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Growth effects of shading and sedimentation in two tropical seagrass species: Implications for port management and impact assessment

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ABSTRACT

Seagrass meadows in many parts of the globe are threatened by a range of processes including port development, dredging and land clearing in coastal catchments, which can reduce water clarity and increase sedimentation pressure. As rates of seagrass loss increase, there is an urgent need to understand the potential impacts of development on these critical species. This research compares the effects of shading and burial by fine sand on two seagrass species *Zostera muelleri* and *Halophila ovalis* in Port Curtis Bay, an industrial harbour located on the continental margin adjacent to the Great Barrier Reef Heritage Area, Australia. The research finds that shading in combination with burial causes a significant decline in growth rates in both species, but that burial ≥10 mm reduces growth rates to a greater extent than shading. The paper concludes by discussing the implications of these findings for port management and impact assessment.

1. Introduction

Seagrasses (marine flowering plants) are critical components of near shore marine habitats. These 'ecosystem engineers' (Bos et al., 2007) act to stabilise soft sediments, improve water clarity, function as nurseries for fish and crustaceans and provide foraging habitat for birds, benthic fauna and endangered species such as green turtle (*Chelonia mydas*), dugongs (*Dugong dugon*) and manatees (*Trichechus* spp.) (Lefebvre et al., 1999; Jackson et al., 2001; Boström et al., 2006; Orth et al., 2006; Rasheed et al., 2006; Bos et al., 2007; Collier and Waycott, 2009). The contribution of seagrasses to local livelihoods and the global economy is valued in the trillions of dollars (Waycott *et al*., 2009; Stoeckl *et al.*, 2011). However, seagrasses are sensitive to changes in light availability, water quality and local sediment dynamics, and as a consequence they are susceptible to a range of natural and anthropogenic pressures that increase suspended sediment loads, including agricultural runoff, flooding, industrial development and dredging (Waycott et al., 2005; Orth et al., 2006; Rasheed et al., 2006; Collier and Waycott, 2009). As a result, these critical species declining across the globe, and rates of loss are increasing (Waycott et al., 2009).

In the Great Barrier Reef World Heritage Area off the north-eastern coast of Australia, port development and the expansion of heavy industry such as coal and gas export terminals have increased pressures on sensitive coastal habitats, including seagrasses (Grech et al., 2011; Chartrand et al., 2012; Coles et al., 2015). Seagrass decline in port areas within the Great Barrier Reef (GBR) is attributed to the interaction of event-based and longer-term processes including flooding, dredging and increased runoff due to land use change (Kroon et al., 2012; Petus and Devlin, 2012; Coles et al., 2014; McCook et al., 2015; McKenna et al., 2015). These processes are known to reduce seagrass growth through the transport and resuspension of sediments, which can reduce water clarity and promote physical disturbance, burial and erosion of seagrass meadows. Seagrasses require sediment to anchor their roots and to facilitate the uptake of nutrients, but excessive sedimentation decreases growth rates and increases the risk of shoot mortality (Duarte et al., 1997; Airoldi, 2003; Halun et al., 2002; Erftemeijer and Lewis, 2006; Cabaço et al., 2008).

Recent port development in the GBR reflects a global trend in the expansion of ports for the export of energy resources, such as coal and gas. The gas industry has undergone unprecedented growth in recent years as producers seek to develop unconventional resources such as shale and coal seam gas, and port facilities are being constructed or expanded to meet export demand (BP, 2015; Global LNG Info, 2015). Across the Indo-Pacific region, which includes the GBR, industrial development and catchment runoff are considered the primary drivers of seagrass decline (Grech et al., 2011; 2012). Port developments frequently require dredging to accommodate tankers, pipelines and gas liquefaction facilities, which can reduce seagrass growth by removing, burying or smothering plants, and by reducing light available for photosynthesis

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(Erftemeijer and Lewis, 2006; Chartrand et al., 2012). Even when dredging occurs at considerable distances from seagrass beds, fine sands, silts and clays resuspended during dredging and spoil disposal operations may be transported some distance and settle out on seagrass beds (Jensen and Mogensen, 2000; Erftemeijer and Lewis, 2006). While coarser sediments settle quickly and are therefore likely to be deposited comparatively close to the dredge plume, fine sediments remain suspended for longer periods, and also tend to settle out in low wave energy environments where seagrasses are more likely to be present (Shepherd et al., 1989; Gacia et al., 1999). Seagrasses in such locations are often exposed to a period of increased turbidity followed by a period of burial, which will vary in duration depending on local flushing times and susceptibility of sediment to resuspension (Andutta et al., 2014; Dunn et al., 2015).

To date, research into the impacts of disturbance on seagrasses has focused primarily on the effects of shading, burial or erosion in isolation (see for example Duarte et al., 1997; Longstaff and Dennison, 1999; Ralph, 1999; Halun et al., 2002; Lee et al., 2007; Cabaço et al., 2008; Chartrand et al., 2012; Collier et al., 2012), or has examined interactions between shading and a range of water quality parameters, primarily salinity, temperature and nutrient availability (see Kerr and Strother, 1985; Moore and Jarvis, 2008; Collier et al., 2011; York et al., 2013). These studies suggest that burial and shading effects can independently cause significant reductions in growth, and that there are important differences in species tolerance to disturbances such as light deprivation (Longstaff and Dennison, 1999; Longstaff, 2003). Currently, it is thought that shading effects play the greatest role in determining growth (Short and Wyllie-Echeverria, 1996; York and Smith, 2013). However, research into the effects of burial remains relatively limited compared to shading studies, and as a result, shading is frequently used as a proxy for burial in the scientific literature and port management (Chartrand et al., 2012). A review of research on 15 seagrass species found that most show 50% mortality at 20–50 mm of burial (Cabaço et al., 2008). More recent work by Ooi et al. (2011) suggests that Indo-Pacific seagrass species experience a significant decline in growth when buried to depths of 40 mm or more. Because burial can lead to physical disturbances and sulphide toxicity in addition to light deprivation, burial stress may be expected to have a greater impact on seagrass growth than light deprivation alone (Pedersen et al., 2004; Borum et al., 2005; Holmer et al., 2006; Ooi et al., 2011). There is also evidence to suggest that shading and burial effects interact to influence growth and diversity of algal and macroinvertebrate assemblages in subtidal environments (Irving and Connell, 2002), suggesting that it is important to understand the interactions between these two disturbances, as well as their isolated impacts.

