Estuaries Vol. 27, No. 6, p. 915–922 December 2004

The Demise and Recovery of Seagrass in the Northern Indian River Lagoon, Florida

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ABSTRACT: Seagrass both disappeared and recovered within 4 yr in one region of northern Indian River Lagoon (IRL). For the specific area referred to as Turnbull Bay, a relatively pristine area of the IRL, over 100 ha of seagrass completely disappeared from 1996 to 1997 and then recovered by 2000. Based on lagoon-wide mapping from aerial photographs taken every 2–3 years since 1986, coverage of seagrass in Turnbull Bay declined from 124 ha in 1989 to 34 ha by 1999 and increased to 58 ha in 2003. Bi-annual monitoring of fixed seagrass transects tells a more detailed story. Species composition along the Turnbull transect shifted from *Halodule wrightii* to *Ruppia maritima* beginning in 1995, and macroalgal abundance increased. By the summer of 1997, seagrass completely disappeared along the transect, as well as in most of the surrounding areas in Turnbull Bay; macroalgae covered much of the sediment surface. No significant water quality changes were detected. Light attenuation and suspended solid values did increase after the seagrass disappeared. Porewater sulfide concentrations, taken after all the grass was gone in 1997, were high (2,000 μM), but did improve by 1998 (1,200 μM). Seagrass recovery was rapid and occurred in the reverse sequence of species loss. Seedlings of *R. maritima* were the first colonizers, then patches of *H. wrightii* appeared. In 2000, *Halophila engelmannii* returned in the deeper water ($>$ 0.6 m). By the summer of 2000, the beds had completely recovered. We conclude that this demise was a natural event caused by a long-term buildup of seagrass biomass and a thick (10–15 cm) layer of organic detritus and ooze. We surmise that such a crash and subsequent recovery may be a natural cycle of decline and recovery within this semirestricted, poorly-flushed area. The frequency of this cycle remains uncertain.

Introduction

Seagrass, because of its many ecological benefits, is the principal focus of a major estuarine restoration and protection program in the Indian River Lagoon (IRL), Florida (Steward et al. 2003). The entire IRL system extends 250 km along the east coast of Florida from 27°N to 29°N latitude and contains about 30,000 ha of seagrass (Fig. 1).

As part of determining status and long-term trends of seagrass in Indian River Lagoon, it is also necessary to understand the natural variability of the system. The St. Johns River Water Management District (SJRWMD) has on-going monitoring programs of seagrass and water quality on different spatial and temporal scales. Seagrass beds throughout the IRL are monitored using two methods: lagoon-wide mapping based on aerial photography and field monitoring of fixed seagrass transects (Virnstein and Morris 1996; Virnstein 2000). Water quality is sampled monthly by a network of agencies and organizations at 26 stations within the SJRWMD's portion of the Lagoon, as well as 12 stations in the tributaries feeding the IRL (Fig. 1). Most water quality parameters have been measured since 1988, and light attenuation has been measured since 1991 (Sigua et al. 1999).

The general study area (Fig. 1) north of Titusville, in the northern Indian River, is a relatively pristine area. The specific focus area, Turnbull Bay, is a small embayment (624 ha) fed through Turnbull Creek draining an 8,000-ha hardwood swamp and marsh system (Fig. 1). At times, the salinity of the water entering the estuarine system from Turnbull Creek is 0‰ and highly colored, greater than 350 cpu (cobalt platinum units). Average (1996–2003) salinity at the IRLI02 station (Fig. 1) was 28.4‰, ranging 15–42‰ over this time period. Salinity varies primarily in response to variations in evaporation and surface runoff in response to Florida's distinct wet-dry seasons.

This paper describes the complete loss and recovery of seagrass at the Turnbull site and the events that occurred before and after this loss, including shifts in seagrass species composition and the sequence of species in the recovery process. We examine evidence in search of a cause and propose a hypothesis that this demise and recovery was a natural event, perhaps part of a natural cycle.

