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Changes In Submersed Macrophytes In Relation To Tidal Storm Surges

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ABSTRACT

We analyzed long-term submersed macrophyte presence-absence data collected from 15 stations in Kings Bay/Crystal River, Florida in relation to three major storm events. The percent occurrence of most species declined immediately after storm events but the recovery pattern after the storm differed among species. Hydrilla *(Hydrilla verticillata* (L. F.) Royle) and Eurasian watermilfoil *(Myriophyllum spicatum L.)* exhibited differing recolonization behaviors. Eurasian watermilfoil recolonized quickly after storms but declined in abundance as hydrilla began to increase in abundance. Natural catastrophic events restructure submersed macrophyte communities by eliminating the dominate species, and allowing revegetation and restructuring of communities. Tidal surges may also act to maintain species diversity in the system. In addition, catastrophic events remove dense nuisance plant growth for several years, altering the public's perception of the nuisance plant problem of Kings Bay/Crystal River.

Key words: Crystal River/Kings Bay, Florida, hydrilla, Eurasian watermilfoil, lyngbya, coastal.

INTRODUCTION

The submersed macrophyte communities of freshwater systems occurring at the land-sea interface are subject to a unique set of influences. Not only are they subject to frequent, regular changes in tidal levels and salinity concentrations, but they are also at the mercy of periodic and violent storm events, such as hurricanes, tropical storms, and unnamed tidal surges.

The effects of major climatic events are often quite obvious. Physical scouring of the sediments can uproot macrophytes (Terrell and Canfield 1996) and salinity wedges can weaken and slowly destroy saltwater intolerant species (Haller et al. 1974). The effects of minor tidal events (e.g., tropical storms) may be less conspicuous but nevertheless can have a measurable influence on the structure and composition of the macrophyte community.

During on-going water chemistry studies in Kings Bay, the spring-fed headwaters of Crystal River on the Gulf Coast of Florida, we observed the effects of two storm events on the submersed macrophyte community. The effects of the first storm, the Storm of the Century in March 1993, were discussed by Terrell and Canfield (1996). For that paper, they obtained long-term presence-absence data of the resident macrophytes species. The data showed dramatic decreases in submersed vegetation and an alteration of the species composition after the storm.

A second major storm event, Tropical Storm Josephine, occurred on the Gulf Coast in October 1996. Observations of these two storm events led us to question how storms may regulate the distribution and abundance of submersed macrophytes in Kings Bay over time. To satisfy our objective, the long-term Sirenia Project data used by Terrell and Canfield (1996) was updated to include both storm events. The period of record of this database also spans the occurrence of Hurricane Elena (September 1985), which allowed us to examine the effects of three major storm events on the submersed plant communities in Kings Bay. The possible role these storm events play on the public's perception of problems in Kings Bay/Crystal River and thus on the management of Kings Bay/Crystal River is also discussed.

SITE DESCRIPTION

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

Receiving an average of 70,000 visitors per year (SWFWMD 1998), Crystal River/Kings Bay is a popular attraction for boaters, anglers, wildlife enthusiasts, and sport divers. Commercial and charter boat fishing and crabbing are also common. One of the most common tourist attractions is the West Indian manatee *(Trichechus manatus* L.), which retreats to the warmer waters of the bay from September through April. Sport divers are also attracted year-round to Kings Spring, the second largest spring vent in the bay, which discharges at a rate of 1.2 m^3/sec. 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 is approximately 2 km long by 1 km wide, with a surface area of about 1.91 km^2. The bay is shallow, typically ranging from 1 to 3 m in depth (Romie 1990). 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). Anecdotal reports suggest that tidal storm surges of over 3 m have occurred with major storms.

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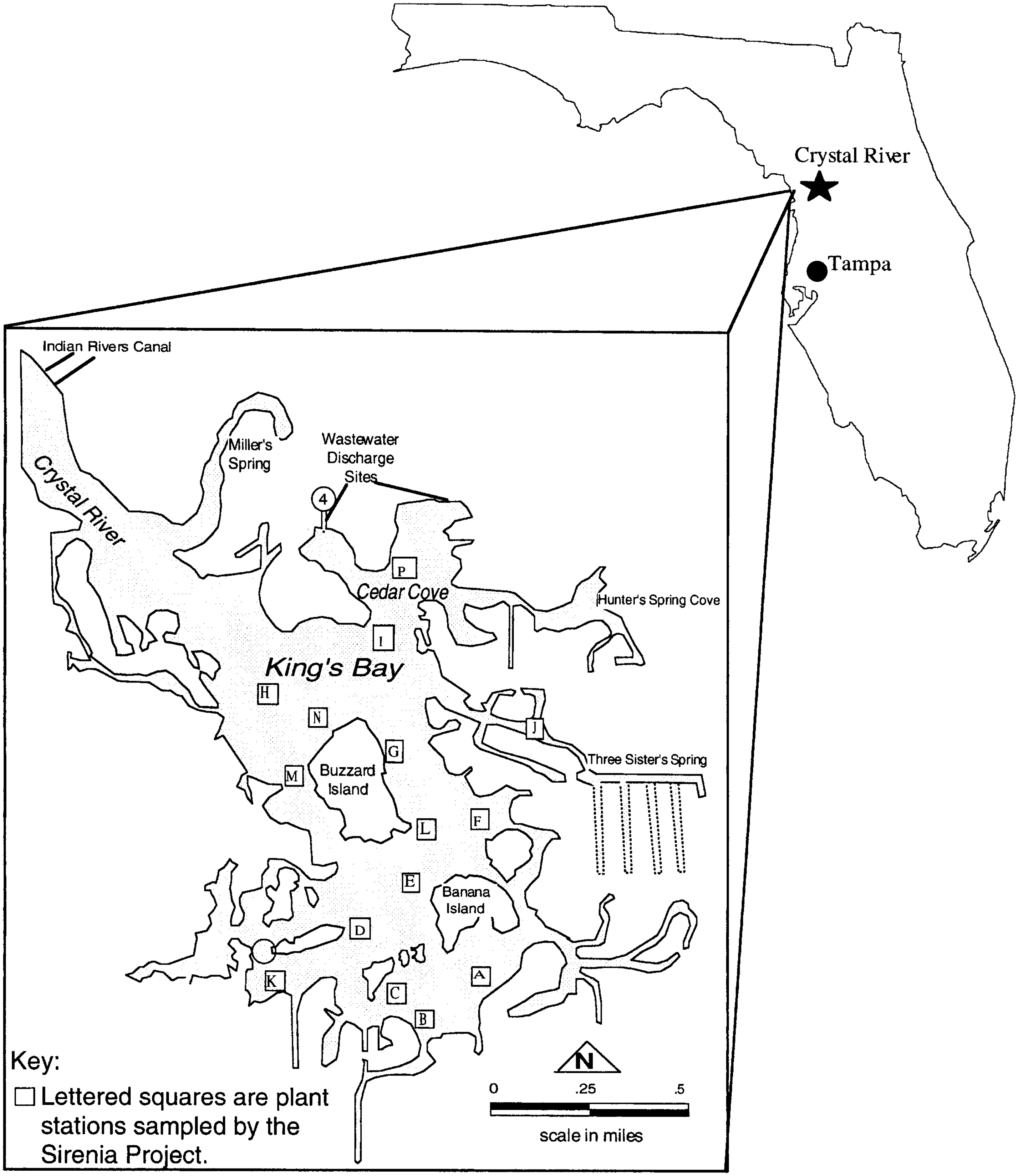

