Gold Coast seagrass sensitivities and resilience (SRMP-003)

GCWA Scientific Research and Management Program

May 2016

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	Project: GCWA SRMP-003
	Title: Gold Coast seagrass sensitivities and Resilience ***Project Leader***: Professor Rod Connolly ***Author(s)***: Rod Connolly, Ryan Dunn, Emma Jackson, Erik Kristensen, Paul Maxwell, Ryan Pearson, Michael Rasheed and Paul York
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Synopsis: This report provides a review of known seagrass sensitivities and resilience, including known minimum stressor thresholds and ranked threats to seagrass relevant to Gold Coast waterways.	
Keywords: Gold Coast waterways, stressors, thresholds, *Zostera muelleri*	

REVISION/CHECKING HISTORY

REVISION NUMBER	REPORT DATE	CHECKED BY		ISSUED BY	
DRAFT	19 June 2015		Rod Connolly		Rod Connolly
0	30 June 2015		Rod Connolly Ryan Dunn		Rod Connolly
FINAL	16 May 2016		Rod Connolly Ryan Dunn		Rod Connolly

Citation

Cite this document as:

Connolly RM, Dunn RJK, Jackson EL, Kristensen E, Maxwell PS, Pearson RM, Rasheed MA, York PH (2015) Gold Coast Seagrass Sensitivities and Resilience (SRMP-003). Report to Gold Coast Waterways Authority, Griffith University, Gold Coast, Australia, June 2015.

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1. Background

This project was initiated by the Gold Coast Waterways Authority (GCWA). The GCWA has created a Scientific Advisory Committee, which is in part responsible for the GCWA Scientific Research and Management Strategy and the accompanying Scientific Research and Management Program (SRMP). This project is part of that program and is intended to enhance the understanding of the Gold Coast waterways (GCWs) and contribute to improved management outcomes.

2. Introduction

The ecological sustainability of the Gold Coast waterways (GCWs) depends substantially on the health of marine plant habitats and their associated animal communities. Seagrasses are a widespread and very important marine plant habitat on the Gold Coast, consisting of intertidal and subtidal meadows throughout the marine and brackish reaches of the waterways (Cuttriss et al. 2013). Seagrass has not been recorded along the exposed oceanic shorelines of the Gold Coast, but does occur in intertidal areas within rivers and creeks flowing directly into the ocean (Natura Consulting 2012, Seagrass Watch 2015). Seven seagrass species are known to occur within the region (*Cymodocea serrulata*, *Halodule uninervis*, *Halophila decipiens*, *Halophila ovalis*, *Halophila spinulosa*, *Syringodium isoetifolium* and *Zostera muelleri*, with *Z. muelleri* as the most common (Natura Consulting 2012, Seagrass Watch 2015). In 2005, seagrass meadows were reported to cover an area of 1,208 ha within the Gold Coast Broadwater (Cuttriss et al. 2013), a central feature of the GCWs.

Seagrass provides key ecosystem services, including carbon sequestration in underlying sediments, shoreline stabilisation, nutrient and sediment capture, fish habitat, and foraging locations for dugongs and turtles (Orth et al. 2006). Unfortunately, seagrass habitat is also particularly vulnerable to human activities in the sea and in adjacent river catchments. Seagrasses have suffered very high rates of loss, degradation and fragmentation globally (Waycott et al. 2009, Short et al. 2011), and locally are under pressure from foreshore development and reduced water quality (McLennan & Sumpton 2005).

Given the importance of seagrass within the GCWs, some areas have been surveyed to establish the distribution, extent, cover, condition and species composition of seagrasses (e.g. Natura Consulting 2012, VDM Consulting 2012a, 2012b). Further efforts form part of the GCWA Scientific Research and Management Program 2015 (Marine Plant Habitat Survey & Monitoring Program SRMP-002).

In Queensland, including in GCWs, seagrass habitat has meaningful legislative protection against deliberate direct damage or destruction. Outside of this intentional damage, deleterious impacts to seagrass communities can arise from many indirect sources. These varied sources typically cause less obvious or immediate impacts than direct physical removal, but can be as damaging in the long-term as they tend to act upon at least one of three broad core habitat requirements for seagrasses: 1) sunlight availability; 2) suitable space/substrate; and 3) suitable water quality. Reducing the availability or quality of any of these three core requirements can trigger a series of successive response mechanisms which, in extreme cases, can lead to the localised extinction of seagrass communities (e.g. Fig. 1).

This report outlines the range of threatening processes and mechanisms through which seagrass communities are impacted within GCWs, and the core requirements that each stressor affects. It also provides minimum tolerance thresholds to each stressor for Gold Coast seagrass species from literature (where available, and using a hierarchical geographic approach; in order of preference from local, to regional, to Queensland, to international) or determined through the opinion of an expert panel. Knowledge gaps that can be addressed through research are highlighted. Finally, we rank threats for seagrass in GCWs by focussing on the most widespread, most light sensitive and best known species, *Zostera muelleri*, as a model species.

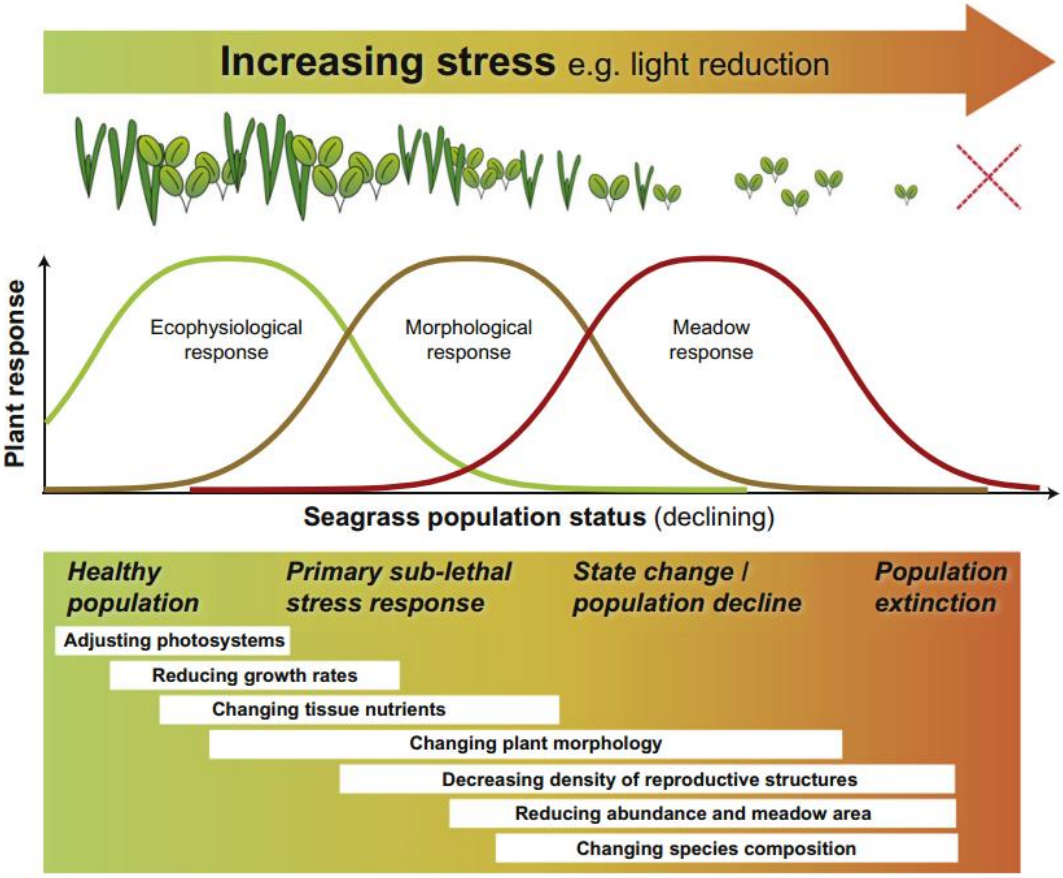

Fig. 1. Seagrass light response model (Source: Collier et al. 2012, adapted from Waycott et al. 2005)

Light stress is often viewed as the largest driver behind seagrass declines (e.g. Ralph et al. 2007, Chartrand et al. 2012). This can be caused by any number of mechanisms including direct shading from overwater structures, turbidity or total suspended solids (TSS), algal blooms, epiphyte coverage, self-shading, water depth and more (e.g. Lee et al. 2007). However, outside of light there are often compounding influences that may be driving seagrass declines and the relationship between these drivers is rarely clear-cut. Light interacts with parameters such as wave and tidal energy, sediment types and sulphide concentrations to influence the suitability of habitat for the growth of seagrasses (Koch 2001). The interaction between these compounding influences can be difficult to manage because each can be driven by a separate factor. For example, dredging can influence all three seagrass core requirements through physical removal (of plants and substratum) or burial, and sediment resuspension (causing light and contaminant stress). A conceptual model has been developed to link these seagrass stressors and their driving mechanisms, in a context specific to GCWs and seagrass core requirements (see Fig. 2). This then leads into a concise discussion of each of the known processes or mechanisms within GCWs.

