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Production of chromophoric dissolved organic matter from mangrove leaf litter and floating *Sargassum* colonies

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ABSTRACT

Chromophoric dissolved organic matter (CDOM) strongly absorbs solar radiation in the blue-green and serves as the primary attenuator of water column ultraviolet radiation (UV-R). CDOM interferes with remote sensing of ocean chlorophyll and can control UV-R-induced damage to light-sensitive organisms including corals. We used laboratory incubations to evaluate CDOM production from senescing *Rhizophora mangle* (red mangrove) leaf litter (yellow, orange, and brown) and floating *Sargassum* colonies. Mangroves exist at the land–ocean interface near coral reefs in sub-tropical and tropical regions while floating *Sargassum* colonies tend to congregate in sub-tropical ocean gyres. CDOM production (~48 h) from mangrove leaves collected during a dry period in June 2004 ($0.17 \pm 0.11\ m^{-1}\ g^{-1}\ l\ h^{-1}$) was lower than production from leaves collected during a wet period in September 2003 ($0.57 \pm 0.42\ m^{-1}\ g^{-1}\ l\ h^{-1}$) suggesting that CDOM production from leaf litter fluctuates in response to environmental factors. CDOM production was greatest for the mid-senescence orange leaves and lowest for the severely senesced brown leaves in both experiments. Along the sub-tropical Florida Keys coral reef ecosystem, the primary source of CDOM is discharge from the shallow seagrass-dominated Florida Bay as evidenced by a strong correlation between field CDOM measurements and previously reported Florida Bay discharge volumes. However, field observations provide evidence that large expanses of red mangroves throughout the Keys could be important CDOM sources to the region's coral reefs during periods of reduced Florida Bay discharge. Floating *Sargassum* colonies also readily produced CDOM in laboratory incubations, but at much more variable rates than mangrove leaves. However, our calculations indicate that large mats of floating *Sargassum* could provide important CDOM quantities to oligotrophic oceanic waters including the Gulf of Mexico and North Atlantic.

1. Introduction

Chromophoric dissolved organic matter (CDOM) strongly absorbs ultraviolet wavelengths within the solar radiation spectrum and serves as the primary attenuator of UV-R in oceanic waters (Blough and Del Vecchio 2002; Nelson and Siegel 2002; Tedetti and Sempere 2006). CDOM also absorbs wavelengths in the visible light region, especially blue wavelengths, and thus interferes with the remote sensing of chlorophyll (Coble 2007; Siegel et al. 2002). Because CDOM strongly absorbs solar UV-R, it can serve as a natural sunscreen to UV-R-sensitive organisms. Corals are especially susceptible to UV-R-induced damage because they grow in shallow, UV-R transparent tropical waters where their symbiotic zooxanthallae can attain sufficient sunlight for photosynthesis. Extended exposure to UV-R causes DNA damage and photoinhibition in corals and can lead to coral bleaching (Baker et al. 2008; Lesser 2000). A variety of other sub-tropical and tropical marine organisms have also been shown to be sensitive to UV-R damage (Hallock et al. 2003). Because of the sensitivity of organisms to UV-R and the need for assessing global oceanic productivity using satellites, it is essential to understand the sources and cycling of CDOM in sub-tropical and tropical ocean waters.

River discharge of degraded terrestrial vegetation provides a substantial pool of CDOM to many temperate and sub-tropical coastal ocean regions (Del Castillo et al. 2000; Kowalczuk et al. 2003; Nelson et al. 2007). In sub-tropical and tropical coastal waters, seagrasses are often primary sources of CDOM (Otis et al. 2004; Stabenau et al. 2004). Another potentially important CDOM source to sub-tropical and tropical coastal regions is mangrove leaf litter (Maie et al. 2006; Scully et al. 2004). On a global scale, organic matter export from tropical mangrove expanses comprises >10% of the terrestrial organic matter pool in oceanic waters (Dittmar et al. 2006; Jennerjahn and Ittekkot 2002), so the potential exists for mangroves to provide an important fraction of the CDOM pool to the global ocean as well as to tropical reef environments.

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CDOM appears to be the primary regulator of solar-induced UV-R damage for corals in the Caribbean and Florida Keys (Otis et al. 2004; Zepp et al. 2008). In the Florida Keys, CDOM accounts for approximately 90% of the UVB and 80–85% of the UVA attenuation with absorption and scattering of UV-R by particles being comparatively small (Zepp et al. 2008). Further, UV irradiances experienced by corals are more influenced by CDOM fluctuations than by changes in atmospheric ozone concentrations (Zepp et al. 2008). The optical characteristics of CDOM along the Florida Keys exhibit a strong seasonal signal with lowest spectral slope coefficients ($S_{325–400}$) occurring during wet summer months (Zepp et al. 2008), suggesting seasonal transitions in CDOM sources to this reef ecosystem. To this point, however, the potential role of mangroves in supplying CDOM to this and other sub-tropical and tropical reef environments has not been thoroughly evaluated.

In the Gulf of Mexico and central North Atlantic Ocean, lines of floating *Sargassum* are sometimes large enough to be visible on satellite imagery (Gower et al. 2006), and thus may provide a key CDOM source that has not been previously reported. Nelson et al. (2004) reported a local microbial CDOM source in Sargasso Sea waters and Steinberg et al. (2004) reported CDOM production by zooplankton and cyanobacteria in the open ocean, but neither study recognized the potential importance of *Sargassum* CDOM production in open ocean waters. Large mats of floating *Sargassum*, common near the Keys fringing reef tract, may also be an important source of CDOM to sub-tropical and tropical ocean waters.

