

# Changes in spectral reflectance in response to salinity variation in *Siderastrea radians* from Florida Bay, Florida USA

M.J. Durako<sup>1</sup>, K.M. Chartrand<sup>1</sup>

1) The University of North Carolina Wilmington, Department of Biology and Marine Biology, Center for Marine Science, 5600 Marvin Moss Ln, Wilmington, NC 28409 USA

**Abstract.** Spectral reflectance ( $R$ ) of coral reefs is an apparent optical property that is widely used to distinguish these communities in remote sensing assessments. In this study  $R$ 's of *Siderastrea radians* collected from five basins in Florida Bay were measured at the termination of a 2-week salinity (30, 20, 15, 10) versus population mesocosm experiment. The five basin populations represented a spatial and freshwater-land influence gradient from northeast (estuarine-to-hypersaline) to southwest (marine) Florida Bay. Spectral reflectances generally increased with decreased salinities with the greatest increases occurring in the more marine populations. The marine populations also exhibited the "brown" reflectance spectra mode while the more estuarine populations exhibited predominantly "blue" reflectance spectra. Two of the interior basin populations exhibited spectral shifts from "blue" to "brown" in response to low salinity treatments. Non-metric multidimensional scaling analyses indicated stronger salinity-based versus population-based clustering of the reflectance spectra. Thus, while coral  $R$  may be independent of taxonomic or geographic differences, reduced salinity does affect this parameter in *S. radians* from this marginal coral habitat.

**Key words:** Spectral reflectance, salinity, *Siderastrea*.

## Introduction

The health of corals may be assessed using a number of metrics (i.e., growth, reproduction, metabolism, etc.), but loss of zooxanthellae or their pigments is the only remotely detectable measure of coral health because of the resulting changes in their spectral reflectance (Holden and LeDrew 1998, 2001). Spectral reflectance ( $R$ ) of corals is an apparent optical property that is also widely used to distinguish these communities and monitor their status in remote sensing assessments (Green et al. 1996; Karpouzli et al. 2004). The magnitude and shape of coral  $R$  spectra are generally distinct from other benthic communities and bare sediments (Hochberg and Atkinson 2000), but independent of within-coral geographic and taxonomic differences (Hochberg et al. 2004). There are generally two spectral shapes of coral  $R$ , the "brown" mode, which is determined by zooxanthellae pigment absorption, and the "blue" mode, which includes expression of a coral host pigment. Reflectance spectra of stressed or bleached corals are generally higher and optically different than those of healthy corals, due to the loss of zooxanthellae pigments (Holden and LeDrew 1998).

*Siderastrea radians* (Pallas) Blainville is a hardy coral found throughout the tropical western to eastern Atlantic and Caribbean region that inhabits so-called

marginal habitats away from characteristic reef communities (Veron 2000). In Florida Bay, this species occurs in areas of little sediment and low abundance of seagrasses (Figure 1). Concern over the long-term health of the Florida Bay ecosystem and the adjacent Everglades led to the Comprehensive Everglades Restoration Plan (CERP). One of the primary goals of CERP is to restore estuarine conditions in the Bay by increasing the quantity and quality of freshwater entering Florida Bay, which will lower salinities. The effects of reduced salinity on coral communities within Florida Bay have largely not been considered. Coral stress or bleaching may occur in response to decreases in salinity (Hoegh-Guldberg 1999), thereby affecting  $R$ .

In this study  $R$ 's of *Siderastrea radians* collected from five basins in Florida Bay were measured at the termination of a 2-week salinity (30, 20, 15, 10) versus population mesocosm experiment designed to examine the salinity tolerance of this species. The five basin populations examined represented a spatial and freshwater-land influence gradient from northeast (estuarine-to-hypersaline) to southwest (marine) Florida Bay (Figure 1). The experimental salinities were chosen to encompass the range of salinities that occur across these five basins.

