solids (mg/L) in Kings Bay/Crystal River.



Conductivity @ Surface (µS/cm @25∞C) = 248.94455 + 1687.0572 Salinity @ Surface (ppt)

Summary of Fit

RSquare	0.98106
RSquare Adj	0.980934
Root Mean Square Error	356.5278
Mean of Response	2493.061
Observations (or Sum Wgts)	153

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	994189711	994189711	7821.364
Error	151	19193922.6	127112.07	**Prob > F**
C. Total	152	1013383633		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	248.94455	38.4016	6.48	<.0001
Salinity @ Surface (ppt)	1687.0572	19.07606	88.44	<.0001

Figure 20. Relation between surface water salinity (ppt) and surface water conductivity measured in Kings Bay/Crystal River, with linear regression summary statistics.

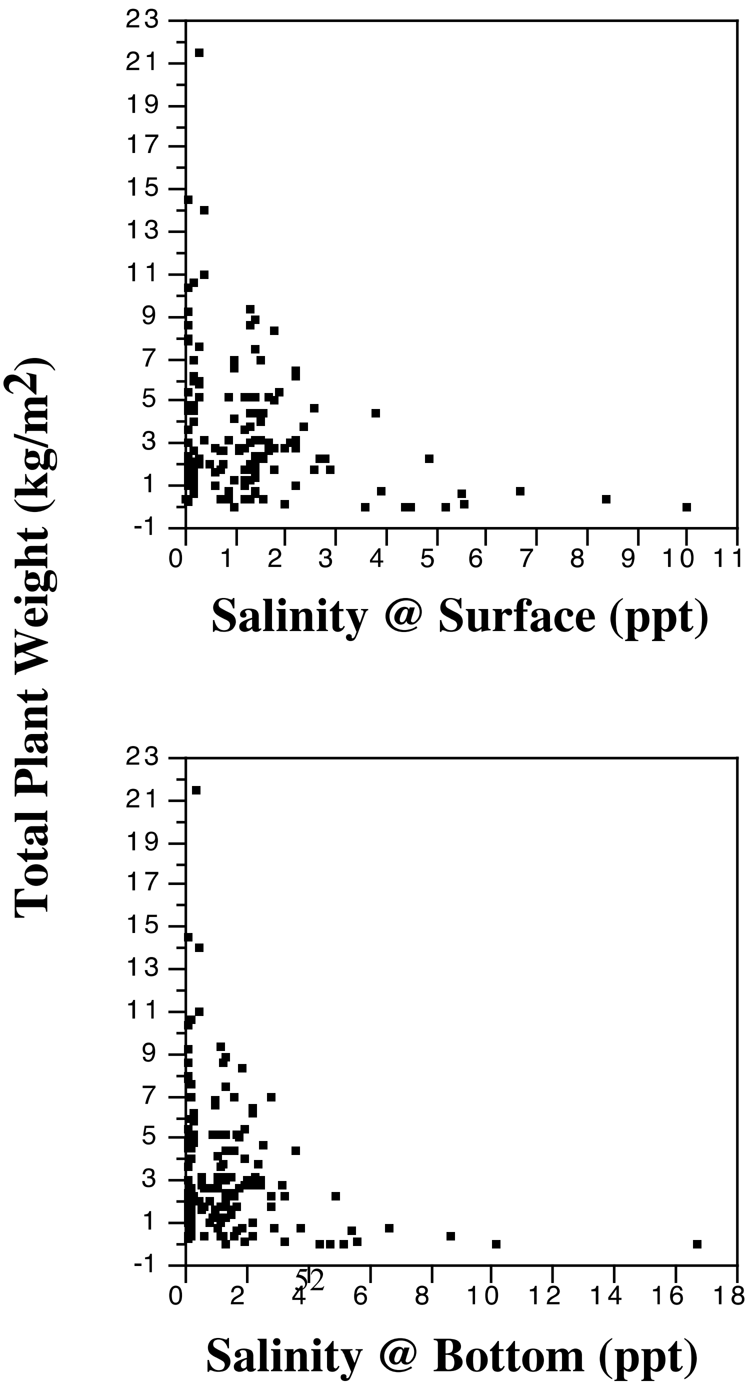


Figure 21. Relations between surface and bottom salinity (ppt) and corresponding total aquatic plant biomass (kg/m^2) in Kings Bay/Crystal River.