Methods

SEAGRASS

The lagoon-wide seagrass maps are photo-interpreted, ground truthed, and digitized from 1:24,000 aerial photographs every 2–3 yr since 1986. The available mapped seagrass years are: 1943,

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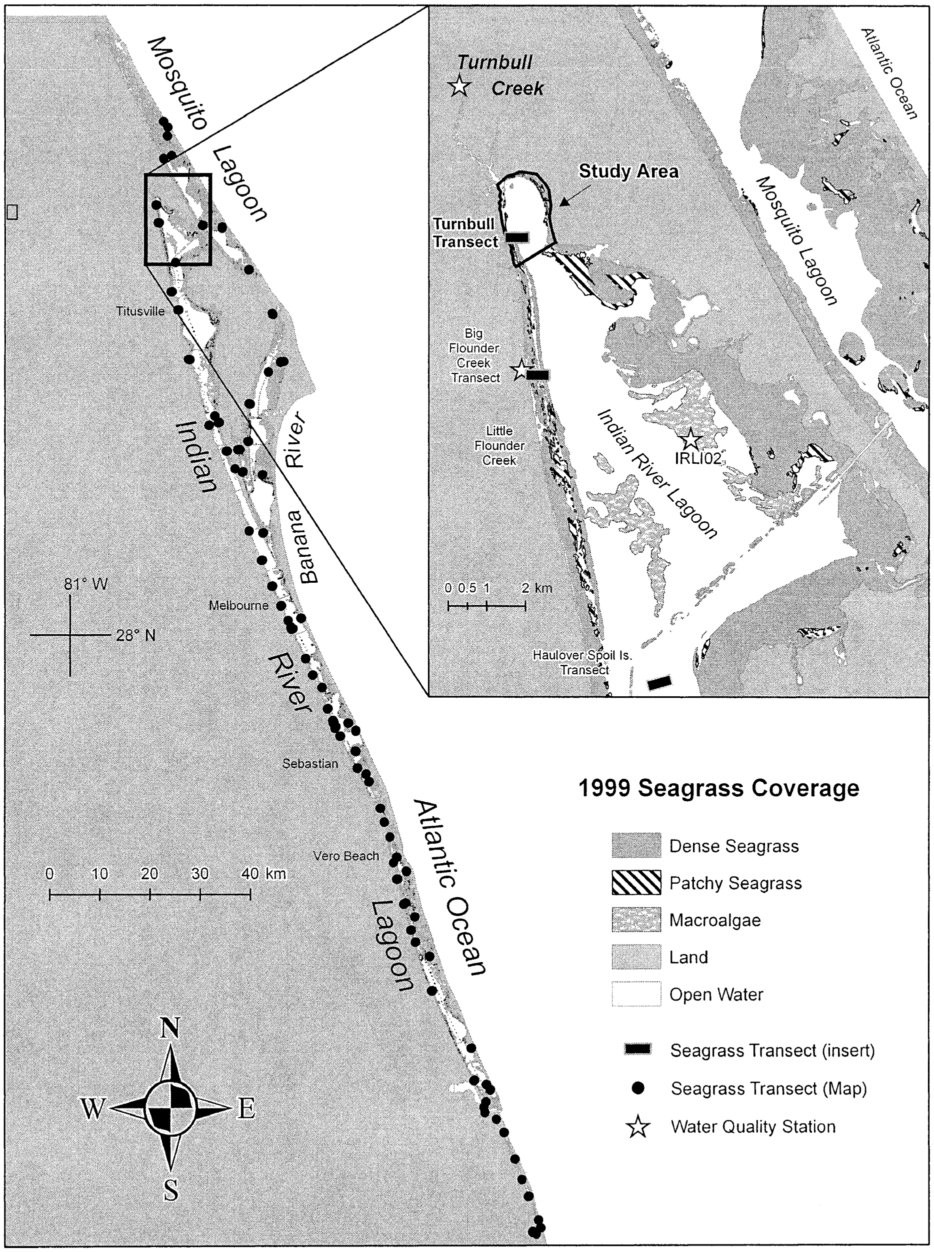

Fig. 1. The Indian River Lagoon system is comprised of 3 sublagoons: Mosquito Lagoon, Banana River, and the Indian River Lagoon proper. The Turnbull study area (outlined) is in the northern Indian River (upper right).

1965, 1974, 1986, 1989, 1992, 1994, 1996, 1999, and 2003. The delineated seagrass coverage is divided into two density classes: patchy and dense, continuous. Seagrass change analyses can be done by comparing coverages from year-to-year.

Fixed seagrass transects have been monitored throughout the Lagoon every summer and winter since 1994 (the Turnbull transect was one of the original test sites for transect methods starting in 1993). All 84 transects are perpendicular to the shore, extending to the deep edge of the grass bed. Every 10 m along the measured line, percent cover and canopy height for all species present are measured along with water depth. Shoot density is measured at the middle (generally dense) and end (generally patchy) of the transect (see Virnstein and Morris 1996; Morris et al. 2001 for complete details of transect methods). There are three transects in the Turnbull area: Turnbull, Big Flounder Creek, and Haulover Spoil Island (Fig. 1).