Figure 1. Location of Kings Bay/Crystal River in the State of Florida and location of submersed macrophyte sampling stations in Kings Bay, Florida sampled by the Sirenia Project.

The 30 known springs and sinks which discharge into Kings Bay represent the fourth largest, first magnitude spring group in Florida (Rosenau et al. 1977). The springs maintain a relatively constant temperature of 25C. Mean total phosphorus (TP) concentrations of the spring discharge range from 22 to 55 μg/L and total nitrogen (TN) concentrations range from 190 to 620 μg/L (Romie 1990). The average concentrations of TP and TN in seven open-water stations from 1992 through 1996 ranged from 24 to 34 μg/L, and from 200 to 310 μg/L, respectively[4].

Kings Bay supports dense growths of aquatic macrophytes and filamentous algae. During peak periods, this vegetation can impair the aesthetic, navigational, and recreational uses of the bay. Citrus County Aquatic Services maintains navigation routes and recreation areas by mechanical harvesting and chemical control. The effect of the county's aquatic vegetation maintenance program upon our data is unknown. However, chemical plant control is limited to canals with low flushing rates, which are located away from the plant sampling stations. Also, due to the manatee's endangered species status and its preferential consumption of hydrilla, aquatic plant maintenance is limited during the manatee season.

MATERIALS AND METHODS

Long-term presence-absence data for each submersed macrophyte species in Kings Bay were obtained from the Sirenia Project, a division of the U.S. Geological Survey Florida Caribbean Science Center (412 NW 16th Avenue, Gainesville, FL 32601). Since 1979, the Sirenia Project has collected macrophyte data from Kings Bay in their efforts to monitor food availability for the manatee. The species composition of submersed vegetation has been recorded monthly from April 1979 to June 1981, bimonthly from August 1981 to May 1983, and bimonthly from November 1985 (two months after Hurricane Elena) through the present. Data obtained through September 1997 were included in this analysis. Note that no data were collected just prior to Hurricane Elena between May 1983 and November 1985. This period of time will be referred to as the "1983-1985 sampling hiatus" in the rest of this report.

On each sampling trip, 15 locations were sampled for the presence or absence of submersed macrophytes (Figure 1). At each of the 15 sampling locations, 10 randomly chosen sites encircling the boat were sampled (approximately 25 m^2). At each of these 10 sites, plants were sampled using a graduated pole with two perpendicular metal crossbars at the bottom. Each crossbar measured 1 m in length. The pole was pushed through the water column to the substrate. The presence or absence of each individual plant species were recorded either by a diver or by using a viewing tube from the boat. A species was considered present if it occurred within 5 cm of the end of each of the four crossbars or at the center of the graduated pole. This resulted in a total of 750 points of presence or absence data that were monitored each sampling trip in Kings Bays (five points at each of the 10 sites encircling the boat at each of the 15 stations sampled). The University of Florida obtained these unpublished data from field data sheets and from computerized records. When only data sheets were available, we manually entered the data into a computer spreadsheet file.

The percent occurrence of each taxon in the bay was determined for each sampling date by measuring the percent of 750 sampled points among 15 stations at which that species occurred. All calculations were performed using JMP Statistical Analysis computer program (SAS Institute 1989). These measurements are the only available long-term (greater than 10 years) measurement of macrophyte distribution and abundance in Kings Bay.

RESULTS

Since 1979, three known tidal events have impacted Kings Bay: Hurricane Elena (September 1985), the no-name "Storm of the Century" (March 1993), and Tropical Storm Josephine (October 1996). After each of these storms, measurable changes in the submersed macrophyte community of Kings Bay were documented.

The most abundant macrophyte species in Kings Bay included introduced species such as hydrilla and Eurasian watermilfoil and native species such as tape grass *(Vallisneria americana* Michx.), southern naiad *(Najas guadalupensis* Spreng.), pondweed *(Potamogeton pusillus* L.), and coontail *(Ceratophyllum demersum* L.). The species composition of filamentous algae was usually unknown, but since we began our efforts on the bay it has largely included lyngbya *(Lyngbya sp.).* Lyngbya grows in a rather distinctive form and has become the major focus of management efforts in Kings Bay and in other coastal areas in Florida (Hoyer and Canfield 1997). Chara *(Chara sp.)* has been recorded in the bay but was not included in this analysis because it was present for only 15 of the 115 sampling dates.

Figure 2A presents the percent occurrence of all submersed plant taxa among the bay stations (the percent of 750 sampled points among 15 stations that had any plant or filamentous algae taxon). Prior to the 1983-1985 sampling hiatus, the percent occurrence of submersed plants ranged from around 50% to greater than 90%. When sampling resumed in November 1985 (two months after Hurricane Elena), the percent occurrence of submersed plants in the bay had dropped to less than 30% but over the next year increased to the high levels observed prior to the sampling hiatus. Plants occurred in over 50% of the bay until the Storm of the Century in 1993, whose immediate effects were to decrease plants to less than 10% of the bay. Between the Storm of the Century and Tropical Storm Josephine, the percent occurrence of plants typically ranged between 25 and 85%, and was just over 90% before Tropical Storm Josephine struck in October 1996. Following this storm, macrophytes declined to about 30% of the bay. By May 1997, macrophytes had again increased to 60 occurrence.