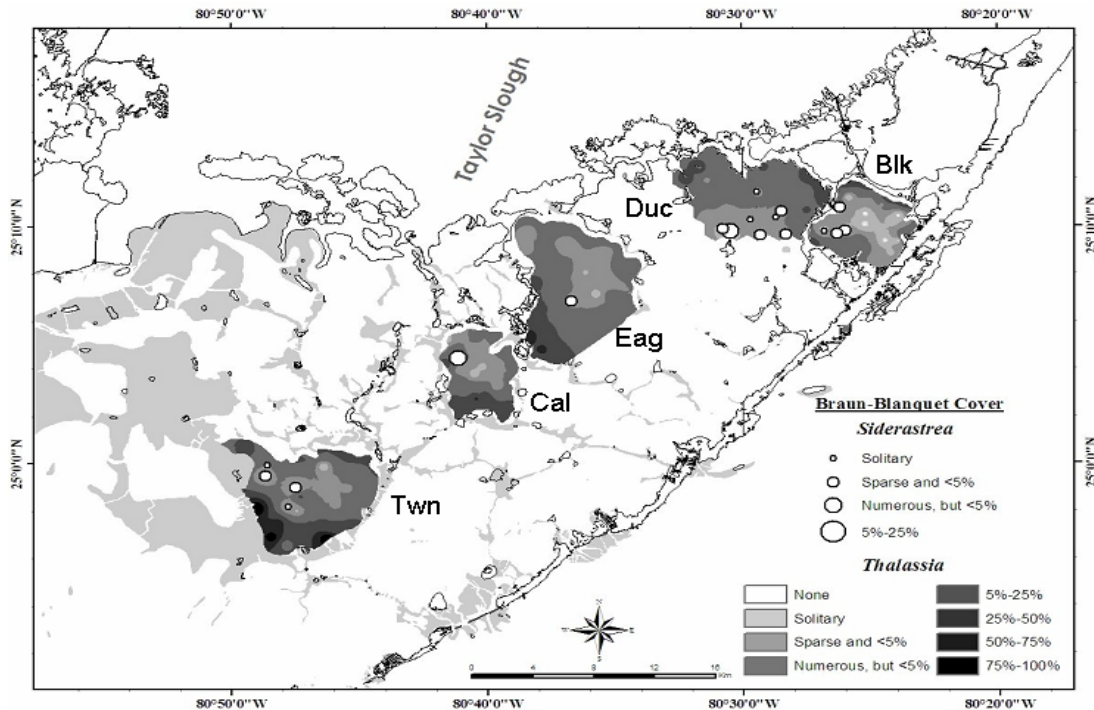


Figure 1 Distribution of *Siderastrea radians* and *Thalassia testudinum* in Florida Bay.

### Materials and Methods

During Fall 2006 Fish Habitat Assessment Program (FHAP) field surveys, sixteen *S. radians* colonies ( $\leq 3$ -5 cm in diameter) were collected per basin from locations where the highest colony densities were previously observed. The five sampled basins, from northeast to southwest, were Blackwater Sound (Blk), Duck Key (Duc), Eagle Key (Eag), Calusa Key (Cal) and Twin Key (Twn) Basins (see Figure 1). Colonies were transported to the greenhouse at the University of North Carolina Wilmington, Center for Marine Science (CMS), Wilmington, NC overnight. Care was taken to ensure colonies were never removed from seawater and that temperatures and salinity were maintained under near-ambient field conditions.

Colonies were placed in 40-l aquaria filled with high quality seawater and containing gravel-bed filter aeration systems. One colony per basin was randomly chosen and placed in each of 16 aquaria. Location was randomly assigned yet placement ensured that a colony from each basin was in each tank position at least twice. After one week acclimation at a salinity of 30 (the average salinity  $\pm 1$  at collection sites), target treatment salinities of 10, 15, 20, and 30 (controls) were assigned to each of 16 aquaria ( $n=4$ , level of replication is the tank). Salinities were decreased daily by adding distilled water to experimental tanks to drop salinity at a rate of  $2 \text{ day}^{-1}$ . This rate of change was chosen to represent a realistic drop in salinity in the Bay during flushing and/or rainfall events (Kahn

and Durako 2005, 2006). We measured  $R$  of the dorsal surface for all coral colonies 4 days after the lowest salinity treatment target was reached.

Reflectance (bi-directional) is the fraction (%) of downwelling radiance that reflects upward as a function of wavelength ( $\lambda$ ) [ $R(\lambda) = L_u(\lambda)/L_d(\lambda)$ ]. Radiance measurements employed an Ocean Optics USB2000 fiber optic spectrometer coupled to a 400  $\mu\text{m}$  diameter UV-VIS reflection probe (Ocean Optics QR400-7-UV-VIS). To measure upwelling radiance [ $L_u(\lambda)$ ], the probe was positioned 1 cm above the coral dorsal surface at a  $45^\circ$  zenith angle (Hochberg and Atkinson 2000). Immediately following, downwelling radiance [ $L_d(\lambda)$ ] was measured using a Spectralon diffuse reflectance target (Ocean Optics WS-1) placed adjacent to, and in the same plane as, the coral. It was assumed that the Spectralon target is Lambertian (i.e., reflects light equally in all directions).