WATER AND SEDIMENT QUALITY

In the Turnbull area, three water quality stations have been monitored monthly since 1989. One of the three stations is in the Lagoon, approximately 6.8 km southeast of the Turnbull transect. The other two stations are in tributaries (Turnbull Creek and Big Flounder Creek) flowing into the Lagoon (Fig. 1). Along with a full suite of water quality parameters, photosynthetically active radiation (PAR) data were also collected. The PAR measurements were used to calculate light attenuation coefficients (K) for the water column. K was calculated as the slope of a semi-log regression of PAR with depth using the method of least squares. The protocol included taking 3 replicates of PAR simultaneously at 20 and 50 cm below the surface and at canopy height (30 cm off the bottom) using 3 LI-COR spherical sensors (4π) and recorded by a LI-COR LI-1400 data logger.

After the disappearance of seagrass in 1997, sediment cores were taken in August 1997 and again in July 1998 to sample porewater sulfide concentrations. Cores were collected in 60-ml plastic syringe barrels, stoppered, and transported on ice to Fish and Wildlife Research Institute (FWRI) St. Petersburg, Florida for analysis (Carlson et al. 1994). Porewater sulfide concentrations were measured with an ion-specific electrode by the procedure of Carlson et al. (1983). Replicate cores (3 each) were taken in shallow and deep areas of the Turnbull transect and the Big Flounder Creek transect at the southern end of the affected area, 3 km south of the Turnbull transect. A last set of cores were taken outside the affected area as a control, near Little Flounder Creek, 5 km south of the Turnbull transect (Fig. 1).

Results

SEAGRASS DECLINE

Seagrass coverage in the specific Turnbull Bay study area, based on mapping from aerial photographs, generally occurred in a continuous band around the shoreline except with a gap near the mouth of Turnbull Creek (Fig. 2). The density of coverage did vary between patchy and dense. The overall coverage varied from 34 to 183 ha (Fig. 3), with a general decline from 1989 to 1999. The sharpest decline (63%), from 92 ha in 1996 to 34 ha in 1999 (Fig. 3), had the largest losses on the west side of the embayment (Fig. 2). Also noteworthy was the extensive macroalgae coverage in 1996 (Fig. 2).

Year-to-year seagrass coverage and seagrass species composition cannot be determined from the large-scale mapping project; data collected twice a year from fixed seagrass transects do distinguish among all seagrass species present. The Turnbull transect data, starting in 1993, supports the mapped data by showing sharp declines in percent cover and transect length (the distance from shore to the deep edge of the seagrass bed) after 1996 (Fig. 4). Average percent cover along the transect declined sharply from 50% in 1996 to 0% in 1997. Total transect length also declined from 200 m in 1996 to 0 m in 1997.

Concurrent with the decline in density through the years was a change in species composition (Fig. 5). Along the transect in 1993, seagrasses were abundant, but not unstressed. The seemingly dense, tall (up to 80 cm) *Halodule wrightii* coverage was full of dead blades, almost as many dead as alive. Most shoots had only 2 blades, as opposed to the normal 4–5, and there was a thick layer of litter tangled among the bases of the plants. By the summer of 1994, the area became very patchy, as most of the dead blades had fallen off. In 1995, percent cover of *H. wrightii* decreased, *Ruppia maritima* started growing in the bare areas, and patches of the green algae *Caulerpa prolifera* and *Ulva* sp. appeared. In winter and summer 1996, *R. maritima* became the dominant species throughout the shallow areas (Fig. 5). By summer 1997, all seagrass at the site and surrounding area was gone and macroalgae dominated.

Through the recent years, other dramatic changes were observed along the transect. Prior to the seagrass crash in 1997, the sediment had become covered with a thick (10–15 cm) layer of detritus (mostly dead *H. wrightii* leaves) and organic ooze in 1995. This ooze was very flocculent, and the seagrass plants were weakly attached to the sediment. By 1997, after all seagrasses had disappeared, the sediment surface had become a firm sandy bottom, and virtually all the organic debris had disappeared, except for macroalgae. Large numbers of mollusks (*Mulinia lateralis, Nassarius vibex,* and *Melongena corona*) were present, which had not been observed previously. Past the deep edge of the historic bed (> 250 m from shore), there was a dense cover of macroalgae, mostly *Gracilaria* spp.