Hydrilla was first discovered in Crystal River in 1960 (Langeland 1990) and eventually constituted a major portion of the Kings Bay macrophyte community. Prior to the 1983-1985 sampling hiatus, the percent occurrence of hydrilla in the bay typically ranged from 25 to 50%, and occa-

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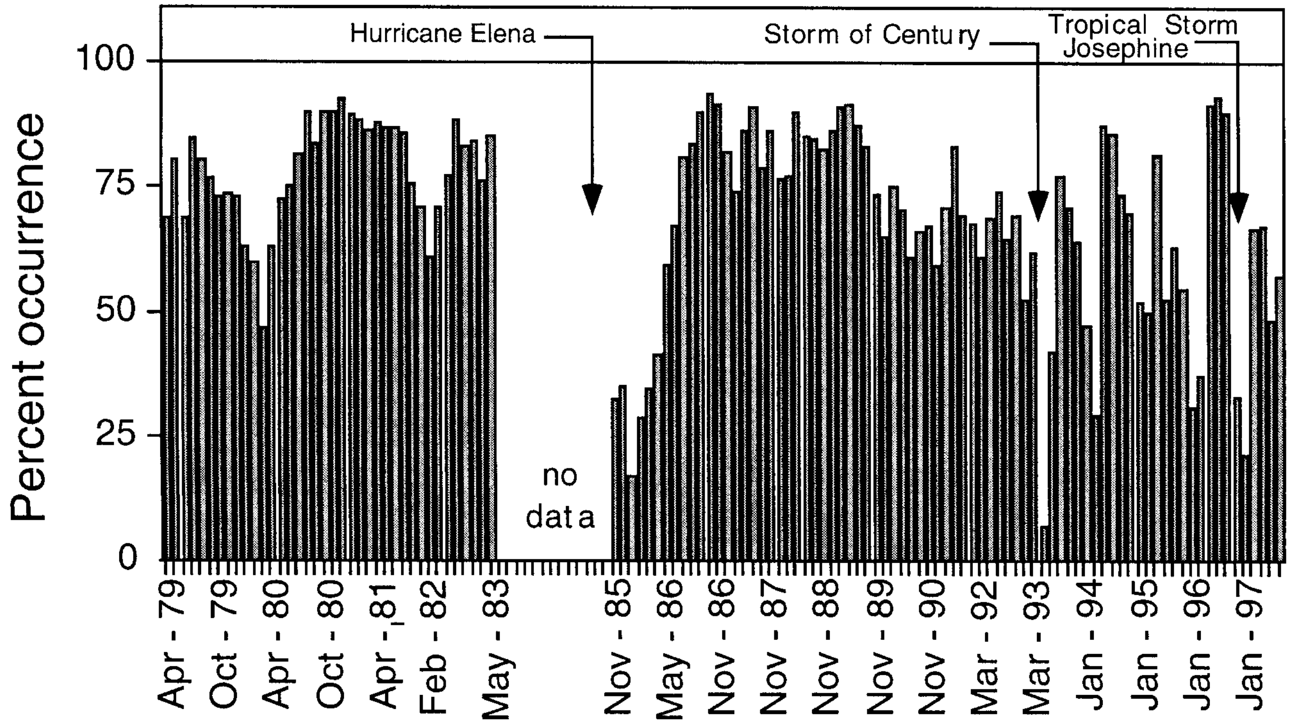
[4] Florida LAKEWATCH. 1997. Florida LAKEWATCH Data 1986-1996. Department of Fisheries and Aquatic Sciences, University of Florida/Institute of Food and Agricultural Sciences. Library, University of Florida. Gainesville. 1108 pp.

(A) All Submersed Plant Taxa



(B) Hydrilla

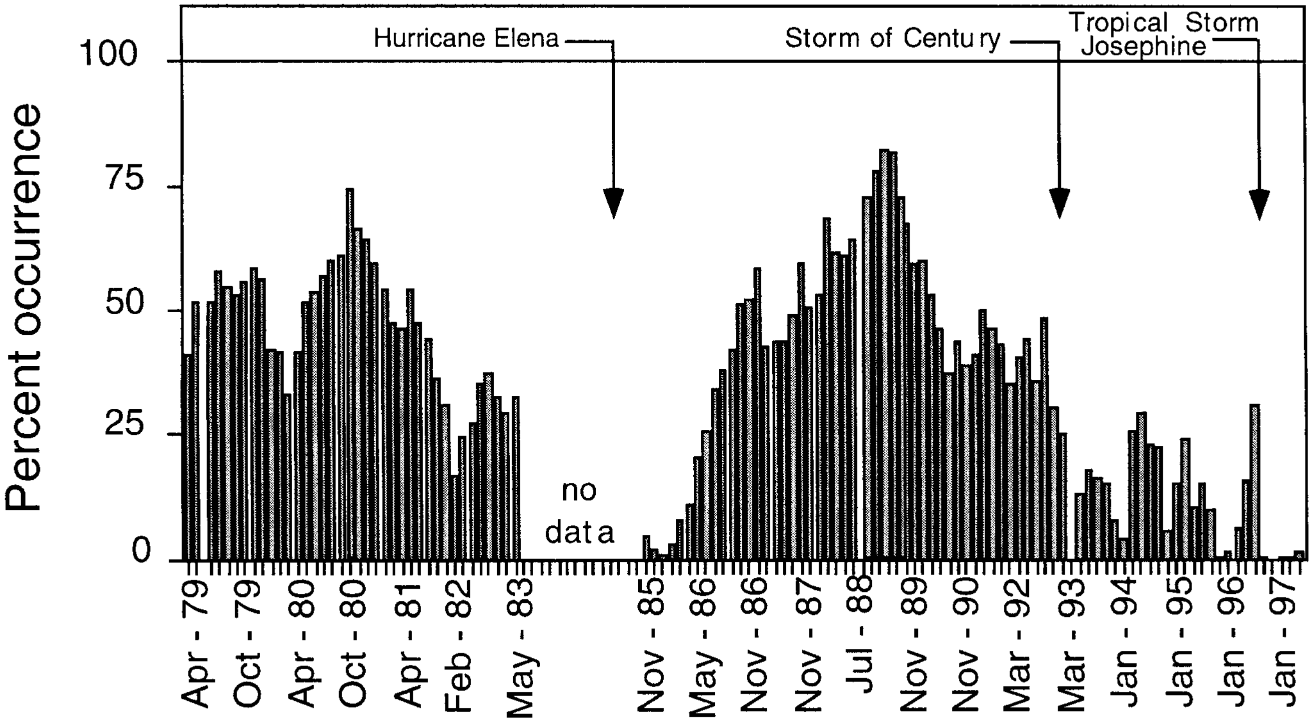


Figure 2. (A) Percent occurrence of all submersed plant species among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997. (B) Percent occurrence of hydrilla *(Hydrilla verticillata* (L. F.) Royle) among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997.

