Seagrass

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Summary: Seagrasses in Australia are extensive and diverse, and function as ecosystem engineers. They oxygenate the water, regulate nutrients, stabilise sediments, protect shorelines by restricting water movements, provide food for finfish, shellfish and mega herbivores including green turtles and dugongs, and support commercially and recreationally important fisheries. As plants living in shallow coastal waters, critical factors for seagrass growth are light, temperature, CO_2, nutrients and suitable substrate, all of which are affected by climate change. Seagrasses are therefore highly vulnerable to a changing climate, and will be sentinels for the changing marine ecosystems of Australian coastal waters.

Correlations between the few long term datasets that exist for Australian seagrasses and climate changes have not been thoroughly tested. Observations of current climate change effects are therefore rare, with just two reported links: 1) 13,000 ha of seagrass was killed by heat stress in a single incident in South Australia in 1993. Anecdotally, these dieback events are suspected of having occurred previously, coincident with ENSO events; 2) a southern extension in range of a tropical seagrass species (*Halophila minor*) into the subtropical waters of Moreton Bay in southern Queensland (300 km south) was recorded in 2008. The confidence with which both of these observations can be linked with climate change is low.

Predictions of expected changes in seagrasses due to climate change can be made with a higher degree of confidence, based on experimental demonstrations of how climate affects critical factors for seagrass growth and what has been observed elsewhere in the world. Expected changes are:

1. General decrease in productivity. Potentially enhanced productivity due to increased dissolved CO_2 and warmer water overridden by increased water depth, and pulsed turbidity from more extreme rainfall events and thus river plumes. Local exceptions in clear, still water (where CO_2 is currently limiting);
2. Local (to large) scale loss due to decreased light (increased water depth, turbidity, storm intensity), increased storm intensity and water temperature. Shallow water seagrass extremely vulnerable;
3. Seagrass community change to heat tolerant species (and/or species favouring CO_2 uptake);

4. Long-term decline of seagrass health and extent in some places; species changes in other places;
5. Changes in distribution of seagrass species. Recolonisation higher on shore, and southward shift (where not prevented by physical barriers or unsuitability of substrate), especially favouring those species with seed dispersal. Diminished range in some species, or lost altogether, especially with synergistic negative effects of other, non-climate stressors;
6. Reduction or loss of ecosystem services provided by seagrass, such as support of dugong and turtle populations, and fisheries productivity reliant on seagrass (and attached algae) either as nursery habitat or for nutrition in adjacent habitats.

Introduction

Seagrasses are distributed globally, but the most extensive and diverse meadows are in Australia (Walker and McComb 1992). Seagrasses occur around the entire Australian coastline, generally in shallow marine waters such as estuaries, protected bays, lagoons and reef platforms protected from strong water movement (Walker and McComb 1992), but also in deeper waters (to 70 m) in northern Australia where water clarity is high.

Seagrasses have been ranked as one of the most ecologically and economically valuable biological systems on earth (Duarte 2002). They are widely referred to as "ecological engineers", because of their significant influence on their physical, chemical and biological surroundings (Orth et al. 2006). They play an important role in:

- regulating oxygen in the water column and sediments
- regulating nutrient cycles
- stabilising sediments
- protecting shorelines through the restriction of water movements
- providing an important food source for finfish, shellfish and mega-herbivores including green sea turtles and dugongs
- providing habitat for microbes, invertebrates and vertebrates including commercially and recreationally important species, as well as crucial habitat for endangered species
- organic carbon production, a large fraction of which is transported to and sustains adjacent ecosystems (Duarte 2002, Orth et al. 2006).

The critical factors for seagrass growth and survival are light, temperature, dissolved carbon dioxide, nutrients and a suitable substrate for anchoring (Green and Short 2003). The present-day distributions and abundances of different species of seagrass reflect their specific requirements for these factors (Waycott et al. 2007). As climate change affects all these factors, changes are expected to seagrass growth, survival, distribution, abundance and community composition (Poloczanska et al. 2007).

