

Establishing tropical seagrass light requirements in a dynamic port environment

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Abstract. Tropical seagrasses inhabit naturally turbid waters with dynamic light environments and variable water quality in coastal waters adjacent to the Great Barrier Reef. Large tidal fluxes amplify the magnitude of these conditions with extreme high and low light over relatively short time scales (i.e. hours). Large port developments in the region have the potential to confound the complex relationships between seagrass physiology and this dynamic light field with the onset of dredging and their associated turbid plumes. Understanding the capacity for seagrasses to respond to changes in the quantity and quality of the light environment will allow for prediction of how seagrass species and populations will tolerate changes in light attenuation that may occur during dredging. We present a strategy for determining seasonal-specific light requirements for an intertidal tropical seagrass community in a port environment. Locally relevant light requirements are established by describing the relationships among photosynthetic inputs and losses, tidal exposure, shifts in spectral light quality, seasonality and the capacity to utilise below ground carbon reserves. The outcomes of the study provide guidelines for a mitigation strategy that is focused on maintaining critical windows of light to support seagrass growth and the longer term survival of these productive coastal ecosystems.

Key words: Seagrass, Light Requirements, Management.

Introduction

One of the major drivers of seagrass growth and distribution in shallow coastal environments worldwide is light availability (Dennison 1987, Duarte 1991, Ralph et al. 2007). However, naturally turbid inshore waters related to coastal runoff, large tidal fluxes and complex hydrodynamics can create narrow windows of opportunity for photosynthetic gains and seagrass viability. Seagrasses adapted to these marginal environments can be particularly sensitive to reductions in light beyond this established range of conditions.

On Queensland's east coast, seagrasses cover approximately 38,079 sq km of inshore habitat, within the boundary of the Great Barrier Reef Marine Park (GBRMP; Fig. 1; McKenzie et al. 2010). These coastal seagrass meadows support the coral reef ecosystem due to the many roles they play including: acting as a nursery for a wide range of fisheries; providing feeding grounds for predatory fish and invertebrates; nutrient filtering from coastal runoff, sediment trapping from riverine catchments and; export of organic matter to adjacent and downstream systems (Watson et al. 1993, Hemminga and Duarte 2000, Heck et al. 2008).

In Australia, human-induced changes to the inshore environment have been documented to cause seagrass loss largely due to light limitation (Walker and McComb 1992, Ralph et al. 2006). Along the Queensland east coast, anthropogenic pressures and the associated risk to seagrasses can be high in areas where urban development and most notably port infrastructure has a strong foothold (Grech et al. 2011). Along the GBR, seagrass meadows are common in close proximity to large port facilities creating conflicts between economic development and ecological success of the habitat.

Currently, there is a push for rapid expansion of new and established ports along the Queensland coast to fulfill a greater demand for mineral- and gas exports to overseas markets (Fig. 1; BREE 2011). The capital works to expand wharves and swing berths puts additional pressure on adjacent seagrass meadows with threats to water quality, (most importantly light availability), from large scale dredging programs and associated turbidity plumes.

Seagrasses have been shown to work well as bio-indicators for assessing the light availability and overall health status of marine coastal environments (Dennison et al., 1993, Abal and Dennison 1996). Government regulators have called for an ecological based approach to managing dredging impacts and

have identified seagrasses as a key indicator of water quality and the need to ensure seagrass viability as important fisheries habitat.

We present a strategy for determining species-specific light requirements along the Queensland coast as a precursor to a light-based management plan for seagrasses under threat from a large-scale dredging program based on a two year study in central Queensland.

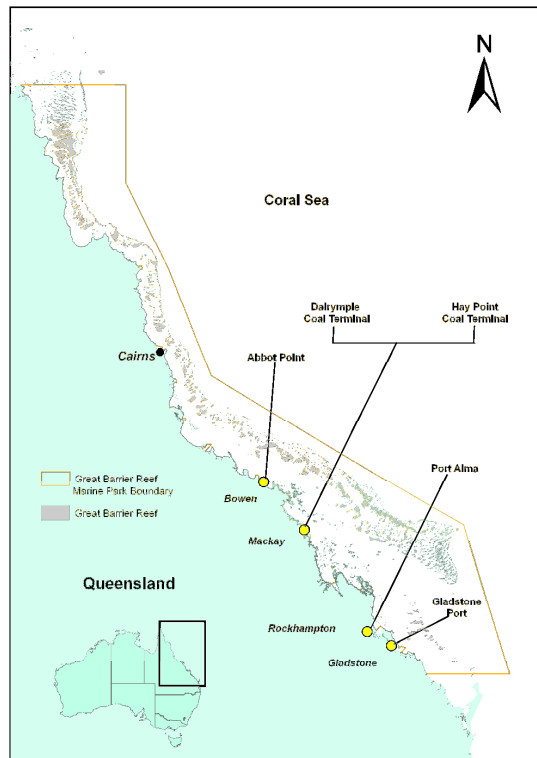


Figure 1: Proposed port expansions along the central coast of Queensland.