sionally peaked near 75% (Figure 2B). After the 1983-1985 sampling hiatus, the percent occurrence of hydrilla dropped to less than 5% but by the last quarter of 1986, the plant had reestablished its pre-1983 levels. The largest peak on record (over 80%) occurred in the summer of 1989. Immediately after the Storm of the Century, the percent occurrence of hydrilla dropped to zero among the 15 bay stations. During the post-Storm of the Century period, the percent occurrence of hydrilla in the bay ranged between 1 and 30% yet never returned to pre-Storm of the Century levels before the next storm occurrence. After Tropical Storm Josephine, the percent occurrence of hydrilla among the bay stations dropped to zero and remained less than 2% for the remainder of the study period. The data suggest that the probability of encountering hydrilla after severe storms is low, but that it will gradually increase over time.

Prior to the 1983-1985 sampling hiatus, the percent occurrence of Eurasian watermilfoil among the bay stations was typically less than 10% (Figure 3A). After the 1983-1985 sampling hiatus, the percent occurrence of Eurasian watermilfoil among the bay stations increased to nearly 20% and then gradually declined to very low (less than 3%) percentages for most of the 1987-1990 period. Just prior to the Storm of the Century (1990 to early 1993), the percent occurrence of Eurasian watermilfoil averaged about 5%. After the storm, and after an immediate decrease, the percent occurrence of Eurasian watermilfoil quickly increased to 39% (the largest peak on record). Between the Storm of the Century and Tropical Storm Josephine, percent occurrences averaged about 20%. After Tropical Storm Josephine, Eurasian watermilfoil declined to about 4% but then increased within one year to nearly 20%. The probability of encountering Eurasian watermilfoil after storms was higher than for other species. The plant seemed to flourish for a relatively short while after storms but was eventually displaced.

Tape grass has been a relatively constant and steady constituent of the Kings Bay macrophyte population since 1979, typically maintaining a percent occurrence between 2 and 15% (Figure 3B). The percent occurrence of tape grass declined only slightly after both the Storm of the Century and Tropical Storm Josephine. Storms appear to have no lasting or significant impact upon the frequency of occurrence of tape grass in Kings Bay.

Southern naiad has been a relatively minor constituent of the macrophyte community since 1979 (Figure 4A). Its percent occurrence among the bay stations typically ranged from 1 to 5% but it was sometimes undetected for several months. Its frequency of occurrence was most notable during three periods: in mid-1981, in 1986 after Hurricane Elena, and between Storm of the Century and Tropical Storm Josephine in late 1994 through early 1996. Southern naiad does not seem to be affected by storm events by any predictable manner.

Prior to the 1983-1985 sampling hiatus, the percent occurrence of pondweed never exceeded 1% (Figure 4B). Shortly after the 1983-1985 sampling hiatus, the percent occurrence of pondweed rose to more than 5% and remained there for most of the following year. It then declined to less than 2% and stayed low until shortly after the Storm of the Century. Between the Storm of the Century and Tropical Storm Josephine, the percent occurrence of pondweed was variable. The percent occurrence of pondweed was at its highest level (38%) three sampling trips before Tropical Storm Josephine and gradually began to decline before the storm (to 16%). After the storm, the decline continued to about 10% and then increased to about 34%. Pondweed may have a slight propensity to be more frequently encountered after storm events, but this was not conclusive.

Prior to the 1983-1985 sampling hiatus, coontail represented a notable portion (between 2 and 31%) of the plant population (Figure 5A). After the 1983-1985 sampling hiatus, the percent occurrence of coontail was consistently much lower and, after the Storm of the Century, declined to undetectable levels. It has not been detected among the 15 sampling stations since May 1995. The probability of encountering coontail after multiple storm events was very low.