The focus of this report is on climate change effects on Australian seagrass systems, although examples from elsewhere are used to show potential implications for Australia. The paucity of long term seagrass datasets in Australia, and in particular the scarcity of those being properly set against climate data, means that in many cases predictions draw on experimental evidence about seagrass responses to environmental variables, married to expected changes in climate.

Observed impacts of climate change on the critical factors for seagrass

Light

As plants, seagrasses require sufficient light for photosynthesis. Light availability is a major factor in determining the maximum depth limit to which seagrasses may grow (Ralph et al. 2007). The specific light requirements for different seagrass species result in differences in distributions and abundances of species over depth gradients from the shoreline to the deeper edges of seagrass communities (Masini et al. 1995). Light availability in the marine environment is affected mainly by water depth and clarity. Water clarity (turbidity) is determined predominantly by the concentration of suspended particles, mainly sediment grains, algal cells and detritus, in the water column (Biber et al. 2009). Climate change will not only affect light availability through rising sea levels, but also by its effect on rainfall (extreme rain events triggering sediment and nutrient plumes into coastal waters) and substrate stability (resuspension of sediments in extreme weather events) that results in increased turbidity.

Many documented cases of seagrass loss in Australian waters have been attributed to reductions in the amount of available light at the seagrass canopy (e.g. Masini et al. 1995; Preen et al. 1995; Ralph et al. 2007), but none have been attributed to changing climate yet.

Temperature

Temperature is a critical factor controlling seagrass growth, survival and reproduction (Poloczanska et al. 2007). Optimal temperature ranges exist for the physiological processes of photosynthesis, nutrient uptake, flowering and germination (Duarte 2002). Elevations in temperatures that exceed the thresholds of the optimal ranges result in a decline in the efficiency of the plants to perform these vital functions (Seddon and Cheshire 2001; Poloczanska et al. 2007). If the duration or frequency of such thermal stress exceeds a plant's ability to recover, the individual may subsequently die (Poloczanska et al. 2007).

Optimal temperature ranges and thermal tolerances vary among different seagrass species, and this is reflected in present day distributions (Walker and Prince 1987). For example, seagrass species occurring in the tropical waters of northern Australia typically show higher optimal temperature ranges (and greater thermal tolerances) than those occurring in the temperate waters of the southern coastline (Poloczanska et al. 2007).

Observations of an association between the health and distribution of seagrasses and temperature increases are the strongest evidence of existing effects of climate change on Australian seagrasses. Most notable is a large-scale dieback of intertidal and shallow subtidal seagrass meadows in Spencer Gulf, South Australia. Nearly 13,000 ha of seagrass died in February 2003, during an El Nino event (Seddon et al. 2000). Extreme air temperatures (> 40°C) during exceptionally low tides in the middle of the day, over several consecutive days, led to water temperatures that damaged such a high proportion of chloroplasts that plants could not survive (Seddon and Cheshire 2001). Seddon et al. (2000) also report anecdotal evidence of a pattern of seagrass dieback coinciding with earlier El Niño events. There has been no rigorous analysis, however, of whether long term patterns in seagrass dieback in Spencer Gulf correspond with changing climate.

The other main effect of warming seas in Australia might be that the distribution of individual seagrass species will shift southwards. One such record has been made, with the recent confirmation of the tropical species *Halophila minor* being found in southern Moreton Bay, near the border of Queensland and New South Wales (Phillips et al. 2008). This extension of the distribution *H. minor* is consistent with a strengthening East Australian Current (EAC) encouraging movement in the southward limit of tropical species. Such range extensions have also been recorded elsewhere, for example in the temperate waters of Korea (Kim et al. 2009).

Long term data sets on the phenology of Australian seagrasses either do not exist or have not been correlated with changing climate. Where this has been done elsewhere, sea temperature has turned out to be strongly correlated with plant characteristics (e.g. the timing of flowering in *Posidonia oceanica* in the Mediterranean; Diaz-Almela et al. 2007).