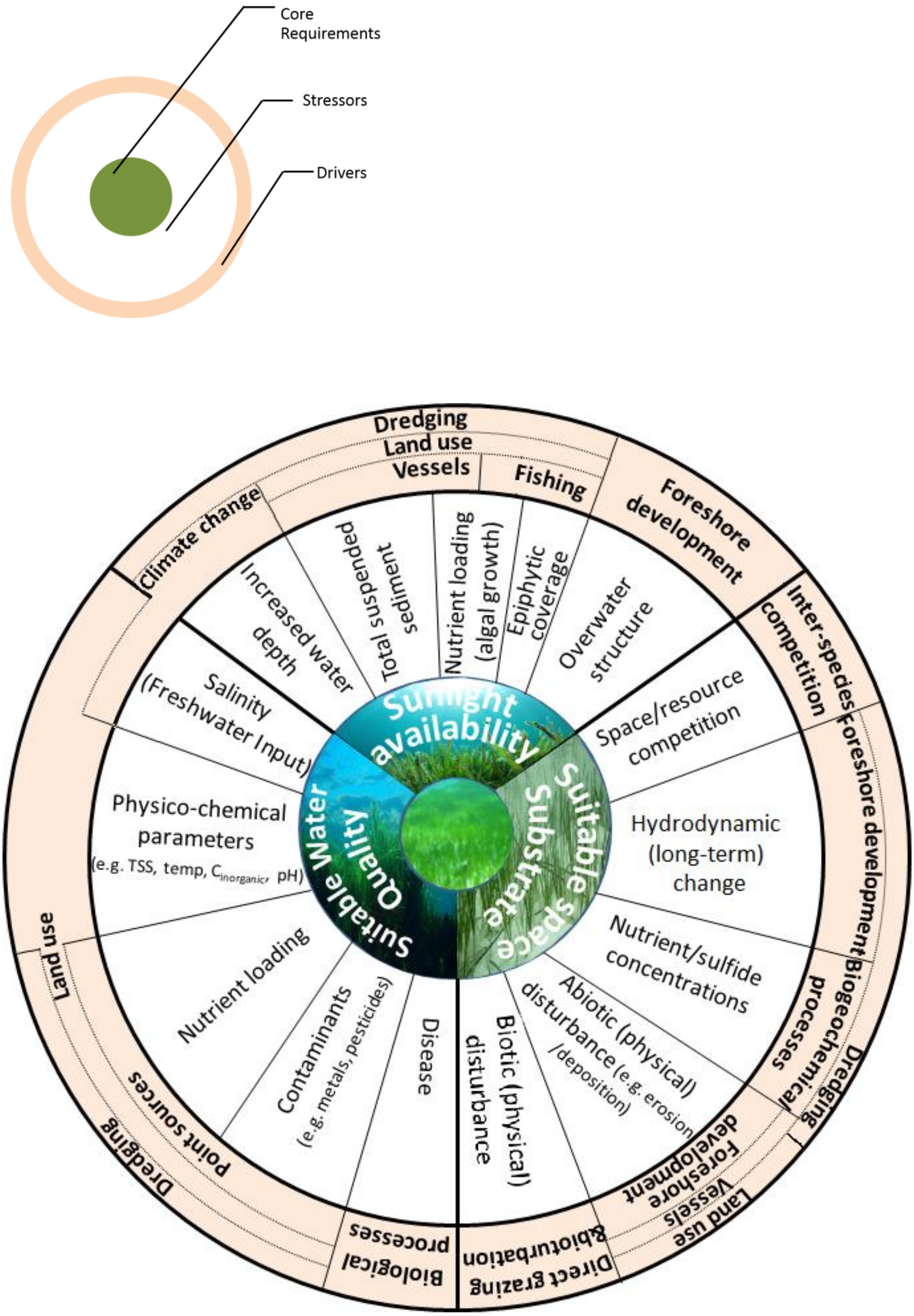

Fig. 2. Conceptual model of key impacts (controlling factors) and the stressors they drive in relation to the three core seagrass habitat requirements in Gold Coast waterways

3. Processes Impacting Seagrass Health and Distribution

This section outlines individual threats and processes and highlights the magnitude, frequency, spatial and temporal impacts of each on Gold Coast seagrass communities.

3.1 Dredging

Impacts upon:

- **Sunlight availability:** availability and spectral quality (through suspended solids), burial, water depth
- **Suitable space/substrate:** substrate availability, erosion, current velocity, wave exposure
- **Suitable water quality:** water column metals, nutrients, total suspended solids
- **Direct damage to seagrasses**: physical disturbance, removal, burial

Dredging impacts upon all three of the core seagrass habitat requirements with the largest threats likely through direct damage to seagrasses (physical removal), reduction of light availability and quality through sediment resuspension, and physical removal of suitable habitat (Erftemeijer & Lewis 2006). Resuspended sediment has the potential to increase contaminants in the water column (e.g. metals) (van den Berg et al. 2001, Eggleton & Thomas 2004) and alter light spectral quality to less useful wavelengths for seagrass photosynthesis which can impact upon seagrass health and growth (Chartrand et al. 2012). Increased water depth through dredging may directly reduce suitable habitat but also allow for potential increases to current velocity and wave height (Larkum & West 1990), which can further condense the depth range of seagrass species. Current velocity can be increased by allowing higher volumes of water to move through deepened channels, and wave exposure may increase due to creation of vertical walls and/or through allowance of faster or larger boat traffic. Current velocity can also impact the ability of seagrass propagules to settle and therefore impact the resilience of beds to disturbance. Natural sediment budgets may be disrupted by both dredging and disposal, with the potential for erosion of some shallow banks and an increase in the degree of slope on seabeds.

Dredging also offers the opportunity to provide an increase of suitable habitat through strategic nourishment in adjacent waters, where nourishment options are permitted. The potential benefits of this option in relation to the creation of potential seagrass habitat, however, are dependent on factors such as: the material type, the coastal processes affecting the proposed nourishment site, the extent of existing uses (e.g. impact from vessel and pedestrian traffic), and the existing values of the habitats over which the nourishment is proposed to occur. These factors need to be thoroughly understood and considered before dredge material is utilised for strategic nourishment to avoid any unintentional increases in the overall impacts from the dredging project on seagrass. Reduction of dredge duration (to minimise light stress) and minimising direct removal/burial of seagrass through dredge operations is recommended (see Table 1).

Frequency and extent:

The direct impacts of dredging tend to be short-term (2-12 months) but burial by nourishment and altered hydrodynamics may be longer lasting. Changing channel structure can lead to erosion of banks and impact substrate suitability for seagrass habitats.