To determine whether this loss along the transect was localized, an extensive reconnaissance of the surrounding areas was made by snorkeling. Despite diligent searching, we could find absolutely no seagrass in the surrounding area for several hundred meters, except for a sparse fringe on the opposite, eastern shore of the embayment. At least 100 ha of seagrass had disappeared, as well as the loose organic matter on the sediment surface. The sediment surface was left completely clean, except for the macroalgae in deeper water.

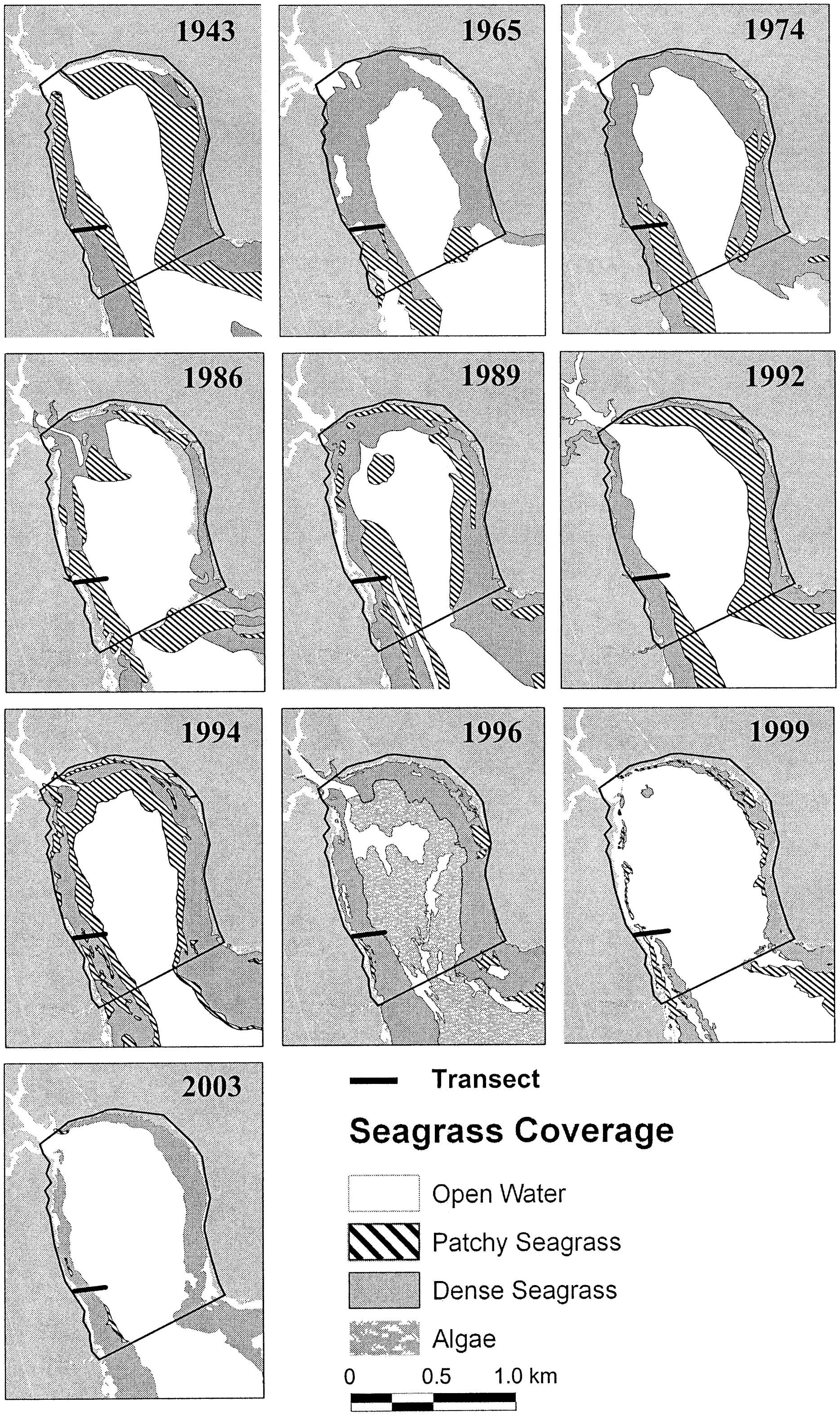

Fig. 2. Seagrass coverage maps in Turnbull Bay in each of the mapped years, 1943 to 2003.