Carbon dioxide

Seagrasses require an inorganic carbon source for photosynthesis and therefore for growth and survival (Green and Short 2003). In a marine environment, the forms of inorganic carbon that may be used for photosynthesis are dissolved carbon dioxide (CO_2) and bicarbonate (HCO_3^-) (Nayar et al. 2009). Despite the predominance of HCO_3^- to CO_2 (approximately 150:1 in seawater at 15°C), most seagrasses studied to date have shown incomplete HCO_3^- uptake systems, instead favouring the uptake of dissolved CO_2 (Palacios and Zimmerman 2007; Nayar et al. 2009).

Unlike the uptake of nutrients, which can occur through the leaves or root systems, the pathway for carbon uptake is limited to diffusion across seagrass leaves (Touchette and Burkholder 2000a). Seagrasses often occur in protected areas with low water movement and, in these situations, their ability to take up inorganic carbon from the water column is restricted. This has been attributed to the width of the diffusion boundary layer at leaf surfaces at low water velocities (Short and Neckles 1999). The combination of low CO_2 concentrations, relatively poor HCO_3^- uptake systems and slow diffusion rates means that most seagrasses are inorganic carbon limited under present day conditions (Palacios and Zimmerman 2007).

No reports of changes in seagrass growth or distribution have been related to elevated dissolved CO_2 concentrations, either in Australia or elsewhere. Several experimental studies have shown however, the short-term responses of increased growth rates under elevated dissolved CO_2 concentrations (Zimmerman et al. 1997; Palacios and Zimmerman 2007). On the other hand, likely long-term responses of seagrasses to CO_2 enrichment remain uncertain, with some studies suggesting the inability of seagrasses to make long-term adjustments (Short and Neckles 1999).

Nutrients

Seagrasses require nutrients, particularly nitrogen and phosphorus, for growth (Larkum et al. 1989). They obtain nutrients from the water column via uptake through their leaves or from sediment porewater through their root system (Touchette and Burkholder 2000b). Since Australian coastal waters typically have low concentrations of nutrients away from urban centres, under undisturbed conditions nitrogen (and to a lesser extent phosphorus) are often limiting factors for seagrass growth (Bulthuis et al. 1992; Udy and Dennison 1997).

The relationship between nutrient availability and seagrass growth has been studied reasonably often in Australia, but mainly this has been done in small-scale field or laboratory experiments, and in any case has not been linked with nutrient changes that might have resulted from climate change.

Substrate availability

Seagrasses are rooted plants that require suitable substrate to obtain nutrients (see section above on Nutrients) and to provide stability and support. For nearly all species, a suitable substrate is soft sediment (sand or mud) that allows root penetration but is not so unconsolidated as to allow constant resuspension and undermining of roots and rhizomes (the single exception is the genus *Amphibolis*, which can grow on reefs with its roots covered by just a few centimetres of sand). Furthermore, in a positive feedback loop, seagrasses themselves provide substrate stability through their root systems and play a role in sedimentation by baffling of water flows and increased sediment deposition (Nayer et al. 2009).

Large losses of seagrass meadows have been observed in Australia following major storms and cyclones, as a result of physical disturbance to the substrate of seagrass habitats (Preen et al. 1995). The link between these events and climate change has not been rigorously assessed.

Potential impacts by the 2030s and 2100s

Light

Experiments indicate that the predicted reductions in light resulting from climate change impacts will most certainly have a negative impact on seagrass growth and present day distributions and abundances. For example, an experimental study by Short et al. (1995) showed that an increase in water depth of 50 cm (the expected change to 2070 in Australia) reduced available light at the seagrass canopy by up to 50%, which led to a reduction in the growth and productivity of the northern hemisphere seagrass *Zostera marina* of nearly 40%.

Experimental studies have also allowed the formulation of quantitative relationships between light intensity, depth and water clarity (Short and Neckles 1999). The light attenuation coefficient shows that the amount of light penetrating through the water column decays exponentially as a function of water depth and clarity. This relationship has been used for the effective management of coastal water quality in parts of Australia (e.g. in Moreton Bay, Queensland; Abal et al. 1996).