Table 1 Dredge mitigation options and their potential applicability to Gold Coast waterways

Dredge Mitigation Measure	Applicability to GCW	Detail/Rationale (Reference)
Minimise dredge duration	High	Limit dredging influence to periods of time that are within the resilience window of the seagrass species.
Appropriate dredge plant	High	Use of dredge plant that creates minimal turbidity (limit overflow etc.), noting that dredge plant is often governed by the material disposal method and location.
Flexible/strategic dredge plan (i.e. timing and location)	Unknown*	Adopt a strategic approach to dredging the GCW to create options for relocation.
Seasonal consideration	Medium/low	Possibly some seasonal windows for deep-water *Halophila*. Benefit for dredging in low growth season for other species is unclear and may not be best option with repercussions at this stage unknown.
Biologically relevant threshold adoption	High	Use of locally derived light thresholds for seagrass species to manage dredge impacts (e.g. Chartrand et al 2012)
Turbidity plume modelling	Medium	Model likely plume extent and duration to manage interactions with seagrass
Limit over-dredge quantities	Low	Minimises duration of dredging campaign, quantity of material to be removed and potentially the hydrodynamic changes to the waterway, but these benefits need to be balanced against the potential increased dredging frequency required to maintain minimum required channel depth.
Apply sub-lethal indicators to management	Medium	Use of sub-lethal indicators of seagrass light stress to inform dredging management. Molecular markers of seagrass light stress can be detected within 24 hours of plant collection (Pernice et al. in press). Will inform if dredge turbidity is leading to light stress.
Redesign of channel locations	Low	Redesign location of channels to avoid impacts with seagrasses. Unlikely to be available for the majority of GCW due to navigation requirements and the presence of seagrass in proximity to the majority of channel locations
**Quantify and strategically monitor seagrass	High	An ambient monitoring program will allow seagrass changes that may occur during (and beyond) dredging activities to be put into perspective with the range of natural seasonal and inter-annual variability. Will also allow the development of locally relevant thresholds and an understanding of the natural drivers of change (http://www.jcu.edu.au/portseagrassqld)
**Quantify relative resilience of GCW seagrasses	High	Seagrass meadows will have varying levels of resilience and ability to recover from dredging impacts. Assessing seagrass meadow seed-banks and their viability, connectivity of meadows and the differing ability of species to recover from loss will provide key information on appropriate levels of dredge related stress that will allow for long term viability of the meadows
**Quantify the characteristics of the material to be dredged and hydrodynamics of the dredge site	High	Understanding the sediment characteristics (e.g. particle size) and hydrodynamics within the dredge area are key considerations in determining the most appropriate mitigation measures.
**Dredge Management Plan/Environment Management Plan	High	Developing strategic Management Plans to draw together and document the agreed mitigations, thresholds (performance indicators) monitoring, reporting and corrective actions in place to ensure minimal impacts to seagrass (and other sensitive receptors).

*Applicability unknown at this stage pending further research

**Grey section of table details actions that would be required as a precursor to effective mitigation action rather than actual dredge mitigation measures

3.2 Vessel Damage

Impacts upon:

- **Sunlight availability:** availability (resuspended sediments), burial
- **Suitable space/substrate:** substrate availability, wave exposure (boat wake)
- **Suitable water quality:** total suspended solids
- **Direct damage to seagrasses:** physical removal

Two key aspects of vessel movement impact on seagrasses – direct damage through propeller scarring (Sargent et al. 1995), and sediment resuspension through vessel wash/wake, which can increase TSS concentrations (Kenworthy et al. 2002, Beachler & Hill 2003). There are also impacts when vessels are not moving. Anchor damage to seagrasses occurs during anchor deployment, during chain and anchor dragging whilst the boat is at anchor and during retrieval. An anchor landing on a patch of seagrass can bend, damage and break shoots (Montefalcone et al. 2006). Traditional swing moorings have a chain attached to an anchoring block on the seabed and then either directly to a buoy at the surface or to an intermediate rope. As the chain pivots on the block it scours the seabed and in seagrass beds usually removes not only the seagrass' above ground parts (leaves and shoots) but also the roots and often a layer of sediment. These combined impacts affect all three core habitat requirements, as well as physically removing seagrasses. Sediment resuspension also has the potential to increase pollutants and nutrients in the water column (Gruber et al. 2011), which can act to inhibit seagrass health, or drive algal blooms which can out-compete seagrasses for light and space. In addition, vessels in high density can also affect sediment quality through input of heavy metals (Warnken et al. 2004). Research on vessel damage to seagrass beds in Australia is scarce and the high boat traffic in the Gold Coast waterways would make them an interesting case study for research in this area. Programs to replace traditional moorings with specially designed "seagrass friendly moorings" have been trialled and implemented in Moreton Bay (DEEDI 2011), including the installation of over 100 seagrass friendly moorings during 2012 and 2013 as part of SEQ Catchments Seagrass Recovery Program (RPS APASA 2014).

Frequency and extent:

In GCWs, the frequency of vessel damage is expected to be relatively high given the regularity and intensity of recreational boat traffic. Severe damage from boat scarring has been well-documented in the USA (e.g. in Florida; Sargent et al. (1995)). Even there, the spatial extent of direct propeller scarring is relatively low per event, but the number of events may be high, hence damage can be substantial (e.g. Fig. 3), and the effect is relatively long-term given the physical removal of plants.

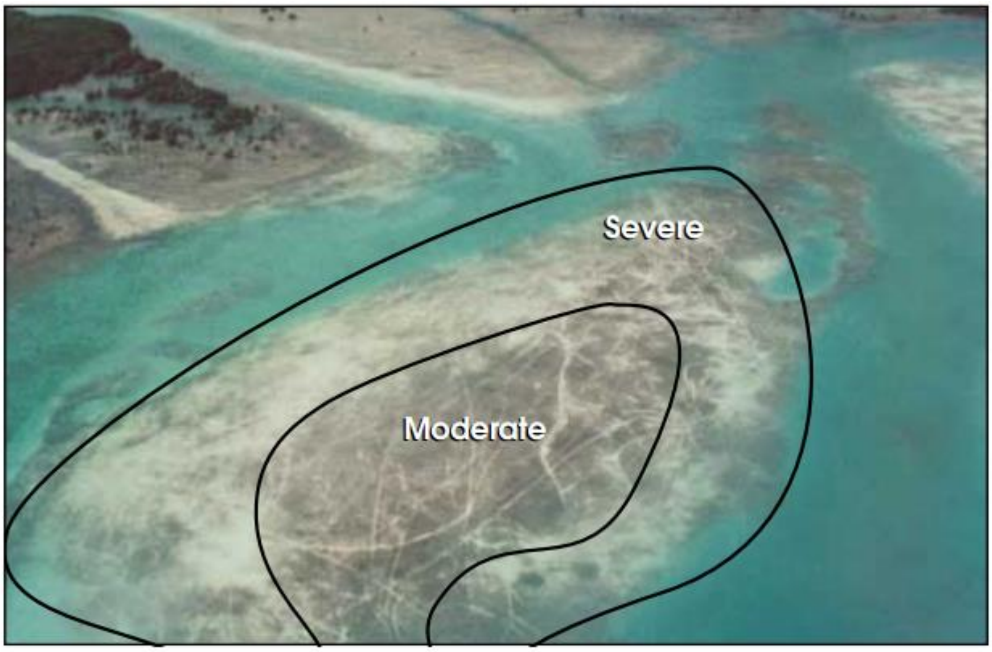

Fig. 3. Ranked boat scarring damage in Florida (Source: Sargent et al. 1995)

Resuspended sediment from vessel movements and boat wash is of significant concern because of the regularity and intensity of recreational boat traffic. Existing well-established seagrass beds are likely to be somewhat resilient to the impacts of boat-induced water movement, but colonising and sporadic communities, as well as established beds near to recent dredge locations, are at risk (NB. dredge activities potentially increase wave and current exposure, and hence affect depth and spatial distribution of seagrass (see Section 3.7)).

Management options suggested by Sargent et al. (1995) to combat boating impacts on seagrasses included improvement of channels, channel markers, and public education. Furthermore, with the development and increased use of Electronic Chart Display and Information Systems (ECDIS) and electronic navigational charts (ENCs), opportunities now exist for creating habitat vulnerability layers (which could be turned on and off) to inform boat users via their GPS systems (http://www.noaa.org).

GCWA's SWIM project includes the creation of a similar platform and seagrass distributions could be provided through this platform to improve public awareness.

