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Using nearshore macrobenthos as environmental indicators adjacent to a major navigational inlet: Port Everglades inlet, Florida

J. A. Craft

Coastal Planning & Engineering, Inc., 2481 N.W. Boca Raton Blvd., Boca Raton, FL, 33431, USA

Abstract. The reefs off Broward County, Florida, USA, lie near the northernmost limits of tropical coral reefs, are non-accreting, and have long been affected by human influences including land-based sources of pollution. Port Everglades, a major industrial shipping port, is a likely source of many anthropogenic contaminants, which are discharged in an effluent plume that sweeps over the coastal reef. The results of two nearshore reef studies were examined here to determine if the inlet effluent plume produces a water quality gradient and associated biological gradient, and if any biological indicators of water quality can be determined. Macrobenthos cover at 33 sites was assessed from Port Everglades inlet south to the Broward County line. Results showed macroalgae abundance significantly increases with proximity to Port Everglades inlet. In addition, water quality data clearly illustrate a low-salinity wedge being discharged from the inlet at low tide, as well as increased levels of nutrients around the mouth of the inlet. These results suggest that Port Everglades is a probable source of coastal pollution that may be causing localized increases in algal abundance that can be detrimental to the benthic ecology of the surrounding nearshore reef.

Key words: land-based pollution, effluent, indicators, coral reefs

Introduction

Coral reefs are used around the world for recreation, food, a source of income, and storm protection. Our lack of understanding of reef ecology and the effects humans have on reefs has taken a toll on these diverse ecosystems. In order to conserve remaining reef systems, proper sensitive and quantifiable biological indicators need to be developed for detection of impacts to reef systems, which can be used on a wide scale.

Monitoring and assessment tools that diagnose coral reef community responses to threats are critical to the management of these ecosystems. Corals themselves are extremely sensitive animals and require a narrow range of environmental conditions in order to thrive. However, corals are slow-growing and may take years to show damage from pollutants. Furthermore, coral growth rates themselves are poor indicators of reef health because growth rates often initially increase with nutrient dumping and land run-off (Koop et al. 2001; Wittenberg and Hunte 1992). Thus, other, more dynamic, taxonomic groups with shorter turnover times, e.g., algae and sponges, may express the effects of pollutants on a reef site in a time frame more feasible for study.

Areas of high nutrient addition often experience increased algal growth rates, which can be detrimental to corals, either by competition for growth and recruitment space or by blocking vital sunlight from reaching the coral (Marszalek 1981; Steneck 1997). High sedimentation, eutrophication, and overfishing of reefs may also reduce the settlement and recruitment of grazers, thereby promoting higher algal cover (Wittenberg and Hunte, 1992; Richmond et al. 2007). Reefs degraded by nutrient over-enrichment often exhibit “phase shifts” from abundant coral to abundant macroalgae (McCrook 1999; Szmant 2002). These observations may be used as early warning signals of reef health degradation.

Heterotrophic sponges may also represent an early warning signal for organic pollution of coral reefs (Wilkinson and Cheshire 1990). Evidence exists that sponge biomass is higher in nutrient-rich waters compared to oligotrophic waters (Wilkinson 1987; Wilkinson and Cheshire 1990). Tomascik and Sander (1985) found the east coast of Barbados, which experiences strong oceanic influences, has a significantly lower biomass of sponges compared to the west side of the island, which is exposed to high levels of nutrients from anthropogenic discharge. Aerts (1998) found that sponges overgrow corals to a greater degree where coral cover is low, suggesting that dying or degraded reefs with reduced living coral cover may be susceptible to increased overgrowth by sponges. These studies suggests that sponge abundance and biomass are related to nutrient availability, water quality, and overall reef health, and have implications for coral reef impact studies and monitoring.