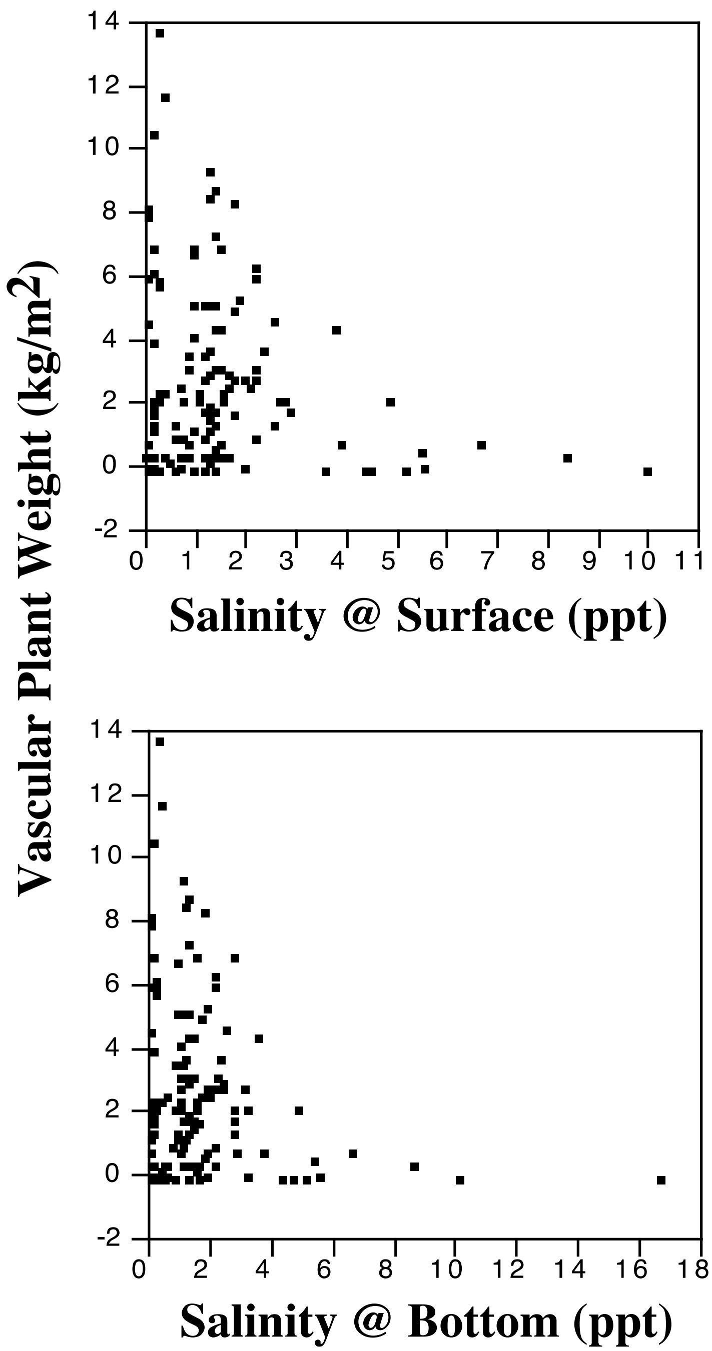


Figure 22. Relations between surface and bottom salinity (ppt) and corresponding vascular aquatic plant biomass (kg/m^2) in Kings Bay/Crystal River.