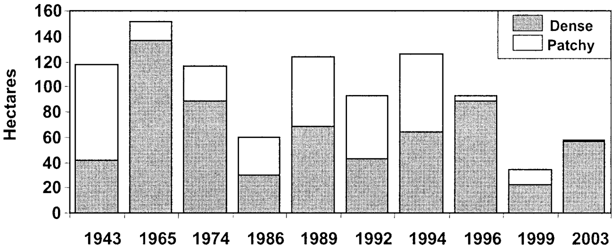

Fig. 3. Seagrass coverage (hectares) in Turnbull Bay in each of the mapped years for the area outlined in Fig. 2.

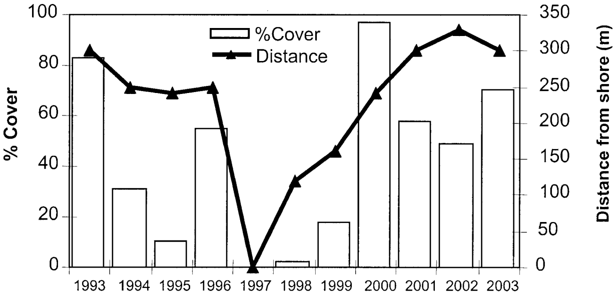

Fig. 4. Average percent cover and distance from shore to the deep edge of the seagrass bed for the Turnbull transect (see Fig. 1). Summer values are from 1994 to 2003. Note complete absence of seagrass in 1997.

SEAGRASS RECOVERY

Recovery was generally rapid and proceeded in roughly the reverse sequence of species loss (Fig. 5). Starting in January (winter) 1998, there were numerous (> 1 m^{-2}) tiny *R. maritima* seedlings with their seed coats still attached. Small patches of *R. maritima* formed and continued to grow. The bivalve *M. lateralis* was no longer present, and there were numerous ray holes in the area. Small patches of short (5–7 cm in height) *H. wrightii* appeared by 1999 (Fig. 5). There were also other sparse patches of *R. maritima* and *C. prolifera.* We do not know whether this recruitment by *H. wrightii* was by seedlings or fragments. *H. wrightii* can potentially recruit by fragments (Hall 2002), and there was a recovering dense coverage on the opposite shore. In 2000, *Halophila engelmannii* returned in deep water (> 0.6 m) and continued to spread into deeper waters (> 1.2 m) by 2002 and 2003.

A follow-up reconnaissance of the surrounding areas showed a somewhat faster recovery of the beds on the opposite shore. Dense coverages of *H. wrightii* and dense patches of *Syringodium filiforme* and *H. engelmannii* were found on this shore. By summer 2000, the transect and surrounding beds had exceeded their 1993 average percent cover (Fig. 4). Dense *H. engelmannii* beds were expanding and extending the deep edge of the bed throughout 2000 and into 2003 (Fig. 5). Preliminary examination of May 2004 aerial photographs indicates a continued expansion of seagrass.

A SEARCH FOR THE CAUSE OF THE DECLINE

Water quality data from the water quality monitoring site, IRLI02, 6.8 km southeast of the Turnbull transect site (Fig. 1) indicated nothing unusual preceding the seagrass decline. Nutrients were not elevated but the salinity measurements have some fluctuations (Fig. 6). The average salinity from 1996 to 2003 was 28.3‰. The wettest, low salinity period was from September 1995 to April 1997, preceding the seagrass decline, when the average salinity dropped to 22.7‰. At the same time, the color measurements went from a 7-yr average of 16.7 to 21.5 cpu. The average K values, for 6 mo prior to the transect sampling, showed very little change through the summer of 1997. There was a large increase in K to 2.4 m^{-1} in 1998, after the seagrass disappeared followed by a recovery to average light values (K = 1.0 m^{-1}; Fig. 7).

The average salinity 3 km upstream from the mouth of Turnbull Creek (Fig. 1) for the 20-mo period prior to the seagrass decline was low (1.4‰; September 1995 to April 1997); the 8-yr average (1995–2003) was 9.8‰.

The porewater from the cores taken in 1997 had sulfide concentrations greater than 1,500 μM in both the shallow and deep areas of the Turnbull transect (Fig. 8). Higher concentrations were found in the shallow area of the Big Flounder Creek transect (2,500 μM) where seagrass persisted. At the control site, Little Flounder Creek, the sulfide concentrations were less than 1,000 μM at the deep edge of seagrass. In 1998, the sulfide concentrations remained high (> 2,000 μM) in both the deep area of the Turnbull transect and the shallow area of Big Flounder Creek and also increased at the control, Little Flounder Creek (> 1,000 μM; Fig. 8). The percent seagrass cover data from the Big Flounder Creek transect shows no decline in density of seagrass from 1997 to 2001 (Fig. 9) despite the high sulfide concentrations.