3.3 Foreshore Development

Impacts upon:

- **Sunlight availability:** availability (shading)
- **Suitable water quality:** nutrients and pollutants (e.g. metals, herbicides/pesticides)
- **Physical removal:** physical disturbance, burial

Foreshore development can affect seagrasses through direct removal of seagrass habitat, shading and contaminant input. Overwater and near-water structures such as high-rise buildings, bridges, wharves, jetties, boat moorings and attached vessels, generally limit light availability during some portion of the day, which can lead to light-stress and eventual die-off in some areas. Land claim (often referred to as reclamation) in relation to coastal development will permanently remove seagrass habitat and/or other riparian vegetation such as wetlands and mangroves that act as a natural filter and improve water quality for adjacent seagrass systems. Foreshore hardening may also influence local hydrology and sediment dynamics, indirectly causing seagrass loss and degradation. Furthermore, increased near-water development can lead to intensified human population density and hence increases to pollutant inputs into waterways.

Frequency and extent:

The urbanisation and hardening of Gold Coast foreshores has expanded rapidly in recent decades, particularly in the lower estuarine reaches of Tallebudgera and Currumbin creeks and the western shore of the Broadwater; these changes are mostly permanent. The spatial extent of overwater structures within GCWs has not been adequately quantified but, where present, the effect is long term.

3.4 Changing Land-use

Impacts upon:

- **Sunlight availability:** availability (nutrient induced algal blooms)
- **Suitable water quality:** total suspended solids, pollutants (metals, herbicides/pesticides, nutrients)

The functional use of nearby land can change the water quality parameters of water bodies. Land use changes through the removal of natural vegetation and replacement with rural, urban and industrialised landscapes have already altered the water quality characteristics of Moreton Bay, including GCWs (Leigh et al. 2013). These changes can alter hydrological cycles, increasing run-off and associated inputs of sediments, organic material, nutrients and pollutants (e.g. herbicides/pesticides) into rivers and estuaries (Vitousek et al. 1997). These inputs are known to reduce water quality and light availability through increasing the amount of total suspended solids in the water column and initiating phytoplankton blooms (Abal & Dennison 1996). In addition, increased inputs of pollutants, such as herbicides, to receiving waters may lower the fitness of seagrass in the presence of other stressors. This effect can be more severe when there is a ‘cocktail effect’ from multiple contaminants (Nielsen & Dahllöf 2007). Geochemical cycles are also affected by these inputs. Increased organic matter is broken down by sulphate reducing bacteria resulting in increased sulphides and anoxia in the sediment which are toxic to seagrasses at high levels (Koch 2001, Pedersen & Kristensen 2015).

Further unregulated change to land-use in the Gold Coast catchment area has the potential to exacerbate these problems and further reduce seagrass health (Freeman et al. 2008, Grech et al. 2011).

Frequency and extent:

Rainfall events drive the frequency and extent of the influence of land based inputs, hence impact is frequent and often widespread

3.5 Wastewater

Impacts upon:

- **Sunlight availability:** availability (nutrient induced algal blooms and turbidity)
- **Suitable water quality:** total suspended solids, nutrients, pollutants (e.g. metals, herbicides/pesticides)

Wastewater inputs in GCWs are predominantly from disposal of treated sewage and from stormwater. The main effect of wastewater inputs on seagrass health is through the introduction of additional nutrients into the system. This can have both positive and negative effects on seagrass growth, depending on the concentration of added nutrients compared to natural levels. Adding nutrients to a generally nutrient limited area is likely to increase growth (Kelaher et al. 2013), while additional nutrients to a nutrient saturated area will likely reduce seagrass health (Fig. 4). This is because additional nutrients can physically reduce light availability by increasing phytoplankton in the water column, or promoting growth of algal species which can out-compete seagrasses for light and space, including shading by epiphytes (Valiela et al. 1997, McGlathery 2001). Stress from wastewater also has the potential to increase the susceptibility of seagrass to disease; however this area is poorly researched and requires further investigation.

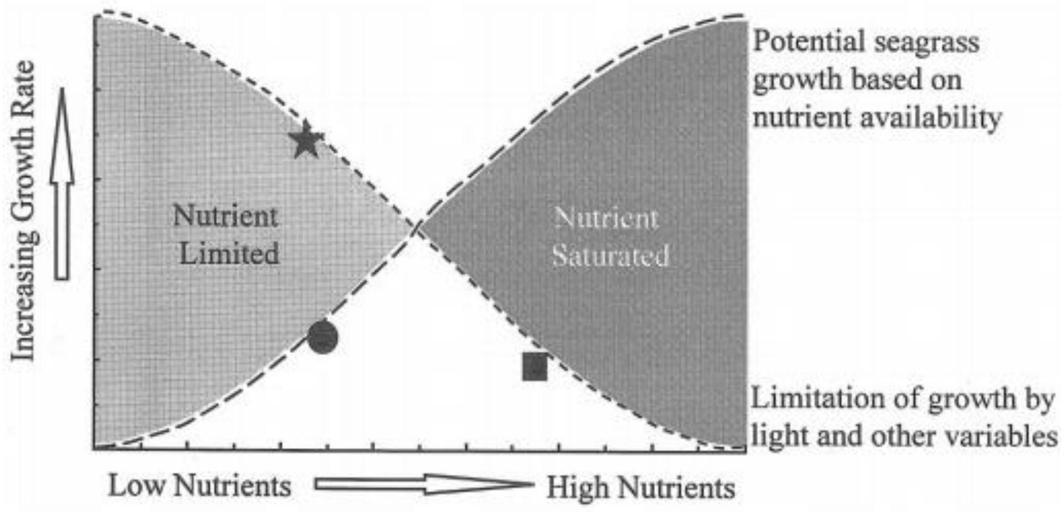

Fig. 4. Model of effects of nutrient availability and other environmental variables on seagrass growth. Dotted lines represent the maximum potential growth rate based on nutrient availability (– – –) or other environmental variable such as light (- - -) (Source: Udy and Dennison (1997a)).
Actual seagrass growth is on the lower of the two lines. Symbols represent sites within Moreton Bay with the star being an intentionally fertilized (within sediment) site, the square being sites close to nutrient sources (e.g. sewage output), and the circle being sites distant from nutrient sources

Frequency and extent:

In Gold Coast waterways, sewage input is frequent (e.g. daily), though only from within the Gold Coast Seaway and only on the outgoing tide (outside of heavy rainfall periods) (Stuart et al. 2009). Our current understanding is that the impact on seagrasses within GCWs is expected to be minimal as sewage loads are usually directed out to sea and diluted, minimising interaction with seagrasses growing in the GCWs. However, future changes to this point-source release regime should carefully consider potential impacts on seagrass. Diffuse inputs via stormwater would increase after rain. The nutrients arriving via stormwater have not been separated from general catchment inflows via river estuaries, and this is an issue in need of attention (City of Gold Coast 2013).

3.6 Inter-species Competition

Impacts upon:

- **Sunlight availability:** availability (shading from other species)
- **Suitable space/substrate:** habitat availability
- **Suitable water quality:** algal blooms

Seagrass species within GCWs are reported to dominate different depth 'zones'. For example, within the Broadwater, McLennan and Sumpton (2005) reported that *Zostera muelleri* (formerly *capricorni*) generally dominated down to 0.7 m while *Halophila* spp. dominated at depths between 0.7 – 2 m. Additionally, biannual survey datasets (2001 to 2015) established by the Ecosystem Health Monitoring Program (South East Queensland Healthy Waterways Partnership) demonstrate the seagrass depth range of *Z. muelleri* (i.e. difference in elevation between the upper and lower depth record at a site) ranges between 0.43 ± 0.23 m – 1.84 ± 0.37 m within the Gold Coast Broadwater. While inter-specific competition among seagrass species undoubtedly occurs and influences depth distributions, seagrass species coexist in mixed stands within GCWs (e.g. McLennan & Sumpton 2005). Regular disturbance events and changes in nutrient availability in mixed species meadows have been shown to competitively benefit some species over others and lead to shifts in relative species compositions (Rasheed 2004). The most significant competitive threat to Gold Coast seagrasses comes from algal species such as *Caulerpa taxifolia*, which can occupy temporarily bare substrate and prevent colonisation or recolonisation by seagrass (Burfeind & Udy 2009). Although *C. taxifolia* is an invasive species in New South Wales, it is native to tropical and subtropical regions of Australia with Moreton Bay being the southernmost extent of its native range (Phillips & Price 2002).