In Broward County, Florida, USA, Port Everglades may be a source of many anthropogenic contaminants, including nutrients and other pollutants carried in freshwater from coastal runoff, which extend in an ebb-tidal plume that sweeps over the adjacent coastal reef (Fig. 1). What direct effects these contaminants may have on adjacent reef life is hypothesized; however, direct studies on the effects of effluent from Port Everglades inlet are limited. This paper examines macrobenthic data collected from two nearshore community assessment studies in Broward County. These data are used to evaluate the effects of proximity of reef biota to a major navigational inlet and identify potential bioindicators of stress on the reef system.

Figure 1: Satellite image of Port Everglades inlet effluent plume (image courtesy of Richard Dodge, National Coral Reef Institute).

Materials and Methods

Monitoring design

Results from two separate studies were combined. The first study (Study 1, Craft 2006) assessed the percent cover of macroalgae and sponge at seven nearshore sites immediately south of Port Everglades inlet. Preliminary results from Study 1 indicated that coral abundance within the study area is highly variable, and primarily dictated by variations in substrate type and availability rather than any existing water quality gradients; thus, other, more dynamic taxonomic groups, e.g. macroalgae and sponges, are examined here. Site placement was based on prior water quality surveys and thermograph stations used by Broward County Environmental Protection Department (BCEPD) (BCEPD, 2007). Sites were numbered from south to north, starting at BCEPD Thermograph Station JUL6. Each site consisted of three shore-parallel 30-m transects. A $0.25m^2$ x $0.25m^2$ quadrat was placed every other meter for a total of 45 quadrats per site, and 2.81 m^2 of area surveyed.

Water quality parameters were also measured during Study 1. A YSI data-sonde was used to measure specific conductivity (as a proxy for salinity). The probe was lowered haphazardly within the inlet plume over the general study area. Vertical readings were taken at these locations with the sonde, from surface to bottom in order to observe changes in specific conductivity with depth, implying a gradation in salinity with depth. Water samples were also taken from select areas across the influence of the plume and analyzed for chlorophyll *a* and nutrients: total phosphorus, nitrites and nitrates (NO_2+NO_3), and Total Kjeldahl nitrogen (TKN).

The second study (Study 2) was conducted as a pre-construction survey for the Segment III Broward County Beach Renourishment Project. Twenty-one transects were surveyed south of Port Everglades inlet to the southern Broward County boundary using the Benthic Assessment for Marginal Reefs (BEAMR) method (Lybolt and Baron 2006). A $0.5m^2$ x $0.5m^2$ quadrat was placed every 2.5 meters along a 30-m transect for a total of 12 quadrats per transect, and 3.0 m^2 of area surveyed. Sponge and macroalgae percent cover data were extracted from this data set and combined with data from Study 1 for analysis.

Data analysis

Benthic coverage data were first standardized for amount of hardbottom sampled (i.e. eliminating sediment cover). Data were then fourth-root transformed and compared, using linear regression, against distance from the inlet (latitude; dd.ddd) to determine if trends exist relative to the location of Port Everglades inlet.

Linear regression was also used to examine specific conductivity relative to distance from the inlet, and plotted against latitude (dd.ddd) and depth (m) to create vertical and surface-planar descriptions of the inlet plume and associated salinity "wedge". Chlorophyll *a* measured from grab samples was examined against specific conductivity in the same manner.

Results

Benthic cover

After standardizing for amount of hardbottom sampled, macroalgae cover ranged from 1.4% to 54.0%. Standardized sponge cover ranged from 0.1% to 2.7% (Table 1).

Table 1. Macroalgae and sponge cover (percent) standardized for amount of hardbottom sampled.

