So you want to develop a Light Based Management Approach…

# Considerations for the Development of a Seagrass Light Based Management Approach for Dredging

## 1. Introduction

Gladstone Ports Corporation (GPC) obtained government approval in 2010 to extend, deepen and widen existing shipping channels and create new berth facilities in Gladstone Harbour through the Western Basin Dredging and Disposal Project (WBDDP).

Stage 1A of the WBDDP was completed in September 2013 after 123 weeks of dredging. Material dredged was either placed at sea (5.11 M $m^3$) or in a reclamation area (17.45 M $m^3$).

The WBDDP implemented a substantial environmental monitoring program that incorporated some of the latest environmental monitoring techniques. This program included more than two years of baseline studies and related research prior to dredging.

A dual turbidity and light based management approach (LBMA) was used to manage the impacts on intertidal seagrass beds of changes to the light climate resulting from dredging. The development of this approach was a specific regulatory condition for approval of the WBDDP.

The LBMA was based on research undertaken by scientists from Fisheries Queensland, Department of Agriculture Fisheries and Forestry (who are now continuing the research as part of TropWATER at James Cook University (JCU)), in collaboration with scientists from Vision Environment (QLD) and the University of Technology (UTS), Sydney.

The approval conditions for the WBDDP also required establishment of a Dredge Technical Reference Panel (DTRP). The DTRP included scientists with specific expertise in environmental monitoring, seagrass ecology and dredging. A key task of the DTRP was to provide advice on monitoring of the dredging and ensure progress was made towards a light based management approach.

The development and application of this LBMA has attracted considerable interest from regulators, scientists and the community. Consequently the DTRP, in conjunction with GPC, has developed this Fact Sheet. It aims to provide guidance to regulators and scientific service providers who are considering conditioning or developing a LBMA.

## 2. **Why measure light in association with dredging?**

In the EIS for the WBDDP it was noted that dredging would result in increased turbidity within Gladstone Harbour; that this had the potential for environmental impacts; and that the aquatic organisms in Gladstone Harbour had different tolerances to elevated turbidity.

Further, it was recognised that turbidity would need to be managed during dredging to avoid unplanned impacts to these sensitive receptors as a result of light attenuation and sedimentation. It described a monitoring program for the WBDDP that was founded on the premise that, if dredging was managed to ensure water quality conditions met required standards and turbidity did not exceed defined levels, then a level of environmental protection would be provided.

The EIS also recognised that seagrasses were the key sensitive receptor close to the planned dredging and placement activities, and that seagrass was the most appropriate sentinel species to monitor during the dredging project. Seagrasses are of high ecological value and are commonly used as sentinel species where light may be reduced due to development activities (Orth et al. 2002, Bricker et al. 2003, Fourqurean et al. 2003, Erftemeijer and Lewis 2006).

Seagrass requires light to photosynthesise. Low light levels due to highly turbid water may place the plant under stress and, if severe or prolonged, may result in mortality. Light requirements for seagrass differ among species and seasons, yet it is well established that changes in the availability of light is one of the primary factors affecting the distribution of seagrasses.

It was considered that managing dredging to maintain light levels at a sufficient level to ensure seagrass health was maintained was a key management objective for the WBDDP, and that this may also afford protection to other key ecological assets.

Measuring turbidity is commonly used as a proxy for measuring light reaching seagrass; however as it is an indirect measure of light it can be inaccurate. Further, turbidity thresholds based on background levels are not necessarily linked to the actual light requirements of seagrasses. Measuring photosynthetically active radiation at the seagrass bed (Benthic PAR, or BPAR) is a direct measurement of the light available to seagrass and, coupled with an understanding of the local light requirements of seagrass, can provide a more robust way of effectively managing dredging to ensure seagrass health.

The WBDDP therefore sought to develop a means of monitoring light to ensure levels were sufficient to maintain seagrass health.

## 3. **What was the light based monitoring approach used in Gladstone Harbour?**

In the beginning of the WBDDP, turbidity was the primary monitoring tool, and sole basis for regulation. However, a light based trigger was introduced midway through the project and was formally acknowledged in regulatory permits and approval conditions.

The trigger related specifically to intertidal meadows of *Zostera muelleri* subsp. *capricorni.* This species has the highest light requirement of the seagrasses in Gladstone Harbour (in addition to being the dominant species with the highest distribution, biomass and density) and it was assumed that ensuring the health of this species effectively ensured the health of other seagrass species in the Harbour.

The light based trigger was initially adopted as a secondary trigger to be considered if turbidity triggers had been exceeded (see attached Flowchart). Exceedance of turbidity triggers required management responses commencing with investigative actions ramping up to more proactive management responses such as altering the nature of dredging (or potentially ceasing) at higher levels of exceedance. Following the initial secondary application, light was adopted as a dual trigger with light having the capacity to initiate dredge management actions independently of a turbidity trigger being reached (however for the WBDPP this situation didn't occur).