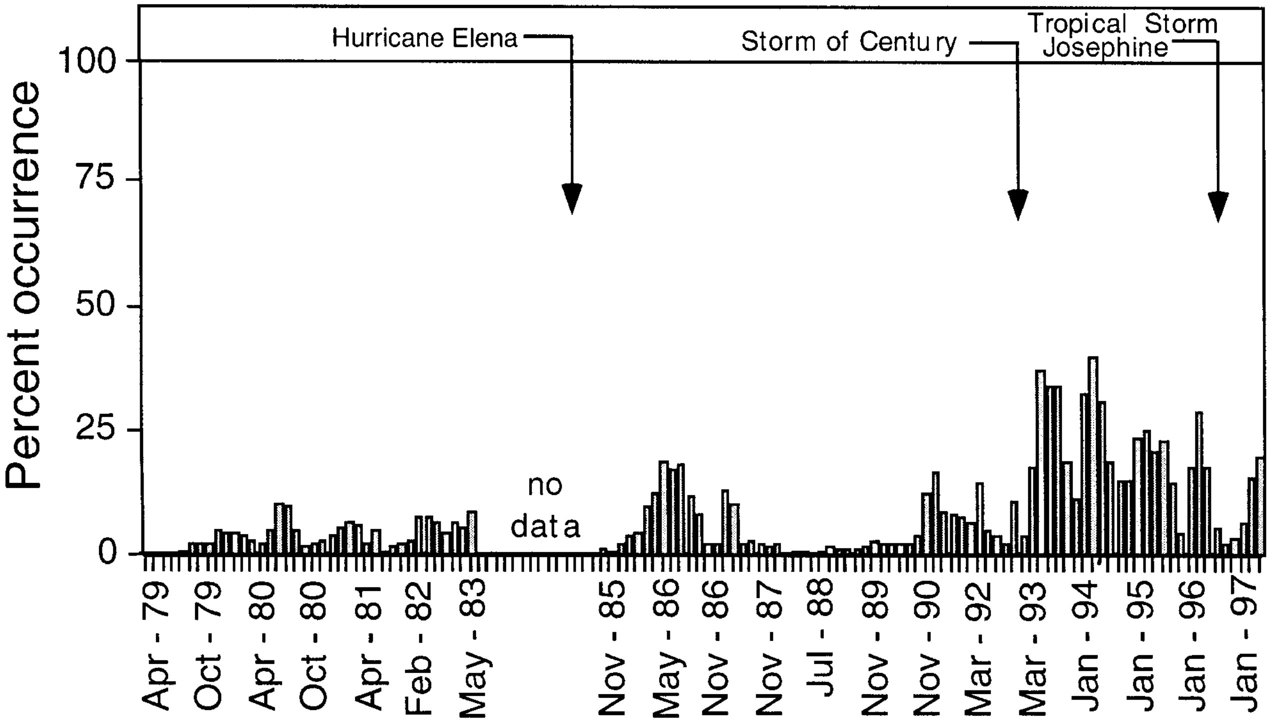
Lyngbya has been a relatively constant constituent of the Kings Bay macrophyte population since 1979, typically maintaining a percent occurrence between 2 and 15% (Figure 5B). Between Hurricane Elena and the Storm of the Century, the percent occurrence remained relatively steady. After the Storm of the Century, the percent occurrence initially declined to zero but increased to pre-storm levels within a year. Two months after Tropical Storm Josephine, the percent occurrence declined to less than 1% but increased to nearly 35% by the following year. Although the percent occurrence of lyngbya may initially decline after severe storms, it quickly reestablishes and becomes a relatively constant portion of the submersed plant community of Kings Bay.

DISCUSSION

After Hurricane Elena, the abundance of Eurasian watermilfoil rose while that of hydrilla declined. Conversely, when hydrilla began to increase a few years later, Eurasian watermilfoil began to decline. One possible explanation for the different responses from hydrilla and Eurasian watermilfoil after these storm events, is the reported differences in growth factors of each species as it is related to salinity. Eurasian watermilfoil can tolerate tidal waters with salinity levels of up to 16 ppt (about 46% sea salinity) and plants can retain growing tips at about 93% sea salinity (Reed 1977). Hydrilla on the other hand failed to grow in water of 7 ppt salinity (Haller et al. 1974) and growth was severely retarded beyond 13 ppt (Steward and Van 1987). Haller et al. (1974) reported that salinity was the most significant factor regulating the distribution and abundance of these species in Crystal River.

Salinity levels associated the with tidal surges following these three storm events are unknown. Salinity levels in Kings Bay/Crystal River, however, have been monitored in other studies and can be used to provide an estimation of salinity levels. Yobbi and Knochenmus (1989) reported that salinities greater than 5 ppt were not frequently observed above Salt Creek (near the Indian River Canal, Figure 1). Salinity levels above the Salt Creek confluence were also never reported above 4 ppt during 15 months of sampling from November 1996 to April 1998 (Frazer et al. 1998). However, on September 3, 1998 following another storm event, Hurricane Earl, surface salinity above the Salt Creek confluence was recorded at 19.9 ppt (Tom Frazer, University of