Frequency and extent:

The ability for algal species to out-compete seagrasses is driven in large part by nutrient input and grazing pressure. These are both discussed more in Sections 3.5 and 3.10, respectively.

3.7 Physical Stress (Water Movement)

Impacts upon:

- **Sunlight availability:** availability (sediment resuspension, intra-specific shading)
- **Suitable space/substrate:** substrate availability
- **Suitable water quality:** total suspended solids
- **Direct damage to seagrass:** physical disturbance, burial

Water movement can fall under two categories, waves and currents, both of which can impact seagrass health and distribution. Wave height can restrict the depths at which seagrasses can grow by either physically damaging seagrasses in shallow water (Fig. 5), or resuspending sediments (hence reducing light availability) and reducing the maximum viable depth (Koch 2001). Furthermore, wave exposure has also been shown to cause self-organised spatial patterning in subtidal seagrasses (van der Heide et al. 2010). Water currents can also reduce available space often through erosion (hence also acting to physically remove the plant and/or influence seed dispersion, removal or burial) (Orth et al. 1994, Valdemarsen et al. 2010). Another potential impact from water movement (especially sustained currents) is through affecting the orientation of seagrass leaves, and causing self-shading within a given meadow. There is a complex interaction between seagrass and local hydrology as water movement affects the distribution of seagrasses, but the seagrasses themselves mediate water movement (Madsen et al. 2001, Nepf 2012, Ondiviela et al. 2014). The capacity of seagrass beds to attenuate waves can be reduced through degradation, fragmentation or loss of the seagrass.

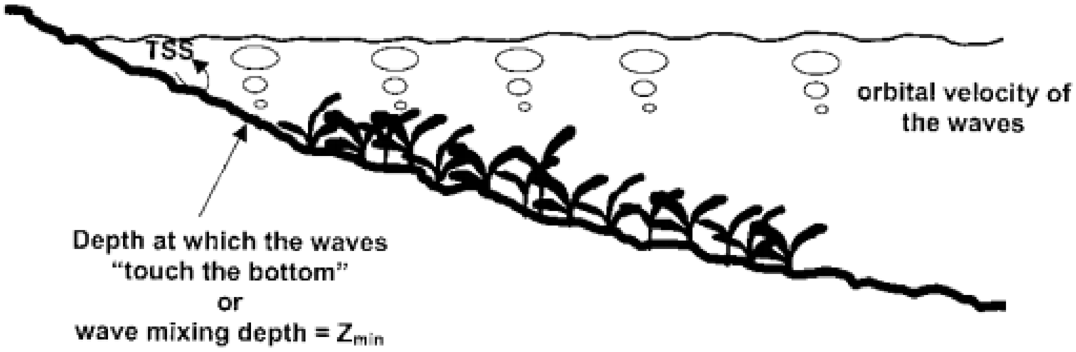

Fig. 5. Effect of wave exposure on depth distribution of seagrasses (Source: Koch 2001)

Frequency and extent:

GCWs, being at least partially enclosed waterways, are somewhat protected from the most extreme wave exposure, but storm events or boat wake and changes to hydrology through channel dredging or shoreline hardening (as discussed previously) can still impact seagrass abundance and distribution. Current velocity within GCWs can be strong, especially on spring tides, and has the potential to impact seagrass beds on a regular and ongoing basis. As mentioned in the vessel damage section (Section 3.2), well-established seagrass beds are unlikely to be affected significantly by water-movement under current conditions. However, future dredging projects that may alter hydrodynamics within GCWs should involve careful consideration of these potential impacts on seagrass communities. Hydrodynamic and sediment dispersion modelling could be used to investigate potential alterations to depositional and/or erosional regimes, which may potentially impact seagrasses.

3.8 Climate Change

Impacts upon:

- **Sunlight availability:** availability (resuspended sediments), burial
- **Suitable space/substrate:** substrate availability (erosion through wave exposure, sea-level rise, temperature stress), competition (range expansions)
- **Suitable water quality:** total suspended solids, temperature changes, altered river inputs (salinity, contaminants)

- **Direct damage to seagrass**

Climate change – specifically sea and air temperature increases, sea-level rise (SLR), and increased extreme weather events - are expected to have, on balance, deleterious effects on all three core habitat requirements for seagrasses although the relationship between these factors are complex and currently not well understood. Intertidal species are likely to be affected by increased desiccation at low-tide, and an inability to ‘move’ higher due to range inhibitions by other habitats (e.g. mangroves) or structures (Fig. 6 and Fig. 7) (Waycott et al. 2007). Increased UV light also has the potential to damage intertidal beds (Unsworth et al. 2012). Subtidal beds persisting at levels approaching light limitation are also vulnerable to increased turbidity from storm and flood events (Rasheed & Unsworth 2011).

Temperature stress on seagrasses will result in distribution shifts, changes in patterns of sexual reproduction, altered seagrass growth rates, metabolism, and changes in their carbon balance (Short & Neckles 1999). Elevated temperatures may also increase the growth of competitive algae and epiphytes, which can overgrow seagrasses and reduce the available sunlight they need to survive (Peirano et al. 2005).

Increased storm activity is also likely to cause direct loss to seagrass through wave exposure and resultant erosion events (as explained under 3.7). Flood plumes may increase frequency, and spatial and temporal extent, which is likely to induce light, salinity, and contaminant stress (Saunders et al. 2013, Rasheed et al. 2014).

Frequency and extent:

The frequency of extreme weather events is likely to increase in the future, and SLR and temperature increases are likely to have both widespread spatial and temporal impacts affecting all species of seagrass in GCWs.

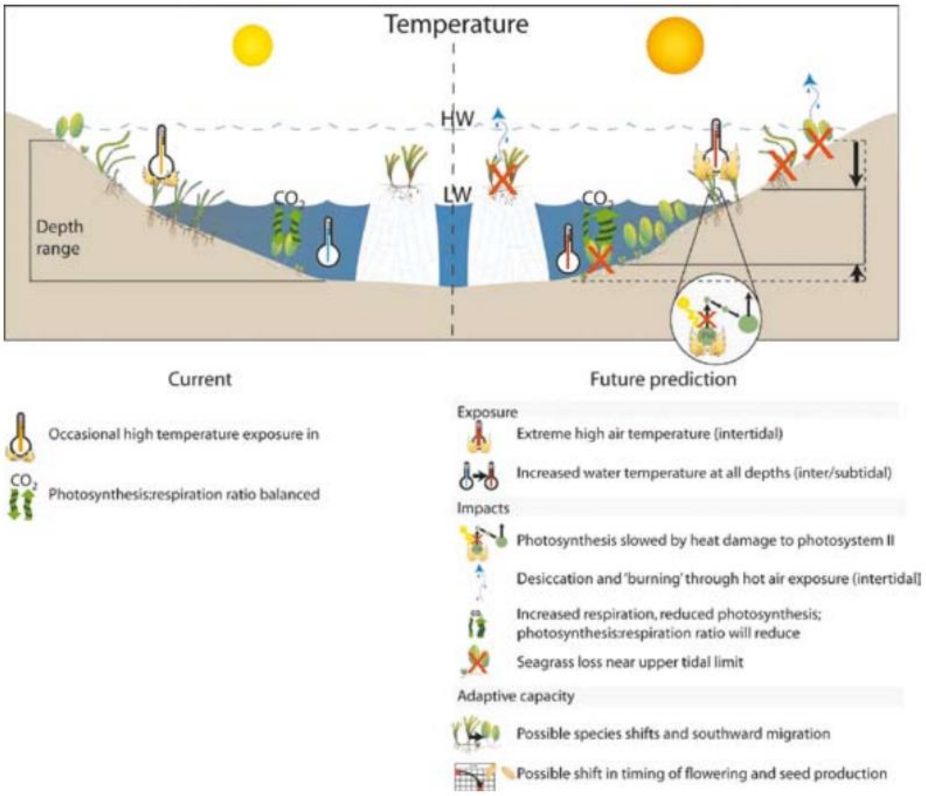

Fig. 6. Expected seagrass response to rising sea and air temperatures under climate change scenarios (Source: Waycott et al. 2007)