Elevations in sea level and an increase in the intensity and possibly frequency of major storms and cyclones as a result of climate change are expected to have a negative effect on light availability at seagrass surfaces. Elevated sea levels will increase the water depth at any given location, thereby reducing the amount of available light (and thus photoperiod) reaching the seagrass canopy (Short and Neckles 1999). Seagrasses growing at their maximum depth limits will therefore be unable to survive, and a shift in the location of the maximum depth limit shoreward is expected (Poloczanska et al. 2007). For instance, the distribution of seagrass species presently occupying subtidal zones will shift shoreward to occupy areas currently existing as intertidal zones

(Waycott et al. 2007). This shoreward migration will depend on the degree of coastal inundation and shoreward habitat availability at any given location (Short and Neckles 1999). Where habitat availability is limited by physical barriers (e.g. either natural, such as mangrove forests, or constructed, such as groynes and wharves) or unfavourable conditions (e.g. lack of soft-sediment substrate), seagrass species diversity will ultimately be reduced (Ralph et al. 2007), and there will be an overall loss of seagrass area (Short and Neckles 1999). Conversely, seagrass might increase in one geomorphological feature particularly prevalent in Australia, the intermittently closed and open lakes and lagoons (ICOLLs) on the eastern and southwestern coastlines. As sea levels rise, ICOLLs will experience increased connectivity with the ocean; the increasing marine influence and water clarity could make them more favourable as seagrass habitat.

At any given location the effect of light attenuation from increased water depth may be exacerbated by poor water clarity. The progressive inundation of low-lying coastal lands as sea levels rise is likely to cause shoreline erosion, increasing the turbidity of shallow coastal waters (Cabaco et al. 2008). Furthermore, the expected increase in intensity of major floods, storms and tropical cyclones will also contribute to increased turbidity and a reduction in light availability in nearshore coastal waters (Hennessy et al. 2007). Stronger winds during these events will create greater water turbulence and storm surges, which are likely to resuspend sediments and erode shorelines, while rainfall will increase the volume of runoff from catchments, bringing increased sediment loads into coastal waters (Waycott et al. 2007).

Light availability at seagrass surfaces is expected to be significantly reduced for some time after these extreme weather events. Deposited sediments can physically smother seagrass surfaces (Cabaco et al. 2008). Furthermore, increased rainfall runoff is likely to increase nutrient loads, potentially decreasing water clarity and light availability by stimulating phytoplankton growth in receiving waters or epiphytic algal growth on seagrass leaf surfaces (Biber et al. 2009). This effect is likely to be most pronounced soon after suspended sediments have settled, since algae also require light for growth (Beer and Koch 1996).

Temperature

The increases in air and water temperatures as a result of climate change are expected to affect all Australian seagrass habitats, through impacts on their growth, distribution, abundance and survival (Figure 1). Elevated water temperatures will directly affect seagrass metabolism and growth rates (Campbell et al. 2006). Slight increases in water temperature can increase photosynthetic rates in seagrass (Campbell et al. 2006). However, a reduction in growth rates and survival can be expected for species currently near their upper limits of thermal tolerance (primarily cold-water species in south eastern Australia; Seddon and Cheshire 2001). This will result in localised losses of such species, an increase in the abundance of thermally tolerant species and an overall poleward shift in species distributions (Poloczanska et al. 2007).