### Results

Reflectance spectra for the control treatment corals (salinity 30) exhibited a brown mode triple-peaked pattern (570, 600 and 650 nm) for the Blackwater Sound, Calusa Key and Twin Key Basin populations and a blue mode plateau between 600 and 650 nm in the more interior Duck and Eagle Key Basin populations (Figure 2, *sensu* Hochberg et al. 2003). Spectral reflectances generally changed little or increased slightly at the decreased salinity of 20, with

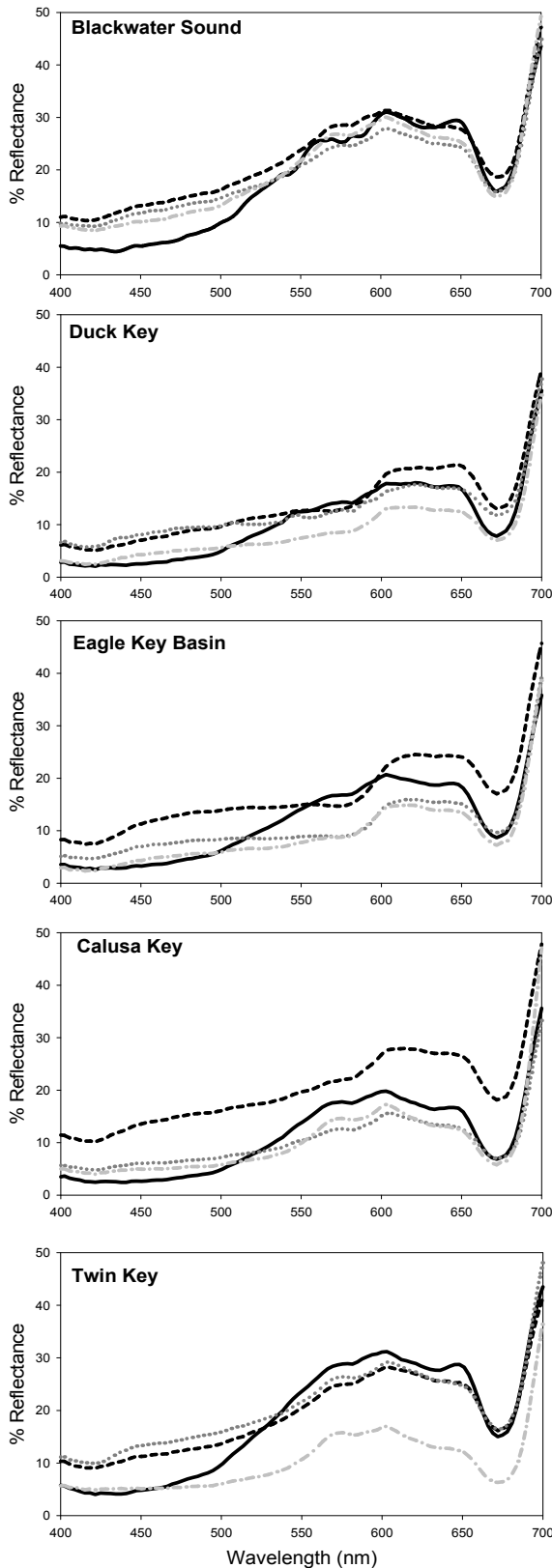


Figure 2. Reflectance spectra of *S. radians* from 5 Florida Bay basins in four salinity (10=black solid, 15= black dash, 20=grey dots, 30=grey dot-dash) treatments (n=4).

the greater increases in  $R$  occurring in the 15 and 10 salinity treatments. At the lowest treatment salinity (10), reflectance patterns were quite distinctive spectrally and exhibited differing population patterns. For all five populations, reflectance was generally lowest in the salinity 10 treatment at wavelengths <500 nm, but was highest at wavelengths >500nm for the most marine populations (Twin Key Basin).  $R$  was relatively high across PAR in the salinity 15 treatment for the three interior basin populations (Duc, Eag, and Cal, Fig. 2). Two of the estuarine basin populations (Eagle & Calusa) exhibited spectral shifts from blue mode  $R$  in response to changes in salinity.

Non-metric multidimensional scaling analyses indicated that reflectance spectra exhibited similarities based on treatment salinity, with high- (30), intermediate- (20 and 15) and low-salinity (10) groupings (Figure 3). There was generally weak population-based clustering. The exception was the Blackwater Sound population which exhibited highly-similar reflectance spectra across all salinity treatments, except 10 (Figures 2 and 3).