While a growing number of studies have been conducted on Indo-Pacific seagrasses in recent years (Duarte et al., 1997; Moore and Jarvis, 2008; Collier et al., 2011, 2012; Ooi et al., 2011), the majority of knowledge about seagrass ecology in relation to sedimentation comes from studies of morphologically large species in the northern hemisphere (Duarte, 1999; Schaffelke et al., 2005). There remain key gaps in understanding the impacts of comparatively low levels of sedimentation (<20 mm) in areas such the GBR, where small, opportunistic species predominate (Duarte, 1999; Lee Long et al., 1993; Schaffelke et al., 2005). Smaller species have been found to be particularly susceptible to burial effects (Cabaço et al., 2008), and there is a preponderance of transient seagrass meadows in the tropics, a characteristic that can influence seagrass resilience to disturbance (Kilminster et al., 2015). There is also a need for improved understanding of how seagrasses respond to burial using natural sediments under a range of conditions, including during dredging operations, when shading and sedimentation may occur either concurrently or in a cyclical as sediment is deposited and resuspended over seagrass meadows. During prolonged dredging campaigns, seagrasses may undergo repeated periods of shading followed by deposition of dredged sediments in a cyclical pattern (Erftemeijer and Lewis, 2006).

In this paper, we address these gaps through experimental studies of the effects of shading and sedimentation on two seagrass species, *Zostera muelleri* subsp. *capricornii* (Irmisch ex Ascherson, 1867; Jacobs et al., 2006) and *Halophila ovalis* ((R. Brown) J.D.Hooker, 1858). These species occur throughout the Indo-Pacific and Southern Oceans, and *H. ovalis* is also found in the Northern Pacific (Short et al., 2007). Both species are soft-sediment colonisers but display different morphological and life history traits (Petrou et al., 2013; Kilminster et al., 2015). *H. ovalis* is a rapid coloniser, and is considered an opportunistic, pioneering species (Green and Short, 2003). It is highly susceptible to sedimentation but regrows quickly after disturbance under the right conditions (Campey, 1995; Green and Short, 2003; Cabaço et al., 2008). *Z. muelleri* is slower-growing but considered more resilient to burial due to its narrower leaf-blade structure and larger carbohydrate stores in a thicker rhizome (Moore and Short, 2007). The aim of this research was to compare the effects of shading and burial on growth rates and shoot density using sandy sediments. Based on observed local sedimentation rates and sediment composition we examined short-term individual, concurrent and sequential impacts of burial and shading on growth rates and shoot density in *Z. muelleri* and *H. ovalis*. In addition, we examined whether seagrass growth and survival varied with burial depth.

2. Study area

This research was undertaken in Port Curtis, an industrial harbour located in Central Queensland, adjacent to the southern Great Barrier Reef World Heritage Area. Port Curtis, also known as the Port of Gladstone, is the largest multi-commodity port in the State of Queensland and a key export hub for the coal, bauxite and gas industries (Grech et al., 2013). The port is a macro-tidal estuarine system comprising an intricate network of rivers, creeks, inlets, shoals, mud banks, channels and islands (Dunn et al., 2015). Complex water circulation patterns occur throughout the port area and these are governed primarily by a large barotropic (pressure driven) tidal flow, which contributes to high natural sediment loads (Herzfeld et al., 2004; Petus and Devlin, 2012). The distribution of rainfall in the region is highly seasonal (Neil et al., 2002). Increased runoff due to extreme weather events (flooding, cyclones and the recent La Niña double dip event) and land clearing, and the timing and volume of dredging and spoil disposal are all thought to play a role in altering natural sediment dynamic processes in the port (Coles et al., 2014; Zheng et al., 2015).

Port Curtis has historically supported extensive seagrass communities (Rasheed et al., 2006; Bryant and Rasheed, 2013). Inter- and subtidal seagrass meadows occur throughout the port (see Carter et al., 2015), and the region is also known to support significant populations of dugong (*D. dugon*) and green turtles (*C. mydas*), species that are highly dependent on seagrass as a food source and habitat (Short et al., 1996; Lal et al., 2010). However, seagrass extent within Port Curtis has declined substantially over the past decade, such that seagrasses in this area are among the most at-risk in the Great Barrier Reef lagoon (Grech et al., 2011, Coles et al., 2015). Recently, land reclamation, construction of liquefied natural gas (LNG) and coal export terminals and the dredging of 22.5 Mm^3 of sediment from Port Curtis to facilitate the export of LNG has increased the threat to seagrasses through light deprivation and physical disturbance (Rasheed et al., 2006; Chartrand et al., 2012; Petus and Devlin, 2012; Gladstone Ports Corporation Ltd, 2015). Ecological modelling and monitoring studies have emphasised the functional role of seagrass meadows in the port environment (Dambacher et al., 2013; Babcock et al., 2015), highlighting the need for further research into the growth dynamics and threats to these critical species.

3. Methods

Shading and burial experiments were conducted over two annual growing seasons in 2014 and 2015 using commercially available