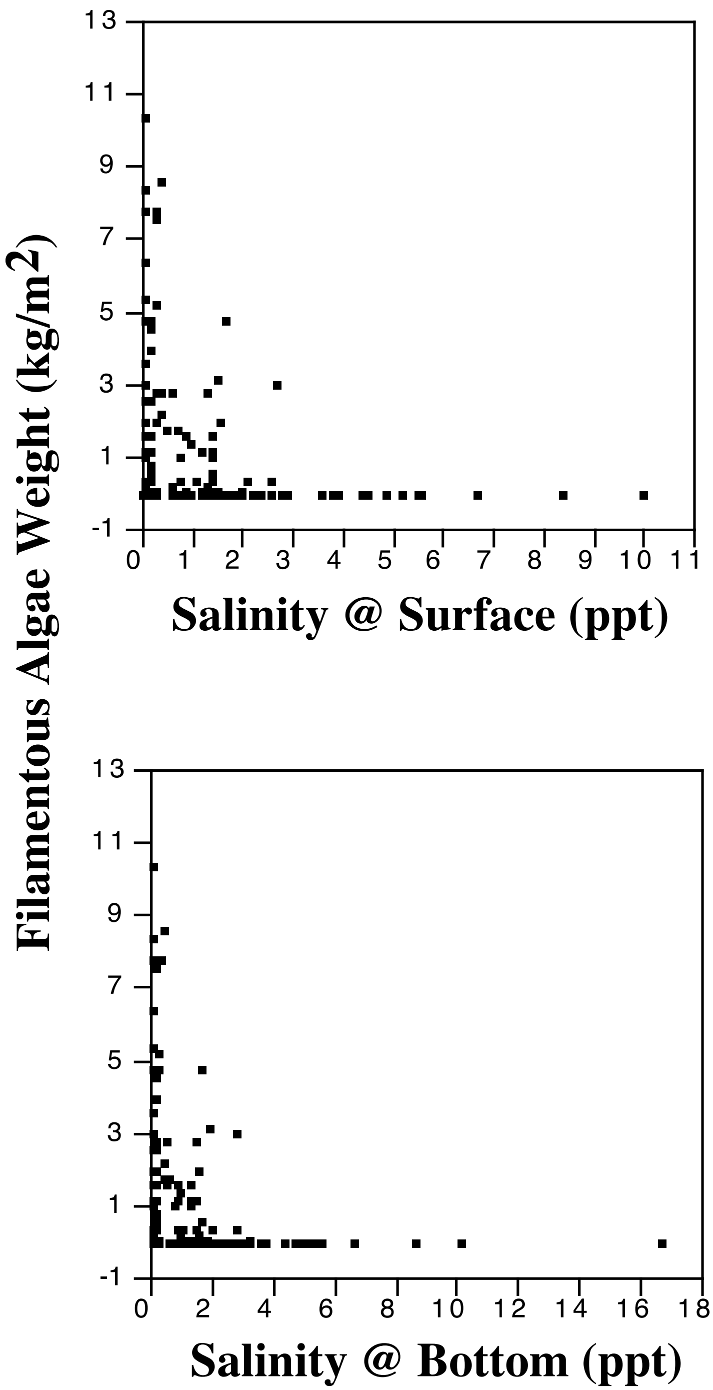
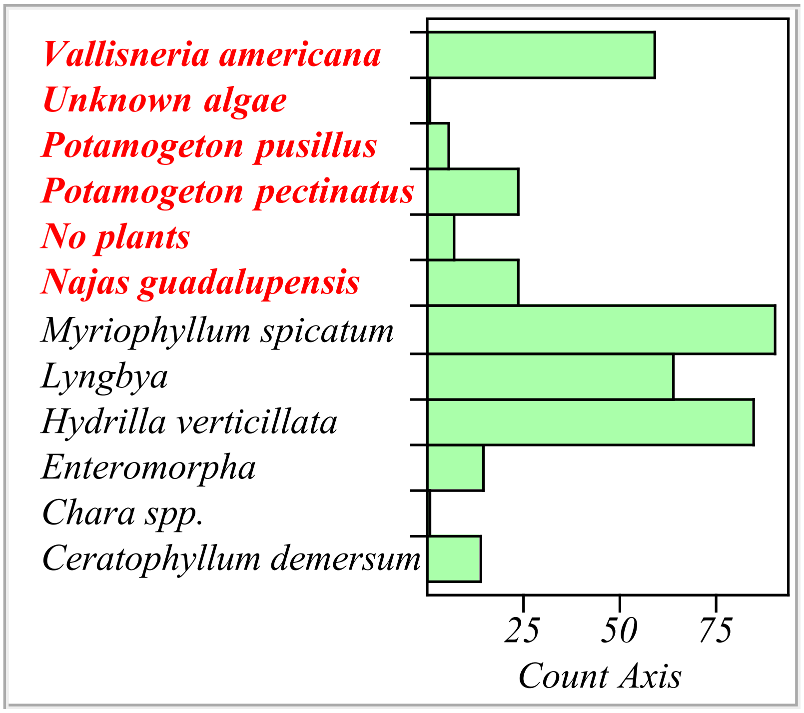


Figure 23. Relations between surface and bottom salinity (ppt) and corresponding filamentous algae biomass (kg/m^2) in Kings Bay/Crystal River.