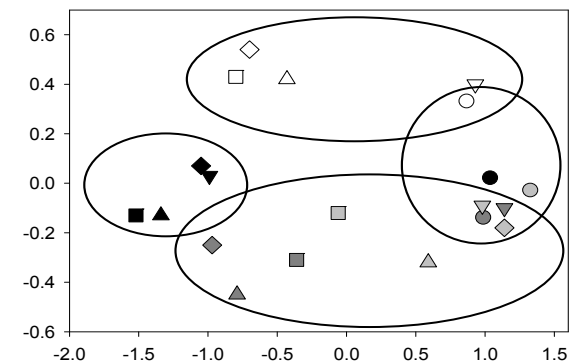


Figure 3. Two-dimensional MDS ordination of reflectance spectra similarity matrices among five populations (●=Blk, ■=Duc, ▲=Eag, ◆=Cal, ▼=Twn) of *S. radians* exposed to four salinity treatments (white=10, light grey=15, dark grey=30, black=30).

### Discussion

The magnitude and spectral shape of coral spectral reflectance ( $R$ ) are determined by absorption and fluorescence of several pigments localized in both the zooxanthellae and the host tissues (Hochberg et al. 2004). Healthy corals are optically dark and generally exhibit low  $R$  between 400-500 nm, increasing from 500-650 nm with a narrow chlorophyll absorption feature near 675 nm, then rapidly increasing at wavelengths greater than 680 nm (Holden and LeDrew 1998; Hochberg et al. 2004). Changes in environmental factors, such as temperature or salinity, may cause decreases in various pigment concentrations or expulsion of zooxanthellae from the coral host leading to spectral shifts and an overall increase in  $R$ . Thus, spectral distinctions between

healthy and non-healthy corals can be based on changes in the shape and magnitude of reflectance (Holden and LeDrew 1998, 2001).

Changes in  $R$  of *Siderastrea radians* from Florida Bay in response to experimental step-wise decreases in salinity indicate a high tolerance to hyposalinity stress, with a tolerance threshold between salinities of 10 and 15. Coles and Jokiel (1992) state that salinities below 15 sustained for more than two days will lead to coral mortality. That does not seem to be the case here as our measurements were obtained after four days at salinity 10 and six days at salinity 15. Other coral species from coastal environments with fluctuating salinities, similar to Florida Bay, have also demonstrated tolerance to reduced salinities (Marcus and Thornhaug 1981, Muthiga and Szmant 1987, Manzello and Lirman 2003). *Siderastrea radians* from Blackwater Sound exhibited almost no change in  $R$  until salinity of 10 was reached and mainly below 500nm.  $R$  was elevated across PAR in the salinity 15 treatment for the two most interior basins (Eag and Cal). Blackwater Sound is a diverse basin with widely fluctuating salinities due to the influences of freshwater inflow from the Everglades via the C-111 canal and oceanic influences due to several cuts connected to the Atlantic Ocean (Hackney and Durako 2004). The small increases in  $R$  with decreasing salinities in the other four populations do suggest some loss of zooxanthellae pigments, but no bleaching of the colonies was observed. In addition, chlorophyll fluorescence measurements ( $F_v/F_m$ ) indicated symbiont health was not acutely affected by decreasing salinities until a threshold was reached between salinities of 10 and 12, a salinity drop of roughly 20 from ambient (Chartrand 2008).

Different populations of *S. radians* across Florida Bay exhibited differing modes of  $R$ . At high salinity, three populations exhibited the brown mode  $R$  and the two most interior populations exhibited the blue mode  $R$ . Zooxanthellae pigments are responsible for the 575 nm peak characteristic of brown mode  $R$  (Hochberg et al. 2003). Coral-host pigments are thought to have strong absorbance in the 560-570 nm region leading to a loss of the 575 nm peak and production of a plateau-like shape from 600-650 nm that is characteristic of the blue mode  $R$ . Many coral taxa exhibit both blue- and brown-mode  $R$  that depend on the concentration of the coral-host pigmentation relative to that of the zooxanthellae (Hochberg et al. 2004). The shifts from “blue” or “brown” spectral shapes of  $R$  with decreasing salinities in two of the more estuarine populations that we sampled may indicate differing among-population salinity tolerances between the zooxanthellae and the coral host for *S. radians* occurring in different basins across Florida Bay. Thus, while coral  $R$  may be independent

of taxonomic or geographic differences, reduced salinity does affect this parameter in *S. radians* from this marginal coral habitat and thus may provide a non-invasive metric for the health of this species within Florida Bay.

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