Marine Pollution Bulletin 121 (2017) 323–330

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Response of the seagrass *Halophila ovalis* to altered light quality in a simulated dredge plume

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ARTICLE INFO

Keywords:
Dredging
Seagrass
Light quality
Light quantity

ABSTRACT

Seagrass meadows are globally threatened, largely through activities that reduce light quantity (photosynthetic photon flux density) such as dredging. However, these activities can simultaneously alter the spectral quality of light. Previous studies showed that *Halophila ovalis* seagrass productivity is reduced under monochromatic yellow/green light, wavelengths associated with dredge plumes, but it is unclear how they respond to spectra produced by real dredging projects. We simultaneously subjected adult *H. ovalis* plants to altered light quality and quantity simulating a real commercial dredging operation (15 mg L^{-1} TSS, 50 and 200 μmol photons $m^{-2}\,s^{-1}$). There was a significant effect of reduced light quantity on physiological and morphological variables and a significant effect of light quality on the pigment antheraxanthin. The lack of effect of light quality on growth indicates that while seagrass are sensitive to changes in light quality, natural- and anthropogenic-driven changes may not always be sufficient to produce strong effects on *H. ovalis*.

1. Introduction

Seagrasses commonly occur in estuaries and shallow coastal zones, where they provide significant ecosystem functions and services that rival tropical rainforests and coral reefs (Orth et al., 2006; Barbier et al., 2011; Fourqurean et al., 2012). These include habitat for commercially important juvenile fish (Bertelli and Unsworth, 2014), cycling of nutrients (Marbà et al., 2007), stabilizing sediments (Koch et al., 2006), and storage of organic carbon (Orth et al., 2006; Lavery et al., 2013). Seagrasses require high levels of light for survival (Longstaff, 1999) and their global decline has been attributed primarily to human activities that alter light, such as eutrophication, sediment loading and dredging (Erftemeijer and Robin Lewis, 2006; Orth et al., 2006; Waycott et al., 2009). While the effects of reduced light quantity on seagrasses are well documented (Ralph et al., 2007; McMahon et al., 2013), effects of the associated changes in spectral quality are unclear and have been identified as a crucial knowledge gap within the seagrass literature (York et al., 2016).

Only one study of the few investigating seagrass responses to changes in light quality, used yellow and green light, the wavelengths associated with dredging (Strydom et al., 2017). Here, plants were grown under narrow wavebands of light at a constant above- saturating light intensity. *Halophila ovalis* adult plants grown in monochromatic yellow and green light had lower below-ground productivity than plants grown in full-spectrum light but seed germination was enhanced in yellow light compared to green, and seedling survival under yellow light was not significantly impacted (i.e. did not differ to full-spectrum treatments). This study confirms that seagrasses do respond to different wavelengths of light, but there is a limited understanding of what drives these responses, and how species respond to interactive effects of changes in light quality and quantity. Seagrass responses to reduced photosynthetic photon flux density (PPFD) include changes to chlorophyll (chl) content, carbohydrates, productivity, leaf area and shoot density (Ralph et al., 2007). Therefore, it is reasonable to expect an interactive effect of altered light quality and reduced light quantity on seagrasses as it has been reported for understory species in terrestrial forest which receive reduced quantity and a green-enriched quality of light (as the upper foliage absorbs blue and red light) (Folta and Maruhnich, 2007). Plants can respond to this under-canopy light by altering their physiology, morphology and reproductive responses, e.g. the shade-avoidance response (Neff et al., 2000).

Both the quality and quantity of light in aquatic ecosystems will vary simultaneously due to a number of factors. For suspended particles, such as sediments and phytoplankton, changes in benthic light quality are dependent on the optical properties of the suspended particles (Kirk, 1994), and the concentration of those suspended particles

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http://dx.doi.org/10.1016/j.marpolbul.2017.05.060
Received 5 December 2016; Received in revised form 19 May 2017; Accepted 22 May 2017

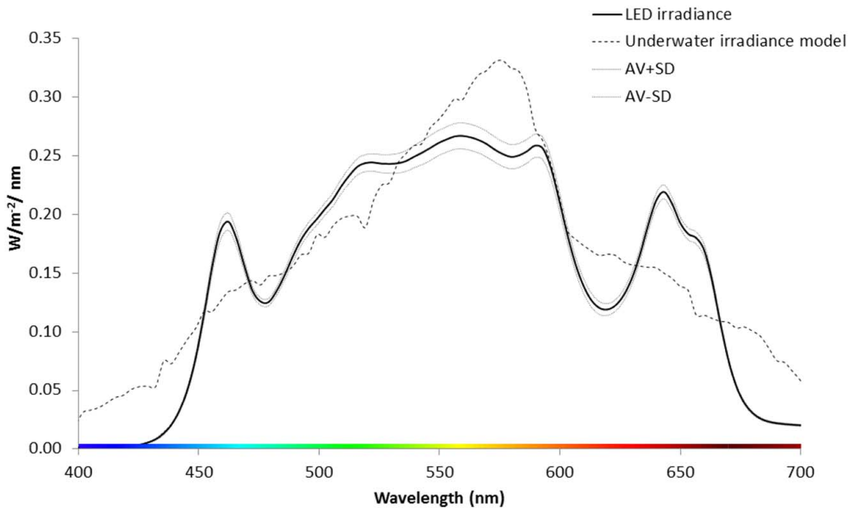

Fig. 1. The underwater downwelling irradiance model (dashed line) was used to create the "dredge spectrum" LED irradiance output (solid black line) based on a dredge plume near Onslow, Western Australia with a measured TSS of 15 mg L^{-1} at 3 m depth. Average (AV) ± SD irradiance spread across light module 30 cm below lights.