Material and Methods

The Marine Ecology Group in collaboration with University of Technology Sydney developed a multi-faceted approach to quantify the light requirements of seagrass in central Queensland ports. The studies were developed as part of the management requirements for one of the largest capital dredging campaigns undertaken in Australian waters and focused on the most sensitive and dominant species found in the area, *Zostera capricorni*, to establish light thresholds and management plans that would ensure a conservative approach to protecting the larger intertidal seagrass community. The program incorporated: 1) *in situ* shading studies to simulate the effects of a dredge related reduction in light from increased turbidity over a seagrass meadow; 2) tidal

flux studies to assess how well seagrasses utilise the dynamic light fields over various stages of a tide cycle, including exposure; 3) laboratory experiments to confirm *in situ* shading results and to assess effects of spectral light shifts on seagrass productivity and; 4) an assessment of the spectral quality of light throughout the port both spatially and temporally in relation to background conditions versus dredge related turbidity plumes.

Field and laboratory-based studies were performed year round to quantify seasonal effects on light requirements while spectral profiling of the port was carried out across neap and spring tides to characterise the effect of tide driven re-suspension and mixing on the light profiles reaching seagrass meadows.

This approach for determining the light requirements of a tropical intertidal seagrass community provides a foundation from which a light-based management plan could be implemented for assessing seagrasses during the dredging program. Light based trigger values were developed based on the above experimental approach together with a multi-year assessment of seagrass trends and recorded light regimes across the port. A current working plan is in place which provides suitable management guidelines, environmental trigger levels and monitoring programs to ensure seagrasses in sensitive port environments receive sufficient light to thrive despite the potential pressures of port development and expansion.

Results and Discussion

Seagrass shading studies conducted to simulate the effects of a dredge-related reduction in light from increased turbidity indicate there are likely differences in seasonal light requirements (Fig. 2) which correlate with seasonal use and storage of carbohydrate reserves in below ground roots and rhizomes (data not shown). Other metrics including pigment analysis, photochemical efficiencies and morphometrics appear to support these findings in that seagrasses are sensitive to declines in light during their natural growing season (July-January) and not during the typical senescent period (February-June).

A second stage assessment of tidal flux established effects of extreme light shifts and air exposure on photosynthetic performance and oxygen production. Exposure or near exposure at the lower tidal range could either provide longer periods for positive net photosynthesis or conversely result in photodamage due to high light stress on photosynthetic tissues. It is also possible that exposed seagrass blades would exceed their thermal tolerance for photosynthesis or become limited in CO₂ supply when exposed for long

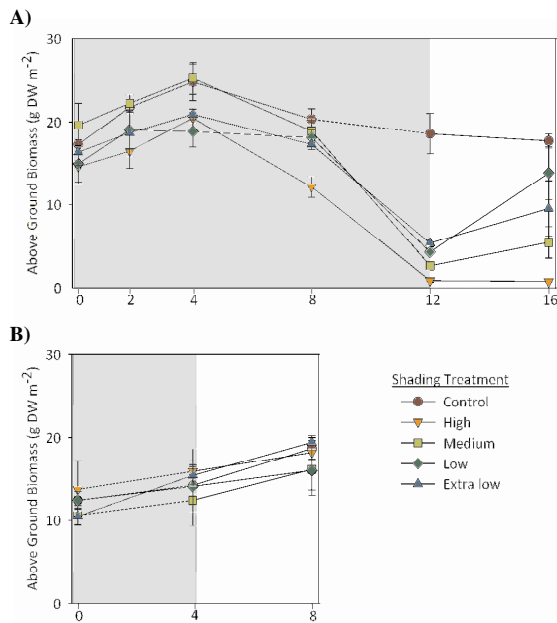


Figure 2: Above-ground biomass and total daily PAR (mol m⁻² d⁻¹) measured in shading treatment plots during *in situ* shading study in the A) growing season (July-January) and B) senescent season (February-June).

periods at low tide which would also lead to a decline in net photosynthesis (Leuschner et al. 1998). It was therefore important to understand whether exposure of intertidal meadows is beneficial or detrimental for seagrass photosynthesis. Results show a significant negative effect of air-exposure on photosynthesis. Initial effective quantum yields and maximum relative electron transport rate declined significantly in *Z. capricorni* blades with air exposure ($P < 0.001$). P:R ratios also increased significantly with increased irradiance, reaching a maximum just prior to exposure and then declining significantly following air-exposure (Fig. 3). These results imply tidal exposure will not provide intertidal seagrass meadows with any respite from high turbidity that may result from dredging related activities or poor light quality in naturally turbid estuaries. They will likely affect how tidal exposure windows are treated as part of dredge mitigation strategies for seagrass management.