Adoption of the light trigger allowed regulators to take into consideration likely impacts to seagrass as a result of changes to the light climate, if turbidity triggers were exceeded. Where light requirements were likely to be met, management actions could be appropriately modified.

During the WBDDP, the light based trigger was used on many occasions when turbidity triggers were exceeded to assess the need for dredge management measures. For example, there were occasions where, due to natural events (e.g. strong winds, spring tidal cycles), a turbidity trigger was exceeded but light based monitoring indicated seagrass meadows were likely to be receiving sufficient light. In these instances, regulatory exemption was sought (and often granted) to allow dredging to continue. In these cases other management actions, such as relocating the dredge to another location, were frequently still required.

## 4. What was monitored?

Light and seagrass condition were monitored at ten sites in Gladstone Harbour. These included sites that were likely to be influenced by dredging and those that were unlikely to be influenced.

Telemetered loggers measured BPAR every minute at each location (although these were subsequently accumulated to 15 minute values to reduce some of the "noise" in that data). The loggers were placed in the seagrass bed near a permanent transect where seagrass condition was also monitored (see below). In addition, surface PAR was measured at a nearby base station. This enabled comparison of trends in light availability at the surface with light levels at the seagrass meadows (e.g. to assess the influence of cloudy periods).

Each day, total daily BPAR was measured at each site and a rolling mean total daily BPAR over 14 days (14 day RA) was calculated and compared to the trigger value. If the trigger value was not reached, it was considered there were likely to be no impacts to seagrass.

Seagrass condition was also monitored. Every month, biomass, cover and species composition were monitored at permanent transects each site, and twice a year the distribution of seagrass was mapped.

These data were supplemented by data collected in baseline studies prior to dredging, and used to confirm that seagrasses were receiving enough light and that their condition was not being adversely affected by dredging.

## 5. How was the light based monitoring trigger developed for Gladstone Harbour?

The light based trigger, and associated monitoring approach, was based on extensive research on the seagrass species and light conditions in the area including:

- developing telemetered real time light monitoring techniques adjacent to seagrass and potential seagrass habitat
- assessing the light and spectral quality requirements of seagrass through artificial shading of seagrass both *in situ* and in the laboratory
- the effect of tidal exposure on photosynthesis, and
- long term monitoring of seagrass cover.

These studies indicated that intertidal *Zostera muelleri* subsp. *capricorni* at Gladstone was likely to require between 4.5 and 12 mol $m^{-2}$ $d^{-1}$ during the growing season over a minimum period of three to four weeks before light related impacts were detected. The shading studies indicated there was no reduction in seagrass cover for this period, regardless of how much the light was reduced.

Based on these studies a working trigger value based on a 14 day RA of 6 mol $m^{-2}$ $d^{-1}$ was established. The 14 day RA was considered to be conservative given seagrass could withstand low light levels for longer than this.

The 14 day period also incorporated spring and neap tide conditions, and the consequent changes in light due to tidal height and degree of exposure. Details on development of the light trigger value are provided by Chartrand *et al* (2012).

This research can be used to assist the development of trigger values for other locations. In developing such triggers, consideration should be given to the condition and resilience of the seagrass. A higher light trigger may be appropriate if seagrass is in poor condition (for example, if recent floods have resulted in significant declines).

## 6. When can the light based approach be used?

In some locations, using a light based approach may only be appropriate at certain times of the year. On the subtropical/tropical east coast of Queensland, there are predominantly two seasons for seagrass:

- the growing season when seagrasses typically increase in biomass and distribution, and
- the senescent season, when biomass and distribution remain static or decrease, depending on species and meadow characteristics.

The timing of these seasons varies somewhat from year to year and between geographic locations, and is likely to be dependent on a number of factors including light and temperature. At Gladstone, the growing season was defined as July to January and the senescent season was defined as February to June.

The shading experiments at Gladstone indicated that seagrass light requirements are markedly lower in the senescent season than in the growing season. As *Zostera muelleri* subsp*. capricorni* in the Gladstone area naturally declines in the senescent season, a light based trigger was considered to be inappropriate in the senescent season for this species.

Light based approaches may not be appropriate for short periods. At Gladstone, research indicated that seagrass could tolerate reduced light for 3 to 4 weeks during the growing season. Consequently, it would not be appropriate to use a light based monitoring approach for dredging projects in this location that are shorter than this timeframe.

Implementing a light based dredge management program would also be more challenging where seagrass species are highly variable, with processes other than light having a strong influence on seagrass change. In these circumstances, it is important to understand the amount of light required to maintain healthy seagrass growth and recovery as well as the influence of other processes so that an ability to separate dredge and non-dredge related impacts is maintained.