Plant Species	Count	Prob
Ceratophyllum demersum	14	0.03590
Chara spp.	1	0.00256
Enteromorpha	15	0.03846
Hydrilla verticillata	85	0.21795
Lyngbya	64	0.16410
Myriophyllum spicatum	90	0.23077
Najas guadalupensis	24	0.06154
No plants	7	0.01795
Potamogeton pectinatus	24	0.06154
Potamogeton pusillus	6	0.01538
Unknown algae	1	0.00256
Vallisneria americana	59	0.15128
Total	390	1.00000

Figure 24. Frequency distribution of an individual plant species occurring in 390 sampling quadrats sampled for this study.

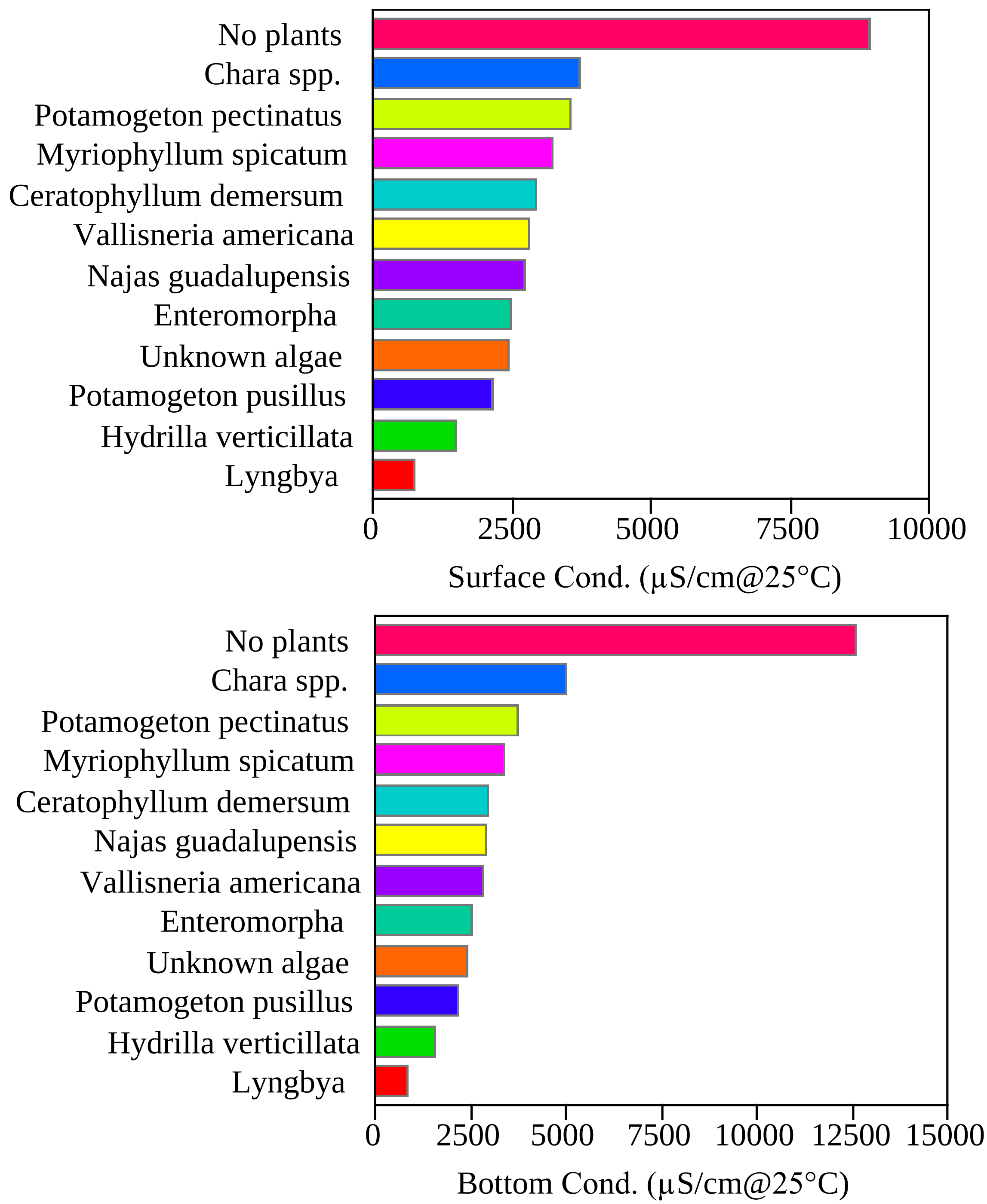


Figure 25. Average conductivity (µS/cm@25°C) for all sampling stations with an individual species present. Conductivity was measured in the surface and bottom waters of Kings Bay/Crystal River at the same time and station that aquatic plants were sampled.