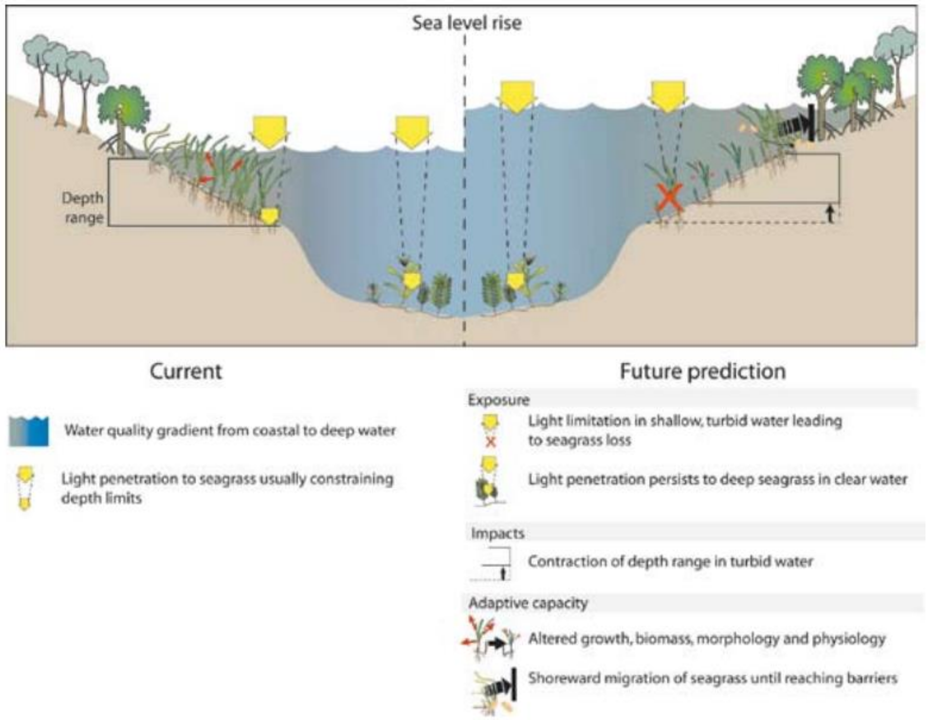

Fig. 7. Expected sea level rise impacts on seagrass communities (Source: Waycott et al. 2007)

3.9 Fishing Pressure

Impacts upon:

- **Sunlight availability:** availability (algal blooms)
- **Suitable space/substrate:** competition (algal blooms)
- **Direct damage to seagrass:** physical disturbance

Although much of the focus on seagrass health is, rightly, about availability of light and substrate, grazing by herbivorous animals has also been shown to significantly affect seagrass abundance and distribution (Heck & Valentine 2006). Alteration of animal populations occurs through cascading effects of harvesting (and especially overharvesting) of predators on the grazing animals (from dugongs and turtles to fish and invertebrates). Increased fishing pressures can lead to a reduction in epiphytic grazers, which in turn can lead to an increase in epiphytic algae, and inhibit seagrass productivity. Often the combined effects of increased fishing pressures and nutrient enrichment will interact to have overwhelmingly negative effects on the seagrass ecosystem (Fig. 8). Recent caging experiments in Moreton Bay, however, led to the conclusion that the effects of altering grazing communities vary in their specifics from place to place, and even in whether they have a negative or positive effect on seagrass (Ebrahim et al. 2014). The application to GCWs requires further evaluation. Impacts from fishing pressure also relate to boat traffic as per the vessel damage section (3.2).

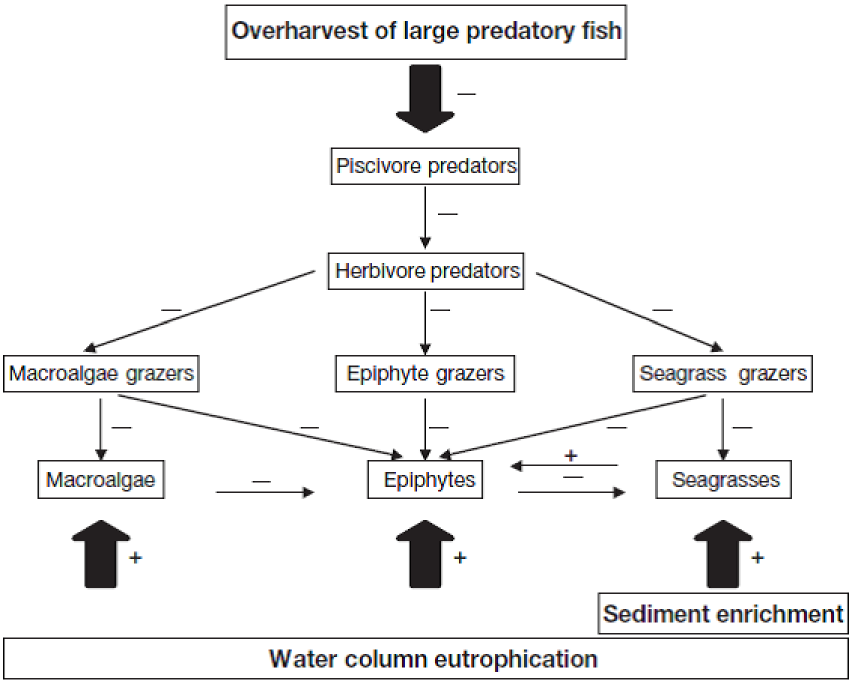

Fig. 8. Effects of the combined stressors of fishing pressure and increased nutrients in the water column on seagrass trophic interactions (Source: Hughes et al. 2004). Positive effects are represented by (+) and negative effects are represented by (-)

Frequency and extent:

Recreational fishing pressure is substantial and constant in GCWs. There is no evidence either way as to whether seagrass has been or is affected as a result. Effects of fishing, however, are considered by Maxwell et al. (2015) to be potentially important when they interact with other factors to affect seagrass resilience in Moreton Bay, and the topic warrants investigation specifically for GCWs.

3.10 Direct Grazing and Bioturbation

Impacts upon:

- **Sunlight availability:** availability (resuspended sediments), burial
- **Suitable space/substrate:** changes to geochemistry
- **Direct damage to seagrass:** physical disturbance, removal, burial

Dugong and green turtles are large herbivores that rely heavily on seagrass meadows for the dominant portion of their diet. Grazing impacts of dugong herds in Moreton Bay often remove 65 – 95 % of above ground biomass and up to 71% of below ground roots and rhizomes (Preen 1995). Green turtles at high densities have also been observed to impact heavily on seagrass systems through overgrazing (Christianen et al. 2015).

In addition to large herbivore grazing, benthic fauna including: burrowing crab, shrimp, polychaete worms and stingray also represent a stressor to seagrass meadows (e.g. Suchanek, 1983, Valentine et al. 1994, Valdemarsen et al. 2011, Delefosse & Kristensen 2012). Mechanisms by which bioturbators directly influence seagrasses are through burial of shoots and seeds, uprooting of shoots and patches, undermining of seagrass patches, damaging roots or rhizomes, and shading by deposition of resuspended sediments onto leaves (e.g. Fig. 9). Burrowing also directly and indirectly changes biogeochemical processes within the substrate (Suchanek 1983, Papaspyrou et al. 2005, DeWitt 2009).

Frequency and extent:

Dugong and turtles are known to inhabit GCWs, however, sightings are rare. Consequently they are not believed to be impacting heavily on seagrass beds within the area. If individuals of the populations in Moreton Bay were to shift into the GCWs in search of food then it is possible that they could have significant grazing impacts on local seagrass populations.

Burrowing faunal groups representing burrowing crab, shrimp, polychaete worms and stingray are known to inhabit the GCWs.