Dredge-related turbidity can change the quality of light reaching seagrasses at depth; light becomes enhanced in the yellow region of the spectrum. As seagrass photosynthesis is sensitive to the spectral quality of light, it was important to establish whether there was a spectrally shifted environment naturally in coastal waters and whether these effects would be amplified during dredging. The dominant photosynthetic pigments in seagrasses are chlorophylls a and b, which absorb in the blue and red wavelengths (400-500 nm and 650-700 nm) of the

light spectrum. Yellow light enhanced conditions (i.e. a reduction in the blue and reds) have the potential to greatly reduce the light available for photosynthesis. Seagrasses have high photosynthetic efficiency in the blue, poor efficiency in the green and yellow and maximum efficiency in the red regions. This pattern is the converse of the light transmission measured at some inshore harbour sites. The turbid water removes most of the photosynthetically useful photons (i.e. blue and red) while transmitting the less photosynthetically active yellow photons.

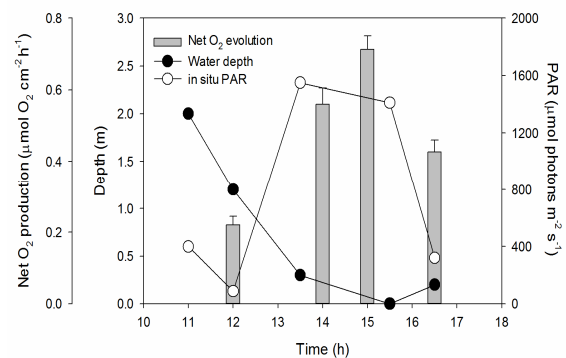


Figure 3: Photosynthetically active radiation (PAR) at the depth of the seagrass and water depth over an Austral summer tidal cycle in 2011 and net oxygenic evolution (grey bars) *in situ* for *Z. capricorni*.

Seagrass condition and light were monitored at field locations across several seasons and years to establish links between light availability and seagrass health. Mean total daily PAR was analysed to assess how often certain light levels coincided with a decline in seagrass percent cover. These results were used together with field and laboratory results to develop and test various light triggers and appropriate management actions. In general, *Z. capricorni* consistently received greater than 6 mol m⁻² d⁻¹ over a two week rolling average at most locations in the harbour during the growing season when seagrass remained stable or increased in abundance. This approach established how effective various triggers would be in maintaining sufficient light for seagrass survival under natural conditions and their suitability as a management tool to protect seagrasses during dredging.

Analysis of benthic PAR data and seagrass trends at monitoring sites is ongoing to validate a seasonal application of a light trigger value. These assessments together with the latest results from the laboratory studies and spectral profiling analyses confirm our current suggested light trigger value of 6 mol m⁻² d⁻¹ over a rolling two week average for the management plan, however modifications may be made as part of

an adaptive management approach until a final plan is formally adopted

An outline for the working light-based management plan was established in parallel with a current turbidity based management plan that is used by the port and regulators to monitor and manage dredge activities. The proposed light-based management plan is not intended to replace existing dredge management strategies. Rather, it is intended to complement turbidity monitoring by measuring a factor, PAR, that is ecologically relevant and directly affects the survivorship and health of seagrasses during dredging. These two programs will work in concert such that the source of turbidity and the effect on seagrasses can be better assessed for making management decisions.

The draft plan assigns rules for potential conditions and associated actions that must be taken based on a decrease in the available light climate over a certain time period adjacent to a key receptor sites (i.e. seagrass monitoring locations with associated PAR data). The multi-staged management response is designed such that minor actions are taken prior to a major response by managers or regulators is needed to avert significant losses of seagrass meadows. For instance, once the light climate at a given site drops below a specified level for a designated length of time (i.e. $6 \text{ mol m}^{-2} \text{ d}^{-1}$ over a two week rolling average), an internal alert is triggered resulting in increased surveillance of data logger function, database accuracy and other potential mechanical factors in data collection. If the light climate has not improved after a specified length of time, a further analysis of weather conditions, dredge activity or the like is initiated. Managers and regulators may be notified at this stage if necessary. Alerts, investigations and actions are part of a working plan that must include researchers, port managers and government regulators to ensure the adoption and implementation of an ecologically relevant approach as suggested here is successful.

To test the sensitivity and effectiveness of this approach, the historical dataset on seagrass condition and light was examined under natural conditions prior to dredging. For the management plan to be effective, the trigger needs to be sensitive enough to protect seagrass but not to result in continual major actions in response to natural events.

While our results have produced an initial set of management triggers ongoing work will lead to further improvements and modifications. This is in line with the adaptive management approach that both researchers and regulators hope to incorporate into large scale port expansions happening in the footprint of a rich and interconnected coastal reef system such as the GBR.

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