Discussion

THE DECLINE

Unlike areas in Florida Bay that saw extensive mass mortality of seagrasses (Robblee et al. 1991), such declines and crashes are unusual and atypical of the IRL. Out of all 84 transect sites in the IRL system, the Turnbull site, is the only site to have completely crashed. Lagoon-wide, average transect length was greater in 2001 (148 m) than it was in 1994 (110 m) (Morris et al. 2001). Total seagrass coverage, based on mapping efforts, generally in-

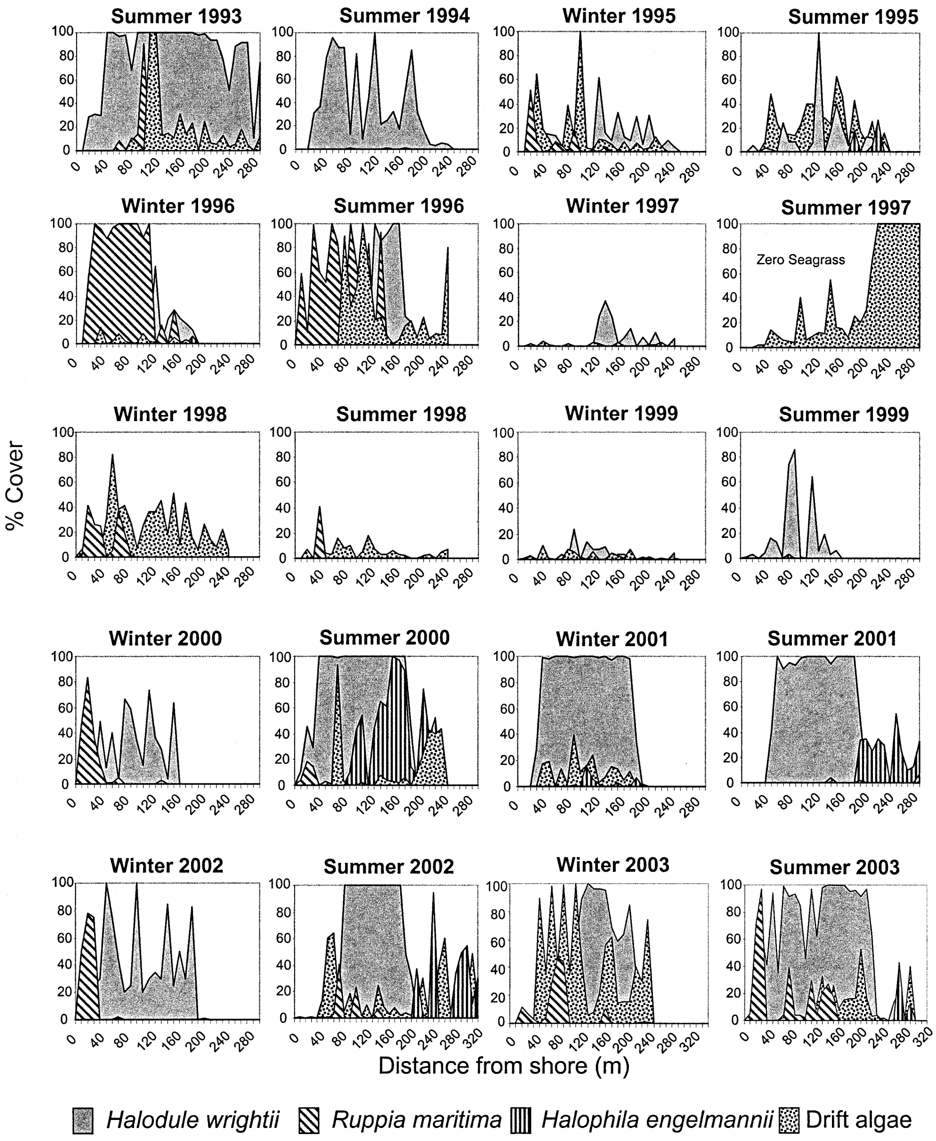

Fig. 5. Percent cover along the Turnbull transect of *Halodule wrightii, Ruppia maritima, Halophila engelmannii,* and macroalgae. Note species change from *H. wrightii* to *R. maritima* in 1996 and the complete absence of seagrass in 1997 and recovery by summer 2000.