## 7. Which species can the light based approach be used for?

The light based monitoring for the WBDDP was specifically developed to manage the impacts of dredging on the dominant intertidal seagrass species (*Zostera muelleri* subsp*. capricorni)* in Gladstone Harbour. Further research would be required to adapt the approach for other seagrass species and for other locations.

Light based triggers are appropriate management tools where the distribution and abundance of a sensitive species is dependent on light and the proposed development impacts light availability. Research is required to confirm light is likely to be an important factor influencing the distribution of a species in the area to be impacted, before a light based approach is developed.

JCU researchers have initiated studies to develop triggers for other seagrass species (e.g. deep water species) but these are still in the developmental phase and further research is required. Similar light based approaches could also be developed for other light dependent taxa such as corals or macroalgae.

## 8. Is it sufficient to monitor light and seagrass condition only for a dredging project?

Monitoring for management of dredging operations needs to be tailored to address the risks identified in the EIS. Where dredging poses a high risk to seagrass through a reduction in light, then a program that includes a light based approach as part of the overall monitoring program is appropriate. If other significant risks are identified, then tools need to be developed to specifically address them. For example, if the sediment being dredged is contaminated, then contaminants and their potential toxicity impacts may need to be considered in the monitoring.

## 9. What information is required to implement a light based monitoring program for seagrass?

To develop a light based monitoring program for seagrass, the following is needed as a minimum:

- area likely to be impacted by the proposed dredging
- likely scale and significance of the impact in different areas
- current distribution and species composition of seagrass beds likely to be impacted
- seasonal and inter-annual fluctuations in seagrass distribution and composition
- seasonal and inter-annual fluctuations in BPAR, and a
- locally derived relationship between seagrass condition and BPAR.

This information will provide scientific evidence on the magnitude of natural variation in seagrass beds, and also help guide the selection of monitoring sites where seagrass is relatively stable and likely to be present over sustained time periods.

## 10. How should monitoring sites be selected?

The selection of monitoring sites needs to take into account temporal and spatial changes in seagrass meadow condition, composition and distribution, and an understanding of the potential changes in light climate caused by the project. Potential changes in the light climate can be determined using calibrated hydrodynamic models which can predict the magnitude and area of influence of potential turbidity plumes. These predictions can be overlaid on a map of seagrass distribution to identify seagrass beds that may be negatively impacted by a reduction in light as a result of dredging.

Monitoring sites should be located across the range of seagrass meadow assemblage types present in the area and include meadows varying in susceptibility to dredging related effects (both spatially and temporally).

Monitoring (e.g. for turbidity) should occur to assist in determining the extent of light attenuation directly due to dredging and this could involve waters adjacent to the seagrass meadows.

### 11. What monitoring equipment is needed for monitoring BPAR?

In the LBMA, accurate measurement of BPAR is critical. There are a variety of sensor/logger types that can be used to measure light. The following issues are of key importance:

- Equipment must be robust and able to withstand strong winds, wave action, sheer-stress, fouling and flood related effects.
- At least two BPAR loggers are needed at each site to ensure effective data capture. Inshore coastal areas are harsh and instrument malfunction is likely. Consequently, multiple loggers to provide a level of redundancy and validation in case of instrument malfunction or environmental interference are required.
- Instruments must be routinely calibrated.
- Loggers should be deployed on the seabed in a manner that minimises the impact of the equipment being picked up, moved or tipped over, but not interfere with light.
- Loggers need to be self-cleaning in addition to undergoing regular maintenance to prevent biofouling. Automatic wipers or equivalent should be used to ensure the sensors remain clean whilst not affecting light readings.
- Recordings should be made at high enough temporal resolution to account for a dynamic light environment. These data can then be used to calculate light received over appropriate timescales (i.e. daily).
- Shading of the light sensors must be eliminated (the design of deployment cradles and installations is important in this regard).
- For intertidal areas, the time the loggers are exposed needs to be accurately determined (e.g. using depth sensors), so that appropriate correction factors can be applied to these data (temperature sensors are optional but highly recommended).
- Additional dual loggers are required to record PAR above the water surface for the general location, which provides a reference for weather-related conditions influencing benthic light.
- Telemetered loggers are required to enable timely application of light data as part of a reactive dredge management program.

### 12. Is the depth at which seagrass is monitored important?

The depth at which seagrass occurs and is monitored is of key importance for a seagrass LBMA. Key drivers for guiding sensor depth are an understanding of the depth profile of existing seagrass and the potential impacts associated with dredging.

