Ecological Indicators 30 (2013) 7–15

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

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

# Identifying robust bioindicators of light stress in seagrasses: A meta-analysis

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ARTICLE INFO

*Article history:*
Received 18 September 2012
Received in revised form 28 January 2013
Accepted 29 January 2013

*Keywords:*
Seagrass
Bioindicator
Light stress
Monitor
Management

ABSTRACT

Bioindicators are used to monitor responses to environmental pressures. They should reflect important ecological values, be scientifically defensible, respond in a predictable manner and be easy to measure and interpret. Seagrasses are significant marine habitat, which globally are under threat and are considered "sentinels" of coastal degradation. Light reduction via (for example) eutrophication, dredging and turbid terrestrial run-off is a key anthropogenic pressure impacting seagrasses. Consequently, seagrasses are regularly included in monitoring programs, both to protect them and for their value as indicators of change in light availability. This paper assessed published literature on seagrass responses to light reduction to identify which seagrass characteristics provide the most robust bioindicators of light reduction. ISI Web of Science was searched in July 2011 to retrieve refereed publications that documented the response of seagrasses to light reduction. Only studies with a control were included, giving confidence that the response was due to light reduction and not other, unexplained factors. This yielded a dataset of 58 published studies, covering eight of 11 seagrass genera and 18 species, with a wide geographic range. In each study, the response of each variable to light reduction was categorised into no effect, reduce or increase. Where studies tested the intensity and durations of light reduction, the consistency of responses at these different levels was also assessed. A set of consistent and robust bioindicators is proposed that respond to the pressure of light reduction and can indicate different timescales and levels of pressure. These include: those that respond early and reflect sub-lethal changes at the scale of the plant, such as rhizome sugars, shoot C:N, leaf growth and the number of leaves per shoot; and those that respond later, reflecting changes at the meadow-scale, such as shoot density or above-ground biomass. We recommend these variables for monitoring programs with the goal of detecting significant light reduction and indicating the severity and duration of impact.



## 1. Introduction

Bioindicators are used to monitor biotic responses to environmental pressures and are applicable to individual species or assemblages (e.g. Markert and Wünschmann, 2011). Many monitoring programs incorporate measures of both environmental pressures and bioindicators. The advantage of measuring biota is that they integrate a temporal component, reflecting both the past and current environmental condition, related to the life-span or residence time of the particular organism in a system, whereas environmental measures usually reflect a single point in time. Good bioindicators should be scientifically defensible, such that the cause–effect pathway that relates the state of the biota to the pressure is reasonably understood, respond in a predictable manner to the pressure of concern across different locations and times and in proportion to the degree of pressure, be repeatable, that is, they can be measured on more than one occasion over space and time, cost effective, easy to measure and provide outputs that are easy to interpret (ANZECC, 2000; EPA, 2008; Niemi and McDonald, 2004). There is a plethora of potential bioindicators but ecological health assessments need to be based on simple yet scientifically sound methodologies (Borja et al., 2008). An integral component of bioindicator development is to pause and review the suitability of the many potential indicators on the basis of the above criteria.

Coastal zones are highly valued for their ecosystem services as well as their socio-economic benefits. Yet, they are exposed to multiple pressures, including eutrophication, construction works for ports and marinas, increased sediment runoff, fisheries activities and aquaculture (Costanza et al., 1997; Gladstone, 2010) and degradation of the coastal zone continues at an increasing rate (Duarte, 2009; Waycott et al., 2009). Effective monitoring, detection of change and management of these localised impacts is growing in importance as global climate changes create further pressures on coastal ecosystems (Hughes et al., 2003).

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http://dx.doi.org/10.1016/j.ecolind.2013.01.030

Seagrass meadows are considered "sentinels" of coastal degradation (Orth et al., 2006) and, as such, they are frequently incorporated into assessments of estuarine and coastal integrity (e.g. Borja et al., 2008; Fourqurean et al., 1997; Romero et al., 2007). They are a dominant habitat of most coastal environments providing important ecosystem services, globally valued at approximately US$19,000 $ha^{-1}$ $yr^{-1}$ (Costanza et al., 1997). This means that, in addition to being good bioindicators of impacts to the coastal zone, changes in the health or abundance of seagrasses indicate likely flow-on effects to the broader ecological and economic systems. One of the key causes of seagrass decline is light reduction (Waycott et al., 2009). They have high light requirements but often occur in shallow estuarine or coastal regions, which are readily impacted by human activities. Monitoring of seagrass condition and health is a key priority in many coastal monitoring programs, and in environmental impact assessment and management, particularly related to dredging e.g. (EnviCom-Working-Group-108, 2010; EPA, 2011; Fourqurean et al., 2003; McKenzie et al., 2010).