(total suspended solids or TSS). Dredging, and other processes that introduce turbidity, will have the dual effect of reducing the PPFD and simultaneously altering light quality (Jones et al., 2016). The amount of light reduction is dependent on the density of the plume, as is the spectral shift, with shifts towards green light at low plume densities and towards yellow (~490 nm) with increased suspended sediment loads (Chartrand et al., 2012). These changes will also be related to the distance from the dredging operation, with highest TSS concentrations occurring close to dredging activities (near-field) but decreasing with distance (i.e. in the far-field) (Jones et al., 2016). The effects of light quality may manifest with increasing distance from the plume, in areas where light quantity is not below minimum light requirements (i.e. PPFD) required to maintain plant survival.

In this study we assessed whether *H. ovalis* responds to shifts in light quality and quantity typical of those produced by real dredge plumes. We tested the interactive effect of reduced quantity (2 levels: 50 and 200 μmol photons m^{-2} s^{-1}) and altered spectral quality (2 levels: simulated dredge spectrum and full-spectrum) on the physiology, productivity and morphology of the widespread seagrass *H. ovalis*. Specifically, we hypothesised that a) physiological adjustments would occur under low light treatments (e.g. increased chl *a* concentration) to enhance light capture, and in addition, b) reduced below-ground productivity would be evident in plants grown under the dredge spectrum (yellow-green shifted spectral quality), and c) an interactive effect of both factors.

2. Methods

2.1. Experimental design and set-up

Adult *H. ovalis* plants were subjected to two fixed factors in a fully orthogonal design: 'Light quality' (provided at two levels: control and dredge spectrum) and 'Light quantity' (provided at high 200 μmol photons m^{-2} s^{-1} and low 50 μmol photons m^{-2} s^{-1} PPFD). The light quantity of 200 μmol photons m^{-2} s^{-1} has been used to successfully grow *H. ovalis* (Strydom et al. 2017; Hillman et al., 1995) and was similar to that measured at canopy height at the site used to collect plants for the experiment (230 μmol photons m^{-2} s^{-1} measured at 11:00 AM). The low light quantity treatment (50 μmol photons m^{-2} s^{-1}) has previously induced lower growth rates in *H. ovalis* (Hillman et al., 1995; Kilminster, 2006). The light quality treatments mimicked a full-spectrum sunlight (control) and far-field dredge sediment plume conditions, as identified from TSS data measured over seagrass meadows during a commercial dredging operation near Onslow, Western Australia (TSS data provided by Mark Broomhall, CSIRO). The sediment concentration of 15 mg L^{-1} was entered into an empirical spectral irradiance model developed for dredge conditions in the region around Onslow to generate an expected spectral light availability at a depth of 3 m (spectrum developed by Dr. Mathew Slivkoff, In-situ Marine optics). This spectrum was chosen because it reflected a far-field dredging plume of moderate TSS concentrations and at a depth that seagrasses typically occur at. Using light characteristics from plumes with much higher TSS concentrations would drastically reduce light intensity, and therefore inhibit our ability to detect an effect of light quality on seagrasses, as the light quantity would be below that required to sustain plant growth. The treatment therefore represents a plume spectrum suitable for studying sub-lethal effects of altered light quality and quantity on *H. ovalis*.

For each combination of factors and levels, four replicate aquarium tanks were established (total $n = 16$ independent glass tanks). Light quality treatments were provided through aquarium Light Emitting Diode (LED) Grow 8 modules (MarinTech Pty Ltd). For the control light quality treatments, the LED modules were customised to a spectrum similar to full sunlight. The dredge spectrum LED modules were customised at In-situ Marine Optics Pty Ltd. (Bibra Lake, Western Australia) by altering the LED configuration and the addition of green and yellow filters (Rosco super gel) using an underwater irradiance model (Fig. 12 in Jones et al., 2016, Slivkoff et al., in prep) to produce a spectrum as close to the field plume as possible (Fig. 1). An underwater hyperspectral radiometer (USSIMO, In-situ marine optics Pty Ltd.) was used to measure the LED output spectrum. The light quantity treatments were achieved by placing the LEDs at a height above tanks that provided 200 μmol photons m^{-2} s^{-1} at the seagrass canopy for the controls. For the 50 μmol photons m^{-2} s^{-1} treatment, a layer of neutral density shade cloth (ARMAShade, Jaylon Pty Ltd.) was placed between the LED units and the tank.

Aquarium tanks (600 × 300 × 300 mm, volume of 54 L) were lined with unsorted, washed, quartz river sand to 10 cm depth containing 1.3% by weight shredded seagrass wrack as a nutrient/organic matter supply (Statton et al., 2013) and filled with approximately 52 L of seawater with a salinity of 36 ppt. The water in each tank was circulated through its own sump tank containing a pump and filter (300 μm foam block), thus ensuring that each replicate tank was independent (full experimental set up described in Strydom et al., 2016).

Light treatments were randomly allocated to aquarium tanks, and each tank was isolated from the others using PVC boards to ensure no leakage of light from surrounding treatments. Light intensity in each tank was measured at the top of the *H. ovalis* canopy using an underwater quantum sensor (MicroPAR). Water temperature and salinity were monitored using a WTW™ conductivity meter. The water temperature was maintained at 20–21 °C, which was measured at the collection site (see below) and has previously been used as an optimal