In this study, our primary objective was to evaluate the production of CDOM from *Rhizophora mangle* (red mangrove) leaf litter and floating *Sargassum* colonies. We also further investigated the importance of the shallow seagrass-dominated Florida Bay as a CDOM source to Florida Keys coastal waters. Although our study focused on providing information on CDOM sources in the Florida Keys, it provides information on *Sargassum* CDOM production that is useful for remote sensing and open ocean biogeochemistry studies as well as information on mangrove CDOM production applicable throughout tropical coral reef environments.

2. Methods

2.1. Site description and water sampling

The Florida Keys are generally divided into three regions: Upper Keys, Middle Keys, and Lower Keys. The Lower Keys begin westward of Seven Mile Bridge and are the focus of this study (Fig. 1). Many of the islands in the Lower Keys are fringed with *R. mangle* expanses, the dominant mangrove in this sub-tropical habitat. Seven Mile Bridge serves as the primary exchange channel for Florida Bay water and the generally southwestward flow of Hawk Channel delivers and disperses Florida Bay discharge across nearshore patches of coral reefs and the offshore fringing coral reef tract of the Lower Keys. Tidal oscillations and seasonal flow patterns impart substantial variability in the optical characteristics of waters in this region (Zepp et al. 2008). As part of this study, CDOM samples were collected at stations throughout the lower Keys over the period 2003–2006 (Zepp et al. 2008). More information on the sampling regime and study sites can be found in Zepp et al. (2008) and Stabenau et al. (2004).

2.2. CDOM production experiments — mangrove leaf litter

The production of CDOM, defined as the absorption coefficient at 305 nm for this study (a_{305} in m^{-1}), from the leaves of *R. mangle* was examined in laboratory incubation experiments. Mangrove leaves from three stages of senescence were collected in September 2003 and June 2004 from sites near Summerland Key in the lower Florida

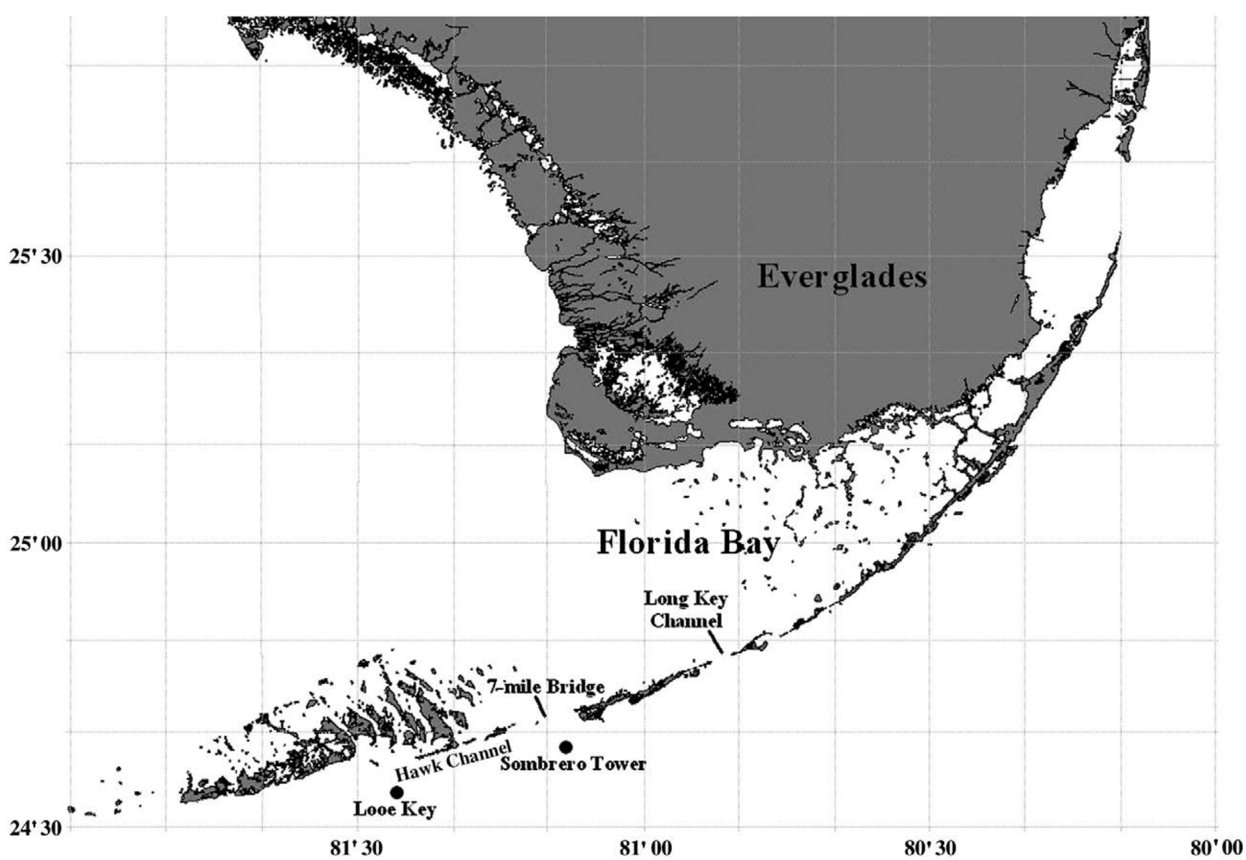

Fig. 1. Map of study location in Florida Keys. 7-Mile Bridge and Long Key Channels are the primary exchange points between Keys coastal waters and Florida Bay. Looe Key and Sombrero Tower are located along the fringing reef line. Hawk Channel transports water generally southwestward between the Keys islands and the fringing reef tract.