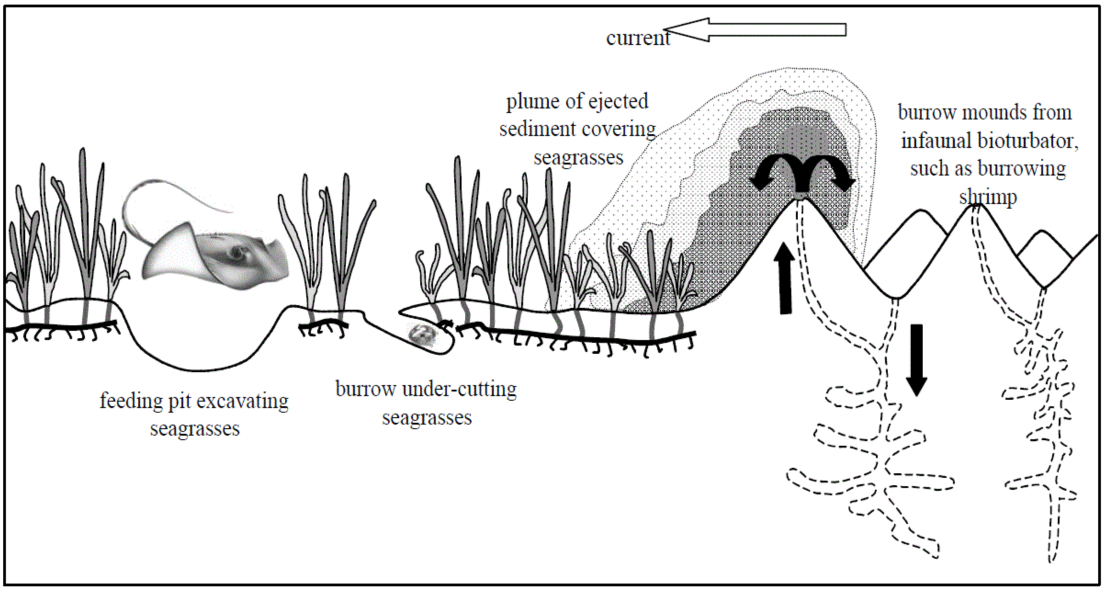

Fig. 9. Illustration of some of the adverse effects of bioturbation on seagrass. Arrows show paths of sediment subduction, advection and resuspension as a result of sediment reworking by burrowing shrimp (Source: DeWitt 2009)

4. Minimum Stressor Thresholds for Gold Coast Seagrasses

Minimum thresholds for stressors as currently understood for Gold Coast seagrass species are summarised in Table 2 (with literature sources in Table 3). These thresholds are baseline requirements for each seagrass species, which should be maintained at minimum (unless otherwise indicated) to avoid declines in seagrass health, abundance, or distribution. Where a species is known to have undergone a nomenclature change, this is indicated by an asterisk with any studies using the previous name being marked accordingly.

Table 2 Minimum threshold requirements for seagrasses in Gold Coast waterways (where available)
Citation codes are presented in Table 3. Grey cells indicate low confidence in values presented and should be updated if more relevant data becomes available. Blank cells indicate no relevant data has been found

Core Req.	Measure/ Effect	Measure	*Cymodocea serrulata*	*Halodule uninervis**	*Halophila decipiens*	*Halophila ovalis*	*Halophila spinulosa*	*Syringodium isoetifolium**	*Zostera muelleri**
Light	**Minimum light Requirements (MLR)**	**Daily Dose: Range (mean) (mol m^2 day)**		**3 - 5 (3.5)**	**(1.5)** from deep water populations				**4.5-12 (6)**
		Citation		15, 38	39				37
		Surface Irradiance (%) (Higher = more sensitive)	**>20**	**14-19**	**2.5-8.8**	**16**	**<6**		**30-36**[#]
		Citation	15	*6	3, 40, 41	7	2		*1, *5
	Survival (below MLR)	**Days @ 0-1% S.I. (Start of loss - complete loss) (total shoot density loss[a]; total biomass loss[b])**	**46 - 100**[a]	**38 - 119**[a]		**?-31**[b]			**31 - 76**[a]
		Citation	15	15		19			15/20
	Burial causing mortality	**cm**	**2**	**4**		**2**		**4**	
Space		Citation	16, 14, 40	16, 14, 40		16, 14, 40		16, 14, 40	
	Depth	**Relative Rank (Max depth: 1= shallowest, 4 = deepest)**	**2**	**2**	**4**	**3**	**4**	**2**	**1**
		Citation	42	42	42	42	42	42	42
	Specific substrate req.	**Preferred substrate type (silt/fines = <63µm grain size)**	**<25%**	**<12%**		**<12%**		**<15%**	**0.5-72%**
		Citation	14	14		14		14	22
	Competition	**Does presence of other species inhibit growth/distribution?**							
		Citation							
	Current velocity	**Velocity (relative rank: 1 = capable of withstanding 'high' current velocity)**		**1**	**2**	**4**	**4**		**3**
		Citation		42	42	42	42		42
	Tidal exposure	**Increased air exposure**	**Negative effect, but not species specific**						
		Citation	21						
Water Quality	**Wave exposure**	**Energy - linked to spp. min depths (21,26)**							
		Citation							
	Nutrient Load	**NH_4^+ sediment pore water - observed range (µM)**[2]	**7.4**	**6.2-7.4**				**6.2**	**7.4 - 25**
		Citation	10	27, 10, 33				*33	*27, *10, *32
		PO_4^{3-} sediment pore water - observed range (µM)[2]	**4.7**	**1.1-4.7**				**1.1**	**4.7**
		Citation	10	27, 10, 33				*33	*10
	Temperature[1]	**Range (°C)**							
		Citation							

	Salinity	**Observed natural salinity range within beds (PPT)**	**32.5-35.5**	**18.8-35.5**		**3.5-36.0**	**22.8-35.7**		**3.5 - 36.0**
		Citation	12	12		12	12		*12
	Metals Threshold for harm = any observable adverse effect on any variable measured	**Iron - threshold for harm (mg/L)**				**1**	**1**		
		Citation				23	23		
		Copper - threshold for harm (mg/L)				**<1**	**<1**		**<0.1**
		Citation				23, 35	23		*36
		Zinc - threshold for harm (mg/L)				**<1**			**<0.1**
		Citation				35			*36
		Cadmium - threshold for harm (mg/L)				**<1**			**>1**
		Citation				35			*36
		Lead - threshold for harm (mg/L)				**1<5**			**>1**
		Citation				35			*36
	Herbicides	**Diuron - threshold for harm (µg/L)**	**<10**			**<0.1**			**<0.1**
		Citation	34			34			*34
	Algal blooms	***Relative* likelihood of impact (based on seagrass size)**	**Med-Low**	**Med-high**	**High**	**High**	**Med**	**Low**	**Low**
		Citation	24	24	24	24	24	24	24
	Total Suspended Solids	**Affects depth range for all spp. - Min requirement = 0m depth range (mg/L)**							**~10**
		Citation							*25

CONFIDENCE Matrix	**Relevance to Gold Coast waterways**		
Methods used in study	Local study	Regional Study	International study
Expert opinion	Intermediate	Low	Low
Inferred from published literature	Intermediate	Intermediate	Low
Direct measure in published literature	High	Intermediate	Intermediate

Observed natural range (not indicative of minimum requirement)

Note: *Halophila minor* has been recorded within Gold Coast waters, however, given the lack of verification and lack of published literature specific to this species, it has been omitted from this table.

***** an asterisk represents a historical nomenclature change and identifies that the species was referred to under a different name within the study presented: *H. uninervis* was *H. pinifolia; S. isoetifolium* was *S. filiforme*; and, *Z. muelleri* was *Z. capricorni*

[#] Values derived from experimental data and therefore might not account for the adaptive nature of *Z. muelleri* to changing antecedent light difference. *Z. muelleri* in the Broadwater has a range of different morphologies which is likely a result of the different light regimes and therefore could have a larger range of light requirements than is reported in the literature.

1 - Global temperature rises expected only to affect distribution of seagrasses already living at temperature extremes. Intertidal seagrass communities may also be affected. Air/shallow water temperature increases may reduce survivability in the upper-intertidal zone (Waycott et al 2007)

2 - Lee et al 2007. "*From available data in literature, productivities of seagrasses were not significantly correlated with water column nutrient concentrations…*"

Seagrass depth range codes: 1 = Intertidal to 1 m**; 2 =** Intertidal to 5 m; **3 =** Intertidal to 20 m**; 4** = 1 m to 60 m.