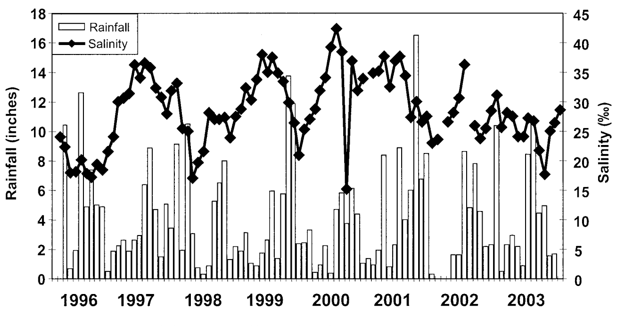

Fig. 6. Monthly rainfall and salinity from 1996 to 2003. Rainfall data are from Turnbull Creek site. Salinity data are from water quality station IRLI02 (see Fig. 1).

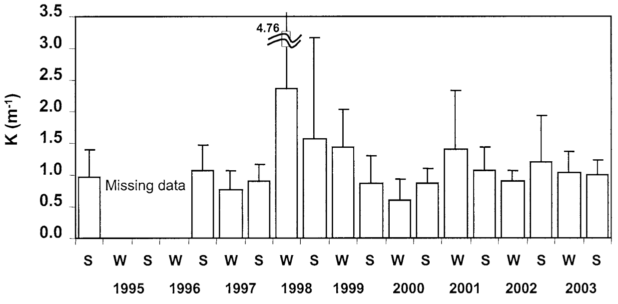

Fig. 7. Average light attenuation (K) values for each 6-mo period prior to transect sampling (+ 1 SD). Data are from station IRLI02 (see Fig. 1). Note that K values increased after seagrass disappeared in summer 1997.

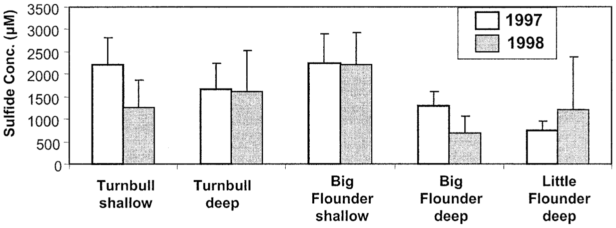

Fig. 8. Sediment sulfide concentration (+ 1 SD) at Turnbull shallow, Turnbull deep, Big Flounder shallow, Big Flounder deep, and Little Flounder deep sites (see Fig. 1).

creased from 1992 (26,445 ha) to 1999 (28,241 ha; Steward et al. 2003).

The cause of the decline is still uncertain. Because of the rapid mortality of the seagrasses, it was unlikely due to eutrophication, which usually produces a slow, gradual decline (Kemp et al. 1983). This slow decline would likely have eliminated the deep edge first (Onuf 2000). But seagrasses at Turnbull declined at all depths, so light was probably not the limiting factor. Had there been a low salinity event, it would not have eliminated *R. maritima,* which can tolerate virtually fresh water. The somewhat lowered salinity that occurred at the end of 1995 through 1996 (average 19.3‰) may have precipitated the shift towards dominance by *R. maritima* (Figs. 5 and 6).

Rather than indicating the cause of the seagrass decline, water quality conditions may instead reflect the impact of the loss of seagrass. The increase in the K values (Fig. 7) may be attributed to the loss of seagrass in the area, thereby inducing increased resuspension of finer sediments. The closest water quality monitoring site was 6.8 km away and sampled only monthly.

We also have no reason to suspect sediment porewater constituents. In a 1999 study that included the Turnbull seagrass transect site, sediment salinities and nitrate levels in seep water were very similar (± 6%) to overlying Lagoon water (Martin et al. 2002).

High sulfide concentrations have been shown to decrease the maximum photosynthetic rate, causing increased light requirements for the plants (Goodman et al. 1995). Pulich (1983) added H_2S to the sediment and found a tolerance of 1,000 µM H_2S for *H. wrightii* but only 500 µM H_2S for *H. engelmannii.* Sulfide levels at Turnbull were above 1,500 µM, so sulfides may be involved in the seagrass decline (Carlson et al. 1983). Sulfide levels were also high at the Big Flounder shallow site (Fig. 8), where seagrass persisted (Fig. 9). The cause of the seagrass decline is uncertain. We cannot definitely attribute sulfides as the cause, largely because we measured sulfides only after the seagrass decline. High sulfides may have been the consequence of seagrass mortality and subsequent decomposition of accumulated biomass; the high sulfide concentrations could have exacerbated the deteriorating condition.