Study	Site	Latitude	Standardized Macroalgae	Standardized Sponge
2	88a	26.0868	27.9	1.1
1	7	26.0819	41.4	0.5
1	6	26.0813	33.6	0.6
2	90a	26.0813	27.4	0.5
1	5	26.0808	8.4	0.2
1	4	26.0803	8.3	0.4
1	3	26.0798	3.4	0.3
1	2	26.0793	9.1	0.4
1	1	26.0788	8.0	0.1
2	96a	26.0649	3.7	0.7
2	98a	26.0593	39.2	0.1
2	99a	26.0566	38.7	0.8
2	99b	26.0552	5.0	0.3
2	100a	26.0540	3.4	2.1
2	100b	26.0520	7.1	2.7
2	101a	26.0509	3.9	1.0
2	104a	26.0428	11.3	1.8
2	104b	26.0411	2.6	0.7
2	105b	26.0383	3.3	1.9
2	106a	26.0369	54.0	0.0
2	108a	26.0316	6.7	0.4
2	110a	26.0258	18.8	0.4
2	113a	26.0176	14.4	0.4
2	116a	26.0093	13.9	0.6
2	119a	26.0008	5.2	1.2
2	120a	25.9977	1.7	0.7
2	120b	25.9962	1.4	0.6
2	121b	25.9935	2.2	0.5
2	122a	25.9921	1.9	0.7
2	123a	25.9891	11.5	0.5
2	125a	25.9835	2.1	0.6
2	126b	25.9790	2.4	0.5

Regression results indicate a significant linear trend in macroalgae cover with proximity to the inlet ($p=0.002$; $R^2=0.275$) (Fig. 2). Regression results for sponge cover indicate no significant linear trend in the data exists ($p=0.373$; $R^2=0.027$).

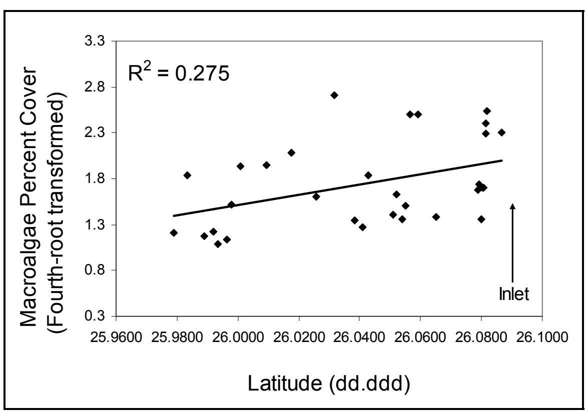

Figure 2. Regression of macroalgae cover (percent) standardized for hardbottom sampled, and fourth-root transformed, against distance from Port Everglades inlet (latitude; dd.ddd).

Water Quality Analysis

Parameters from water grab sample data near the inlet were plotted against latitude to demonstrate surface nutrient levels surrounding the inlet (Table 2; Fig. 3). Peak levels of nutrients can be observed immediately adjacent to the inlet, and dissipate with distance.

Table 2. Nutrient levels measured from grab samples taken at the surface within the inlet plume. *Denotes chlorophyll *a* sample not obtained at that location. Specific conductivity was measured at ~28°C.

Latitude	NO_2+NO_3	TKN	Total P	Chl *a*	Sp. Cond
dd	mgL^{-1}	mgL^{-1}	mgL^{-1}	μgL^{-1}	μScm^{-1}
26.08443	0.0244	0.959	0.0672	0.49	52900
26.08535	0.0305	0.535	0.0378	*	52500
26.086	0.0261	0.252	0.0366	0.81	51500
26.08712	0.165	0.648	0.039	1.06	53700
26.08783	0.0942	1.38	0.0555	*	48400
26.08867	0.0679	0.968	0.0433	*	45000
26.09117	0.0257	0.502	0.0256	*	50000
26.0920	0.061	0.461	0.0486	1.33	47100
26.0961	0.0772	1.15	0.0341	1.35	49100
26.09762	0.0736	0.692	0.0469	*	48600
26.0982	0.0266	0.812	0.0448	*	43700
26.10317	0.0296	0.746	0.0338	0.74	51200
26.10495	0.0622	1.43	0.051	*	48100

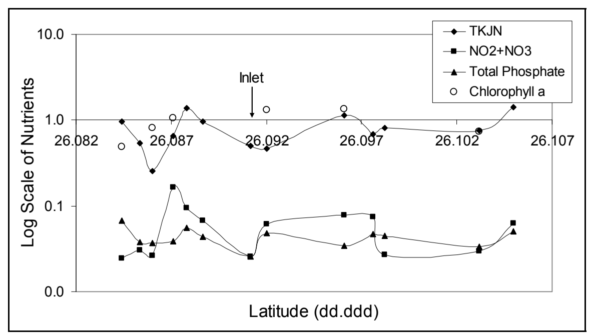

Fig. 3. Nutrient levels measured from plume water grab samples plotted against latitude across the mouth of Port Everglades inlet (log scale).