Table 3 Reference key to Table 2

Reference number	Citation
1	Abal and Dennison (1996)
2	Collier and Waycott (2009)
3	Duarte (1991)
4	Kenworthy and Fonseca (1996)
5	Longstaff (2003)
6	Longstaff and Dennison (1999)
7	Schwarz et al. (2000)
8	Short et al. (1990)
9	Short et al. (1993)
10	Udy and Dennison (1997b)
11	Vermaat et al. (1997)
12	Young and Kirkman (1975)
13	Waycott et al. (2007)
14	Terrados et al. (1998)
15	Collier et al. (2012)
16	Cabaço et al. (2008)
17	Duarte et al. (1997)
18	Short et al. (2011)
19	Longstaff et al. (1999)
20	Grice et al. (1996)
21	De Boer (2007)
22	Edgar and Shaw (1995)
23	Prange and Dennison (2000)
24	Thomsen et al. (2012)
25	Dennison and Abal (1999)
26	Koch (2001)
27	Lee et al. (2007)
28	Masini et al. (2001)
29	Hillman et al. (1995)
30	Dawes et al. (1989)
31	Ralph (1998)
32	Hansen et al. (2000)
33	Udy et al. (1999)
34	Haynes et al. (2000)
35	Ralph and Burchett (1998)
36	Macinnis-Ng and Ralph (2002)
38	Collier et al. (2011)
39	Chartrand et al. (2014)
40	Dennison (1987)
41	Williams and Dennison (1990)
42	Expert workshop participants(2015)

Expert workshop participants exchanging shared knowledge and insight into the project topic included:
Prof. Rod Connolly (Griffith University)
Dr Ryan Dunn (Griffith University)
Dr Emma Jackson (Central Queensland University)
A/Prof. Erik Kristensen (University of Southern Denmark)
Dr Paul Maxwell (Healthy Waterways)
Mr Scott McKinnon (Queensland Parks and Wildlife Service)
Mr Ryan Pearson (Griffith University)
Dr Mike Rasheed (James Cook University)
Dr Paul York (James Cook University)

5. Threat ranking for *Zostera muelleri*

Key stressors and threats to *Z. muelleri* on the Gold Coast are ranked based on a series of threat characteristics (Table 4). The stressors are considered individually, below, but can also act in concert with one and another and are often not mutually exclusive. *Zostera muelleri* was selected as the model species because it is the most widespread in GCWs, but also because it is known to be one of the most sensitive species[1] to light stress (Table 2) and hence may be the best candidate to inform practical management decisions to protect all Gold Coast seagrass species as per Chartrand et al. (2012).

The adopted stressor characteristics and assigned scores are based on inferences from published literature and expert opinion, including those arising from the expert workshop (see page 20). Stressor characteristics are defined following descriptions presented by Thom et al. (2011), and are summarised below.

Magnitude: High: the stressor typically results in mortality. Medium: strong effect but sub-lethal, in the absence of compounding stressors. Low: sub-lethal effects unlikely to contribute to mortality (i.e. may limit growth or resilience).

Spatial extent: High: the stressor will likely influence >80% of regional meadows. Medium: stressor likely to influence 20-80% of regional meadows. Low: likely to influence <20% of regional meadows.

Temporal extent: High: persistent and continuous. Medium: regular (e.g. during spring tides or particular season) but not continuous. Low: infrequent (e.g. less than an annual basis).

Reversibility: the degree to which the stressor can be removed or avoided (only focusing on the physical ability to remove the stressor not the likelihood of doing so) High: easily removed. Optimal conditions return quickly and without remediation. Medium: Difficult to remove and/or some remediation is necessary. Low: Practically impossible to remove or reverse. Changes to habitat are extensive and/or require large-scale remediation.

Characteristic scores were assigned values, where High = 3, Medium = 2 and Low = 1, with the exception of the Reversibility category which, being beneficial, was assigned values in reverse order. All characteristic scores are weighted equally when determining the threat score.

The **Threat score** was calculated as the mean of all four characteristic scores, standardised between 1 (lowest threat) and 3 (highest threat). Higher values reflect a greater threat to Gold Coast *Z. muelleri*.

Uncertainty regarding stressor characteristics is incorporated into the table by assigning a **Knowledge score**. Scores ranged from possible values of 1 = speculative or anecdotal, 2 = information exists however specific are not well understood and 3 = well understood.

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[1] Although *Z. muelleri* is one of the most sensitive species to light reduction it demonstrates a widespread range within the GGWs attributable to the species phenotypic plasticity.

Table 4 Stressors of *Zostera muelleri*, stressor characteristics and ranking within Gold Coast waterways
Characteristic scores assigned High = 3, Medium = 2, Low = 1 with exception of Reversibility category, which being beneficial, values were assigned in reverse order, were used to determine overall standardised threat score. Knowledge score ranged from possible values of 1 = speculative or anecdotal, 2 = information exists however specifics are not well understood and 3 = well understood. Colours identify relative ranking with Red being greatest overall threat and lowest knowledge and green being lowest threat and highest knowledge

Process	Characteristic of stressor					
	Magnitude	Spatial Extent	Temporal Extent	Reversibility	Threat score	Knowledge Score
Dredging (excluding disposal)	High	Low	Low	Low	1.0	2
Vessel damage	High	Medium	High	Medium	2.0	2
Foreshore development	High	Low	High	Low	2.0	2
Land use	Medium	High	Medium	Medium	1.5	2
Point sources	Medium	Medium	Medium	Medium	1.0	2
Inter-species competition	Medium	Low	High	Medium	1.0	1
Climate change	High	High	High	Low	3	1
Fishing pressure	Low	High	High	Medium	1.5	1
Biogeochemical Process Change	Medium	Medium	High	Medium	1.5	1
Direct grazing and bioturbation	Medium	High	High	Low	1.5	1

Threat and knowledge score/s colour key spectrum

Threat score	1	🟩	2	🟧	3	🟥
Knowledge score	3		2		1	

6. Critical Knowledge Gaps about Sensitivities and Resilience of Gold Coast Seagrasses

Table 5 Critical knowledge gaps about sensitivities and resilience of Gold Coast seagrasses
(drawn by synthesis from the text and tables in this report, and limited to major gaps); and level of urgency for research to fill the gap

Level of urgency:
Green = findings required urgently on a critically important topic;
Yellow = research is required on important topic but can afford to delay;
Grey = research will be valuable but is not critical in the short term.

Ordering within an urgency level is solely alphabetical.

Critical knowledge gaps about sensitivities and resilience of Gold Coast seagrasses
Determination of minimum light requirements (daily dose calculations) for different seagrass species – ground truth general paradigm of sensitivity rankings from elsewhere
Effects of indirect consequences of dredge works (reduced light, sediment deposition) on seagrass *at different times of year* (i.e. resilience window)
Applicability of non-lethal monitoring techniques developed recently in tropical Queensland?
Barriers to natural recovery of seagrass in areas from which it has been lost – propagule supply, germination and establishment to seedling stage
Capacity of seagrass in GCWs to cope with effects of climate change including increased water temperatures, fluctuations in salinity regimes, acidification and rising sea levels (initial desktop assessment and/or modelling)
Effects of burial by different amounts (depths) of sediment on seagrass
Fine-scale changes in seagrass distribution in critically important areas (e.g. Southport foreshore), and determination of causes for apparent very localised losses of seagrass
Investigate the ecosystem importance of seagrass in different regions of the GCWs (e.g. how important are meadows for local fish communities?)
Assess the combined effects of multiple stressors on seagrass resilience
Barriers to natural recovery of seagrass in areas from which it has been lost. Determine areas at risk of seagrass loss that will not recover (e.g. areas of bistability) – health and growth of established plants
Grazing impacts on seagrass and the algae growing on them
Quantitative assessment of existing and potential threat of replacement of seagrass with macroalgae (e.g. Caulerpa)
Role of sediment biogeochemistry in seagrass health, growth and seedling establishment
Variation in effects of nutrients (eutrophication) for different species and in different parts of GC waters

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