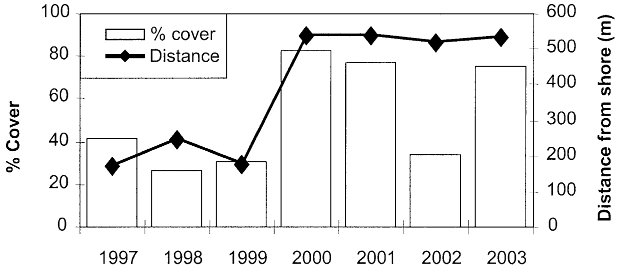

Fig. 9. Average percent cover and transect length for the Big Flounder Creek transect (see Fig. 1). Summer values are from 1997 to 2003. Compare to Turnbull transect (Fig. 4) with no seagrass in 1997.

The low importance of water quality monitoring in explaining the drastic changes is vexing. The location of the nearest water quality station (6.8 km away) may be inappropriate for relating to the seagrass at the Turnbull site (Fig. 1). The monitoring programs were not designed for such site-specific questions and the monthly monitoring may not capture short-term events. Frequent monitoring of water quality and sediment pore water sulfides within the seagrass bed may have provided far better clues to the demise of seagrass. Such changes are being considered.

THE RECOVERY

The Turnbull area completely recovered within 3 years, with all three species present. In fact, seagrass density in 2000 was greater than before the decline. Such a rapid and complete recovery was a surprise, and attests to the natural resilience of seagrass. The numerous seedlings of *R. maritima* in the early stages of recovery indicate that a seed bank was present for this species. The method of recruitment of *H. wrightii* and *H. engelmannii* is unknown. Hall (2002) has demonstrated that *H. wrightii* and *Halophila johnsonii* fragments can settle and attach to the sediment in mesocosms. The quiescent shallow waters of Turnbull Bay may allow for such settlement, where *H. wrightii* did initially recover as small patches. A more extensive dieoff, such as occurred in Florida Bay (Robblee et al. 1991), would be expected to take longer to recover without a nearby source for new recruits.

A PROPOSED HYPOTHESIS FOR THE CAUSE OF THE DEMISE

In the absence of known processes to account for the loss of seagrass documented in this study, we suggest that long-term natural cycles of decline and recovery may operate in isolated areas with poor flushing, such as Turnbull Bay. The complete demise and recovery to even denser seagrass suggests the possibility that the site was cleaned out and made more suitable for seagrass growth. According to this conceptual model, dead seagrass leaves and mats of drift algae accumulate in beds to the extent that plants become poorly rooted in an organic ooze where they are stressed by high sulfides (Zimmermann and Montgomery 1984). Mass mortality ensues. Without a living rhizome mat and aboveground parts to hold the soup in place, storm conditions may flush the organic layer from the site. Recolonization then begins on a largely mineral sediment.

Such natural cycles may take many years or decades to be detected. These cycles and events could be missed if infrequent, large-scale seagrass mapping is the only method used for long-term seagrass monitoring. Our lagoon-wide seagrass mapping, with the gap from 1996 to 1999, missed the 1997 crash at Turnbull. The 1943 seagrass map of the Turnbull area (Fig. 2) is merely a snapshot. We have no way of knowing whether the area may have been declining or recovering. The smaller-scale, more frequent monitoring of the lagoon-wide seagrass transects is more effective at detecting small-scale changes, both in space and time, within target areas. Even with the current sampling schedule of twice a year (summer and winter) some short-term events might be missed. But together, the two programs, mapping and transects, complement each other and are highly valuable for discriminating short-term events from long-term patterns.

ACKNOWLEDGMENTS

Lauren Hall and Robbyn Miller-Myers (SJRWMD) provided many hours of field work, from start-up (1993) to current. Paul Carlson (Fish and Wildlife Research Institute) provided all sampling equipment and analyses for the sediment sulfides. Joseph Beck and Edward Carter (Jones, Edmunds and Associates) provided GIS analyses and maps of the seagrass coverage data. David Clapp (SJRWMD) provided rainfall data. Christopher Onuf (U.S. Geological Survey, National Wetlands Research Center, Texas) provided a thorough review with helpful insights to improve clarity.

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Received, October 29, 2003
Revised, July 23, 2004
Accepted, July 26, 2004