Figure 4 shows the vertical salinity gradient, or "salt wedge" in the waters immediately surrounding the inlet. Specific conductivity readings of surface water adjacent to the inlet were as low as 37,337 micro-Siemens per centimeter (μScm^{-1}), and increased as depth increased. Average oceanic conductivity ranges from 53,000-58,000 μScm^{-1} (measured between 25°C and 30°C). According to the figure, standard average ocean salinity is reached at approximately 3 m depth.

Figure 5 shows the change in surface salinity with latitude. This figure depicts the extent of the plume at the time of sampling and illustrates that specific conductivity is lowest adjacent to the inlet and increases with distance from the inlet to the north and south.

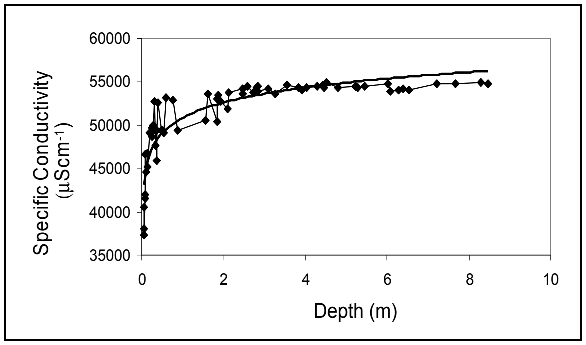

Figure 4. Vertical salinity gradient (measured as specific conductivity) across the mouth of Port Everglades inlet. Standard oceanic salinity is reached at approximately 3 m depth.

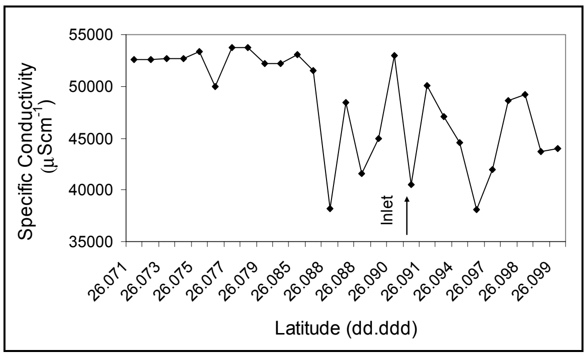

Figure 5. Change in surface salinity (measured as specific conductivity) surrounding the mouth of Port Everglades inlet with latitude. Salinity is lowest directly out from the inlet.

Regression results show that specific conductivity significantly decreases with proximity to the inlet ($p=0.0005$; $R^2=0.445$) (Fig. 6). Chlorophyll *a* was observed to increase with decreasing specific conductivity, though not significantly.

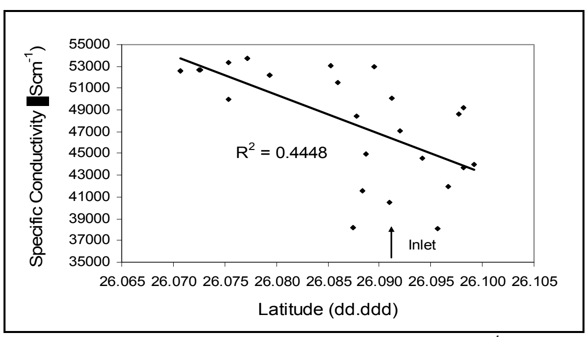

Figure 6. Regression of specific conductivity (μScm^{-1}) against distance from Port Everglades inlet (latitude).