Seagrass responses to light reductions have been reasonably well documented (Fig. 1). Plants initially respond to stress through physiological adjustments and later, if the stress continues or increases in intensity, through morphological adjustments (Waycott et al., 2005). Consequently, a set of sub-lethal effects occur, where the plant modifies its physiological processes, resource allocation or structure (Lee et al., 2007; Ralph et al., 2007), in order to maintain a positive carbon balance (Collier et al., 2009; Touchette and Burkholder, 2000). In the face of ongoing pressure, declines in spatial extent or density of seagrass meadows will then occur (Backman and Barilotti, 1976). These responses can be easily explained through a cause–effect pathway of reduced light interception through to meadow-scale changes (Fig. 1).

### *1.1. The need for this review*

Due to the relatively long history of research on responses of seagrasses to light related stress, there is a reasonable mechanistic understanding of the plant responses to light reduction (Fig. 1). However, even in experimental studies where conditions can be tightly controlled, there are inconsistencies among studies as to whether potential indicators do respond to changing light levels. Effective monitoring programs need to be part of a broader management framework that requires responses to the monitoring data. Typically, this is in the form of predetermined criteria or thresholds, which, if exceeded, trigger a management response. Given the often significant implications in triggering management actions, it is important that there is confidence in the choice of indicators on which monitoring is based. It is timely to assess what are the most robust seagrass bioindicators of light reduction while considering the following criteria:

relevance and appropriateness – they respond to light reduction;

consistency – respond in the same manner (increase or decrease) with increasing intensity or duration of stress or at a particular point along the stress-response pathway;

reproducibility & repeatability– responds across the range of locations and times that light reduction is imposed; and

easy-to-measure and cost-effective.

This paper reviews the published literature on seagrass responses to experimental light reduction in order to identify the most robust bioindicators. A sub-set of bioindicators of light reduction in seagrasses is then proposed taking into account the above criteria.

## 2. Materials and methods

ISI Web of Science was searched in July 2011 to retrieve refereed publications that documented the response of seagrasses to light reduction. *Ruppia*, a genus which is not universally recognised as a seagrass, was not included. Two sets of keywords were used. The first set included words associated with seagrasses (seagrass or eelgrass or SAV or all the seagrass genera names (e.g. *Halophila*, *Posidonia*, etc. and including old genera names such as *Heterozostera*). The second set of keywords contained words associated with light reduction (light or shade/shading or dredge/dredging or irradiance). Each word in the first set was searched in combination with each word from the second set. In addition, to take into account older references that may not be available through ISI Web of Science, the reference list in each article was also scanned for any other relevant publications. This process generated 184 refereed publications. Only those studies that included a control were included to account for any seasonal changes in the seagrass variables that may be related to factors other than the light reduction (in aquaria studies control was 100% surface light or the maximum light intensity treatment, in *in situ* experiments the control was typically ambient light within the seagrass meadow). There were a total of 58 publications on experimental manipulation of light, once those without control treatments were removed which are listed and numbered in Appendix A. This yielded 104 independent studies, considered observations, as many publications included more than one experiment and multiple species. Data was extracted from each of these publications to generate the summary statistics presented in this paper as described below.

From each publication the following information was extracted: country and location where experiment was conducted; experimental set-up (in situ, mesocosms); genus and species studied; start, end and duration of study; season of study; light reduction treatments; and response variables ($n = 119$).

Each response variable measured in each study was assessed to determine if, and how, it responded to a particular level of light reduction relative to the control (increase, decrease or no effect). 'No effect' was defined as not statistically significantly different to the control (typically $p > 0.05$), 'Increase' was defined as significantly ($p < 0.05$) greater than the control and 'Decrease' as significantly lower than the control. These allocations were further subdivided into the time-step at which the response was observed as follows: hours (where the treatment was imposed for <24 h), days (<8 d), weeks (<4 weeks) and months (>4 weeks). If there was more than one light reduction treatment, we recorded whether the response varied among the treatments at different time-steps. In some cases, it was not possible to categorise a particular response variable into the three main categories (increase, decrease, no effect). For example, there may have been more than one light reduction treatment and a variable responded in different directions in the different treatments (e.g. under extreme light reduction, responses differed to those under mild light reduction). If an observation could not be assigned into the three categories, it was deemed inconclusive and not included.

Where variables measured similar plant responses, or where there were only a few observations, they were pooled together with functionally similar measurements. These included: leaf growth ($g\,t^{-1}$) with growth per meristem ($g\,meristem^{-1}\,t^{-1}$); and cluster and shoot mortality, cluster and shoot density and leaves per shoot and leaves per cluster, as a cluster is analogous to a shoot. Leaf biomass per leaf, shoot and $cm^{-2}$ were also combined. After this consolidation, only variables that were recorded in three or more different studies or species were included in the analysis of seagrass responses to light reduction, a total of 56 response variables (Appendix B). These response variables were categorised into five groups: those associated with photosynthesis, other