(A) Eurasian watermilfoil



(B) Tape grass

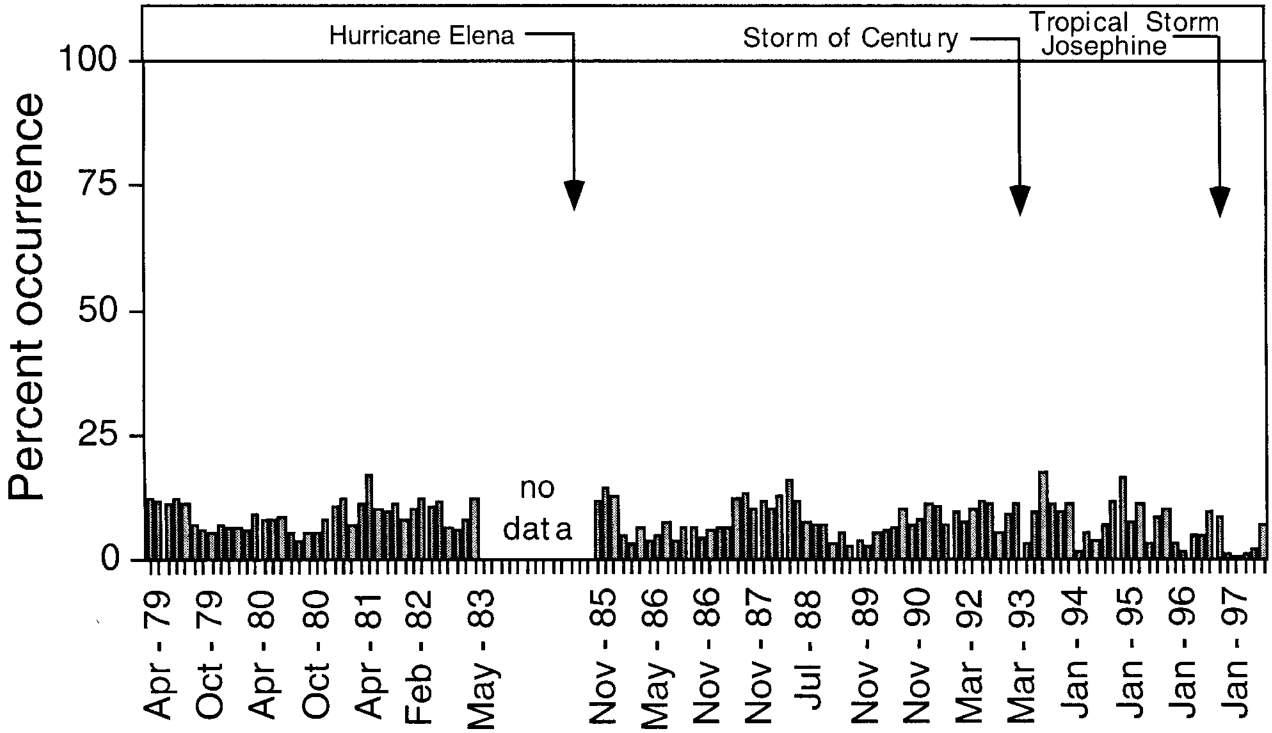
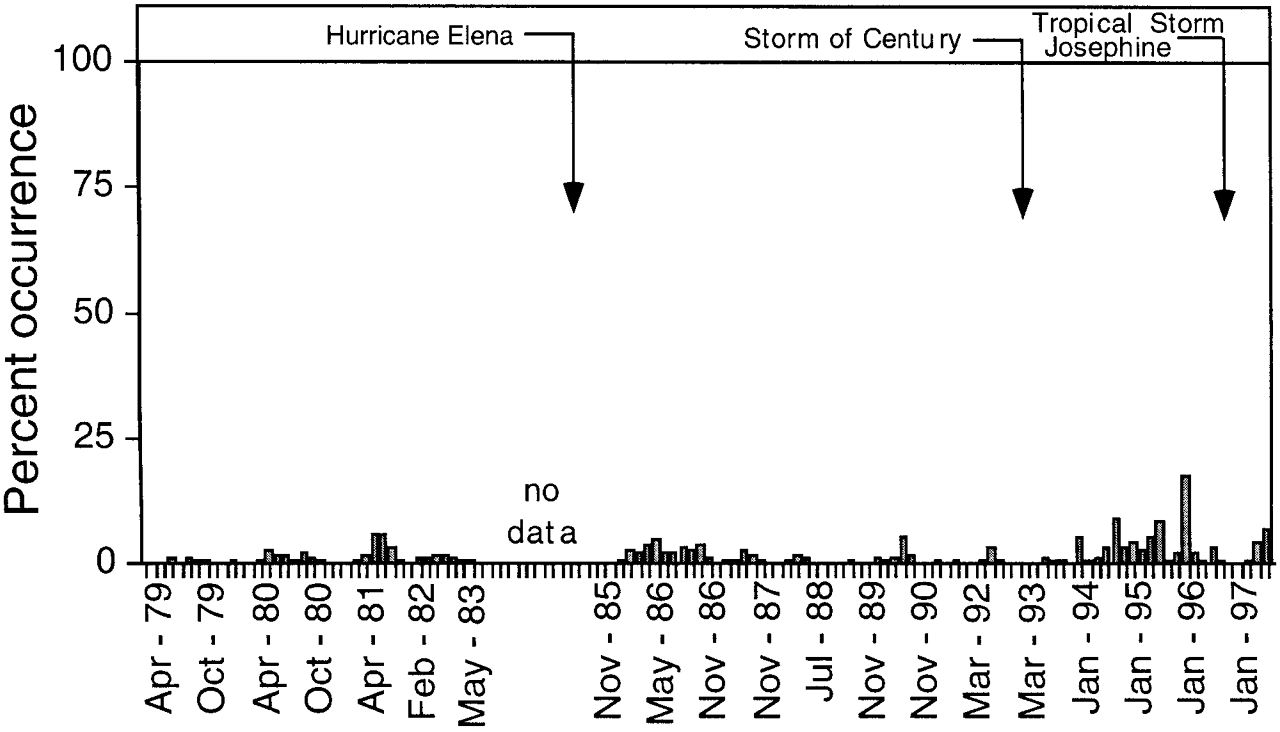


Figure 3. (A) Percent occurrence of Eurasian watermilfoil *(Myriophyllum spicatum* L.) among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997. (B) Percent occurrence of tape-grass *(Vallisneria americana* Michx.) among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997.