Discussion

Because nutrients and other pollutants coming from the inlet are carried in a plume of lower-salinity water that flows as a surface “wedge” over the surrounding reef area, specific conductivity readings were used as a proxy indicator to map the approximate extent of the plume, both vertically and horizontally. The profile in Fig. 4 suggests that the plume sweeps out over the adjacent reef area at an angle influenced by the existing specific conductivity gradient (i.e. water of lower salinity will move over water of higher salinity). The combination of vertical specific conductivity profile and the general increase in surface specific conductivity with distance from the inlet (Fig. 5) suggest that benthos closer to the inlet and its discharge will be more strongly affected by the effects of lowered salinity. Lower-than-oceanic-salinity water has been proven detrimental to coral health (Linton and Warner 2003). According to Fig. 4, shallow reef areas near the inlet, especially at low tide, would be exposed to lower salinity and plume contaminants, since probe measurements do not reach normal seawater specific conductivity until approximately 3 m depth.

Abundance of inorganic nutrients in nearshore environments, particularly coral reefs, has a potentially strong influence on phytoplankton communities and trophic processes there, and has thus been recognized as a critical aspect of coastal management (Devlin et al. 2000). Dissolved nutrients in the marine environment are rapidly converted to particulate form and in turn rapidly recycled. Because of this, planktonic algae, specifically their chlorophyll *a*, have been used as a proxy indicator of nutrient abundance when monitoring water quality (Devlin et al. 1999; Linton and Warner 2003). Fig. 3 shows nutrient and chlorophyll *a* levels from grab samples highest around the mouth of the inlet, and chlorophyll *a* increased with decreasing specific conductivity (although the relationship between chlorophyll *a* and specific conductivity was not found to be significant). As specific conductivity was significantly correlated with proximity to the inlet, it appears that increased chlorophyll levels may be linked to low-salinity water, as well as increased levels of nutrients, being discharged from the inlet, although a larger sample size is desired for thorough chlorophyll *a* analysis. Though coral cover appears largely dictated by substrate variability in the nearshore area surrounding Port Everglades, corals growing near the inlet may be at risk of higher stress levels than those further from inlet influence. Heavy concentrations of phytoplankton in the water column over reefs as a result of nutrient addition may increase coral mortality due to competition for light and effected production/respiration (P/R) ratios (Marszalek 1981; Yentsch et al. 2002).

Although sponge cover was not significantly correlated with distance from the inlet, benthic macroalgae significantly increased with proximity to the channel. Water samples from each monitoring site were not obtained for nutrient measurements; however, Fig. 3 suggests that this increase in macroalgae is due to increased nutrient availability near the inlet. Reefs experiencing nutrient addition often exhibit a shift from abundant coral to abundant macroalgae (McCrook 1999; Szmant 2002).

Although coral cover within the study areas was not significantly correlated with distance from the inlet, nearshore stony coral cover throughout Broward County south of Port Everglades inlet is naturally low, likely due to stochastic events such as hurricanes and tropical storms that frequently bury portions of the nearshore hardbottom (Prekel et al. 2008). Thus the coral-depauperate area of the nearshore benthic habitat in Broward County should be treated as a reef habitat continually under stress from natural stochastic events, as well as pollution, coastal construction and other physical impacts, and managed appropriately.

When examining the extent of the inlet plume and its influence on the surrounding benthic area, specific conductivity was found to be a reliable proxy for delineating the extent of inlet effluent plume, and abundance of benthic macroalgae and chlorophyll may be indicators of nutrient addition to the area.

It is the conclusion of these studies that Port Everglades is a source of low-salinity water, and may be discharging pollutants that can cause localized increases in phytoplankton and macroalgae abundance, all of which may be detrimental to the benthic ecology of the surrounding nearshore reef. However, lack of long-term records of variations in water quality and plume distribution make concrete determinations difficult. It is suggested here that continued benthic monitoring, as well as further water quality monitoring in proximity to Port Everglades, are needed in order to establish a more thorough analysis of the effects of inlet discharge on the surrounding nearshore reef habitat, and to make accurate predictions of changes to the habitat in the face of on-going coastal impacts.

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