Monitoring approaches and light based triggers will both vary depending upon the depth at which seagrass is growing and where monitoring occurs (including elevation within the intertidal zone). Triggers for one species, at a certain depth at a given location, cannot be simply transferred to another species or to seagrass growing at a different depth.

The depth at which light sensors are placed is important, as in very turbid water, small changes in monitored depth may result in large changes in total daily BPAR. Additionally, for intertidal seagrass areas, the depth at which monitoring occurs will determine the amount of aerial exposure at that location. For some species, such as intertidal *Zostera muelleri* subsp. *capricorni*, tidal exposure results in reduced photosynthetic activity (Petrou et al. 2013) and the seagrass is likely to depend on the critical light windows immediately before and after tidal exposure for the greatest productivity. Consequently, it is important to accurately measure the datum depth and calculate the exact time and period of exposure (e.g. using depth sensors) so that an exposure correction factor (Collier et al. 2009) can be applied to the BPAR data.

## 13. Reporting results and associated metrics

Data processing and a Quality Assurance protocol are required to ensure the integrity of data. Due to logger malfunction, floating debris, or other mishap, multiple light loggers at the same location may record significantly different values. Statistical Quality Assurance/Quality Control processes for management of data therefore need to be developed and implemented to define the erroneous logger and then treat or quarantine associated data. Some of these processes for the WBDDP were automated to remove subjectivity.

## 14. Future use of light based monitoring and research needs

The LBMA developed for the WBDDP in Gladstone Harbour offers considerable scope to better manage impacts to seagrasses related to dredging. However, there is scope to further improve and refine the technique and trigger values through further research.

Importantly, the results for the WBDDP and in particular the trigger value used, cannot be transferred to other locations or used for different species without validation for that location and species. This will require site-specific research to ensure triggers are relevant for local seagrass meadows.

The extent of the scientific research for developing the LBMA at Gladstone has provided a significant basis to build on. It is likely that future work to develop a LBMA for seagrass in another location will not require as much effort. The trigger used in the WBDDP is currently being refined with alternative statistical approaches being applied to the existing data, and as more data is collected on seagrass health. Alternate triggers, and in particular triggers that address repeated short periods of exposure to low light may also provide useful management tools.

JCU in partnership with UTS has also been working towards developing sub-lethal indicators of light stress to assess seagrass condition. This would enable impacts to be detected prior to any morphological changes to the plant or changes in meadow cover or extent. This approach focuses on developing a genetic technique that is capable of rapidly assessing seagrass health based on key genes that regulate a response to light stress. GPC has agreed to support this work for developing a world leading rapid seagrass health assessment tool. Once this genomic approach has been scientifically validated, it will offer capability to further evaluate the effectiveness of the LBMA developed for the Gladstone WBDDP.

## 15. Useful References and LBMA Flowchart


Bricker S.B., Ferreira J.G., Simas T. (2003). An integrated methodology for assessment of estaurine trophic status. Ecological Modelling 169: 39-60

Chartrand K.M., Ralph P.J., Petrou K., and Rasheed M.A. (2012). Development of a Light-Based Seagrass Management Approach for the Gladstone Western Basin Dredging Program. DAFF Publication. Fisheries Queensland, Cairns 126 pp.

Collier C.J., Lavery P.S., Ralph P.J., Masini R.J. (2009). Shade-induced response and recovery of the seagrass *Posidonia sinuosa.* Journal of Experimental Marine Biology and Ecology 370:89-103

Erftemeijer P.L, Robin Lewis R.R. (2006). Environmental impacts of dredging on seagrasses: A review. Marine Pollution Bulletin 52:1553-1572

Fourqurean J.W., Boyer J.N., Durako M.J. Hefty L., Peterson B. (2003). Forecasting responses of seagrass distributions to changing water quality using monitoring data. Ecological Applications 13:474-489

Gladstone Port Corporation (2013). Monthly and summary water quality (undertaken by Vision Environment Pty Ltd) and seagrass (undertaken by TropWATER, James Cook University) monitoring reports prepared for Gladstone Port Corporation and provided on the Western Basin Dredging and Dredged Material Disposal website: http://www.westernbasinportdevelopment.com.au/environmental_reports.

Orth R., Batiuk R., Bergstrom P., Moore K. (2002). A perspective on two decades of policies and regulations influencing the protection and restoration of submerged aquatic vegetation in Chesapeake Bay, USA. Bulletin of Marine Science 71:1391-1403

Petrou K., Jimenez-Denness I., Chartrand K.M., McCormack C., Rasheed M.A., and Ralph P.J. (2013). Seasonal heterogeneity in the impact of air-exposure on the photophysiology of two tropical intertidal seagrass species (Zostera muelleri and Halophila ovalis). Marine Ecology Progress Series Vol. 482 93-106.

## GPC Dual Water Quality Management Flow Chart