(A) Southern naiad



(B) Pondweed

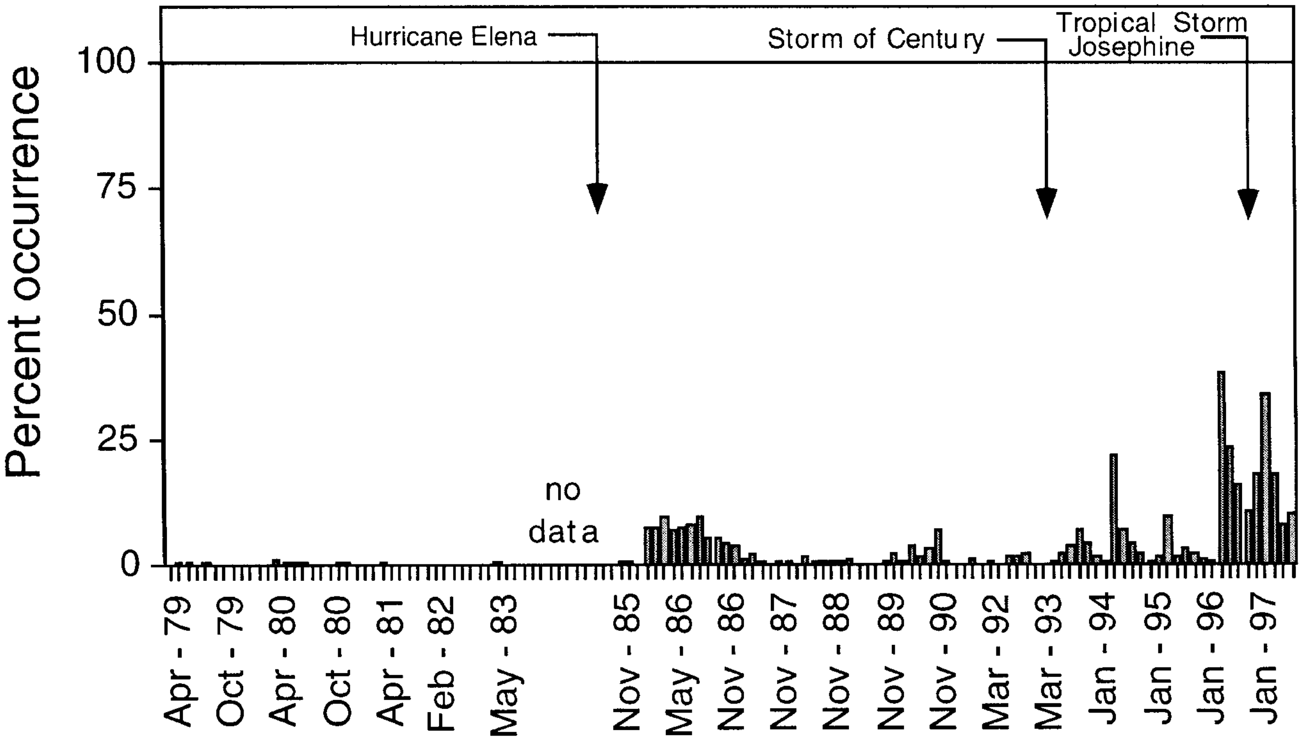
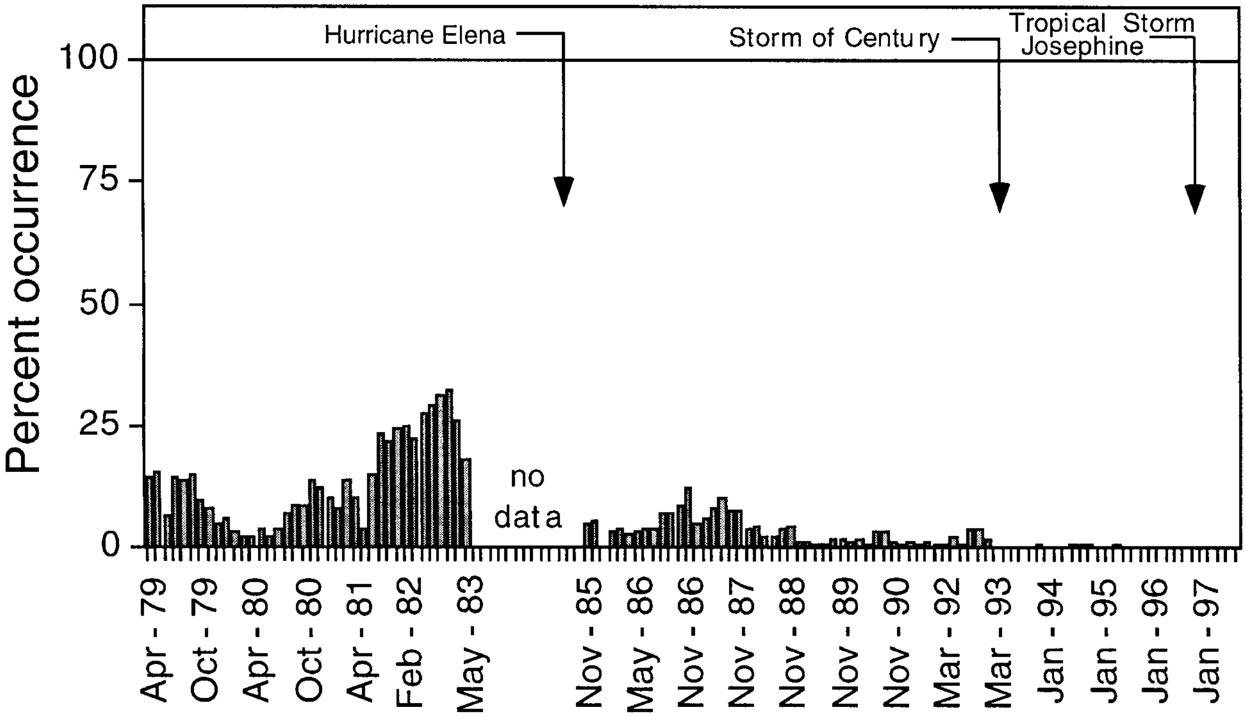


Figure 4. (A) Percent occurrence of southern naiad *(Najas guadalupensis* Spreng.) among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997. (B) Percent occurrence of pondweed *(Potamogeton pusillus* L.) among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997.

(A) Coontail



(B) Lyngbya

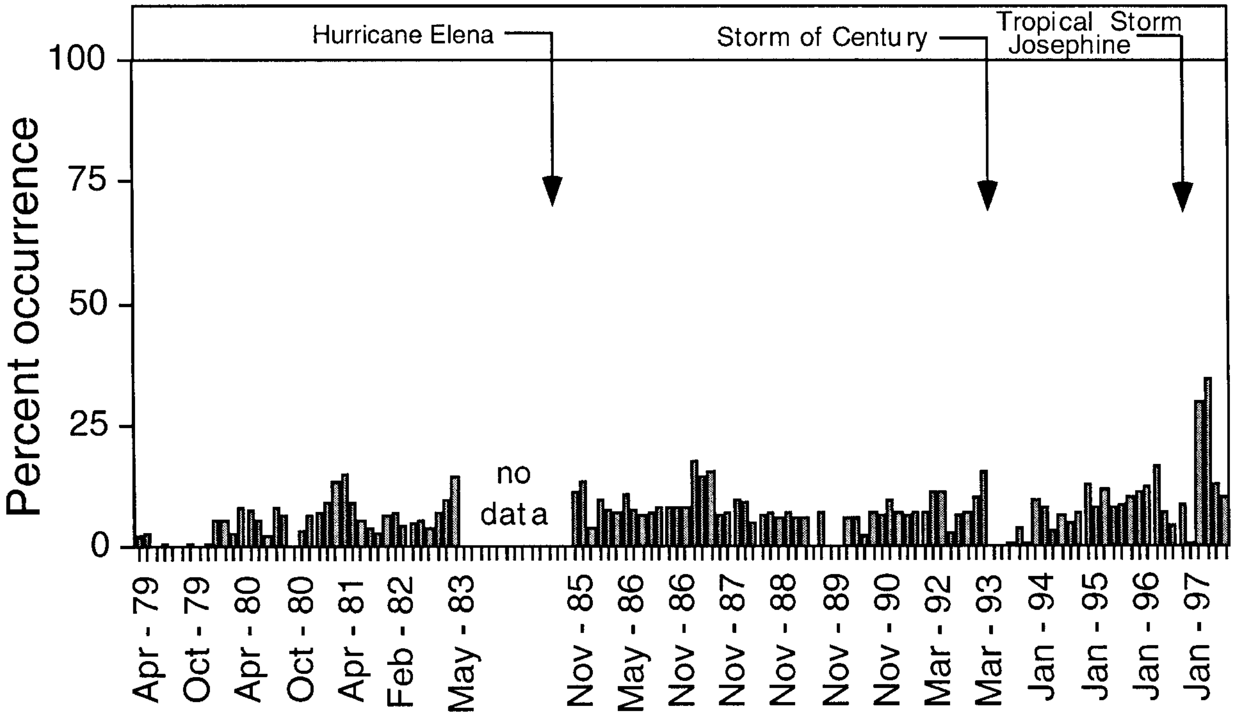


Figure 5. (A) Percent occurrence of coontail *(Ceratophyllum demersum* L.) among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997. (B) Percent occurrence of Lyngbya among 15 stations in Kings Bay, Florida from April, 1979 to September, 1997.

Florida, unpubl. data). Therefore, salinity wedges from tidal storms into Kings Bay could be responsible for the decrease in salinity intolerant macrophyte species (specifically hydrilla) and for the increase in salinity tolerant macrophyte species (specifically Eurasian watermilfoil).

Hydrilla experienced dramatic declines in abundance after each major storm. After Hurricane Elena, however, its abundance eventually increased to pre-storm levels. Between the Storm of the Century and Tropical Storm Josephine, however, the probability of encountering hydrilla was lower than it had been during any point in the period of record. A possible explanation for this is that the time span between the Storm of the Century and Tropical Storm Josephine was too short for hydrilla growth to recover to pre-storm levels. The time span between Hurricane Elena and the Storm of the Century was seven years. Whereas the time span between the Storm of the Century and Tropical Storm Josephine was only three years. Seven years was sufficient time for hydrilla to reestablish to pre-storm levels. The time period of three years was possibly insufficient for hydrilla to reestablish to pre-storm levels. This suggests that the timing and frequency of storm events may influence the distribution and abundance of aquatic macrophytes in Kings Bay.

Other studies have suggested that the growth of aquatic plants may be limited by environmental factors such as light availability (Spence 1975, Chambers and Kalff 1985, Canfield et al. 1985), depth (Pearsall 1917, Spence 1982, Duarte and Kalff 1986, Haller et al. 1983), and sediment characteristics (Pearsall 1920, Haller et al. 1983, Andersson and Kalff 1988). Limitations due to light are probably insignificant in the Kings Bay/Crystal River area because of the comparatively clear water of the bay. The effects of depth and sediment characteristics in Kings Bay/Crystal River have been investigated by Haller et al. (1983). In January 1981, soil, water depth, and plant species along fourteen fathometer transects in Kings Bay were collected. These data suggested that depth and sediment characteristics were not independent of each; the deeper water had more silt and muck soil types than in the shallower water. The effect of sediment characteristics appears to affect hydrilla more than that of depth. Hydrilla occurred at all depths but preferred silt as a substrate over pure sand, organic sand, or muck. Eurasian watermilfoil preferred muck as a substrate and the only depth that it did not occur was 2.5 to 3.0 m. When evaluating the effects of substrate, it is important to note that hydrilla and Eurasian watermilfoil did not occur on the substrate of pure sand. Pure sand was the substrate that lyngbya dominated. It appears that environmental factors such as depth and/or sediment characteristics may play a role in the distribution of individual species, including hydrilla and Eurasian watermilfoil, in the aquatic plant communities in Kings Bay/Crystal River.

Haller et al. (1983) also developed grass vegetation surveys and mapped the major plant communities along 14 fathometer transects in September and December 1980 and in February, May and August 1981. The biomass at a total of 199 sites in Kings Bay in September and December 1980 and in May and August 1981 were also evaluated. These data suggested that the vegetation coverage of the bay changed very little throughout the year probably due to the relatively constant environment in Kings Bay/Crystal River. This data suggests that as a whole, vegetation coverage changes very little throughout the year—unless a storm event has occurred within at least the last three years.

Management Implications. Natural catastrophic events may influence more than just the submersed macrophyte communities of Kings Bay. In our experience with citizen volunteers, management agencies, and other groups in Crystal River we have observed how public concerns have shifted over the years in relation to fluctuations of aquatic macrophytes in the bay. For example, during public meetings at Kings Bay in the 1980s, citizens recalled when submersed macrophyte biomass was low and unproblematic (Daniel E. Canfield, Jr., pers. comm.). Newcomers to the area may have been recalling the period right after Hurricane Elena in 1985, when macrophyte occurrence was at one of its lowest levels recorded. When macrophyte occurrence increased to similar levels recorded in the late 1970s and early 1980s, they believed that aquatic macrophytes had substantially increased and complained that their use and enjoyment of the bay was impaired.

At public meetings, the public complained that nutrient input from a nearby wastewater treatment plant was the causal factor for the increase in macrophyte occurrence and rallied for diversion of its sewage effluent[5]. Despite evidence from the scientific literature and surveys which were also presented at these public meetings and which suggested that removal of the wastewater would not control the growths of aquatic plants in this system, management agencies decided to divert sewage effluent from the bay[6].

Sewage effluent was removed from Kings Bay in August 1992 and the Storm of the Century struck the bay in March 1993. After the storm, hydrilla and lyngbya were temporarily eliminated from the bay. While the notion was common that the nutrient abatement had finally resulted in a decline in macrophyte abundance, Terrell and Canfield (1996) determined that the Storm of the Century was instead responsible for the decline. Had the Storm of the Century not occurred, the wastewater diversion may have been considered an expensive failure by the public.

The submersed plant community at Kings Bay has not recovered to pre-Storm of the Century levels (the timely occurrence of Tropical Storm Josephine in October 1996 may have partially precluded this recovery). In this period of low macrophyte biomass, public attention has shifted away from aquatic plant problems, to impaired water clarity problems (Hoyer et al. 1997). If the submersed macrophyte community returns to the high levels observed in the 1980s, we might expect public attention to shift away from water clarity to macrophytes once again.

Management agencies responsible for managing systems like Kings Bay/Crystal River should be aware of the influence that natural storm events could have not only on the macrophyte communities but on the public's perception of the "quality" of the system.

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[5] *Citrus County Chronicle:* Aug. 2, 1985; Aug. 2, 1985b; Mar. 23, l986; and Apr. 23, 1986.

[6] *Citrus County Chronicle:* Apr. 27, 1986 and May 14, 1986.

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