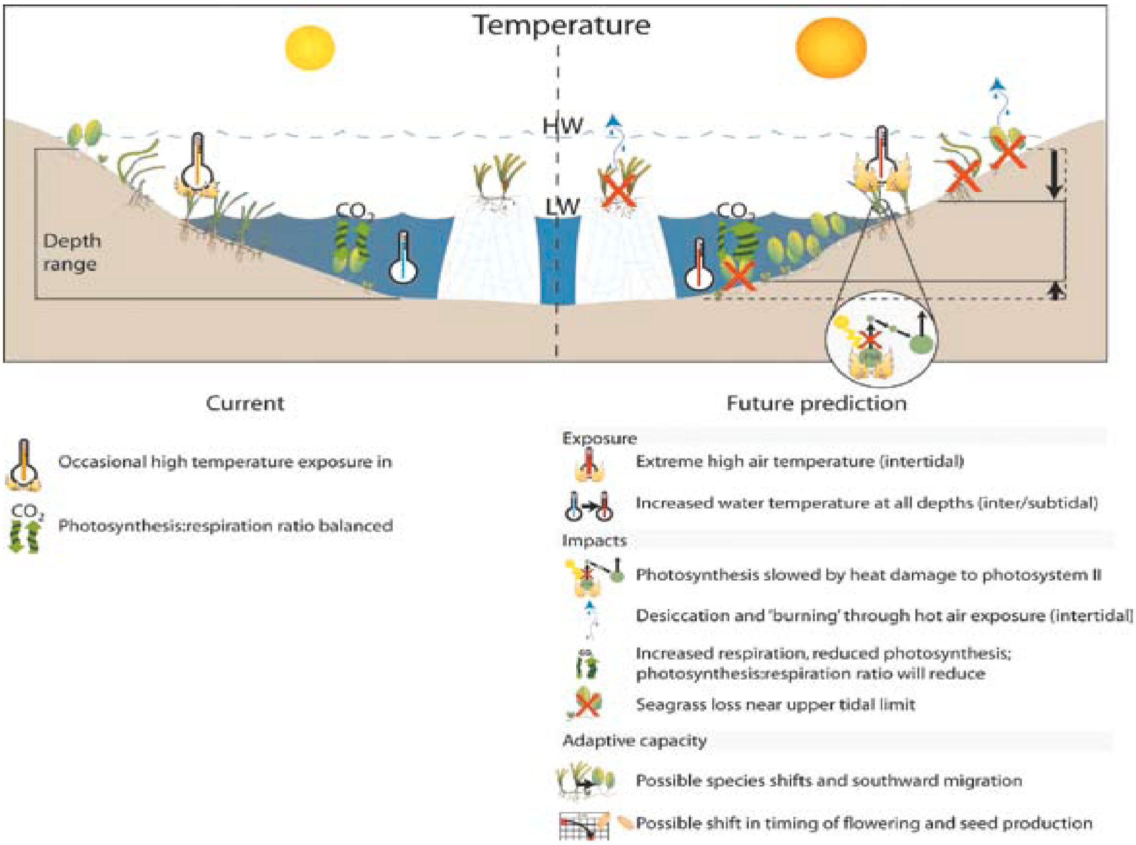

Figure 1. Predicted impacts of climate change on temperature and consequences for Australian seagrasses (from Waycott et al. 2007).

Warming temperatures will affect species differently. Species that colonise new areas rapidly may be favoured (Campbell et al. 2006). Short-lived, faster growing and structurally smaller species such as *Halophila* for example, can recover quickly after extreme events and therefore are likely to increase in abundance (Waycott et al. 2007).

This southward range extension is expected to increase the length of coastline supporting most tropical species, while distributions of temperate species are likely to contract (Poloczanska et al. 2007). This contraction will result from the inability of temperate species presently occupying the southern-most coastlines to migrate poleward, as they are already located at the limits of the Australian continental shelf (Poloczanska et al. 2007). This effect is expected to be greater on the eastern than western seaboard, as the expected strengthening of the southerly East Australian Current will extend the flow of warm waters further south on the east coast, reaching the relatively sensitive seagrass habitats of southeastern Australia (Poloczanska et al. 2007).

Just as temperature is likely to affect seagrasses more strongly in temperate rather than in tropical seas, shallow seagrasses are more vulnerable than deep water seagrasses to ocean warming. Increased ambient air temperatures affect water temperature much more strongly in shallow than deeper waters, where depth itself and possibly stratification of a cooler bottom layer buffer against warmer surface waters (Waycott et al. 2007). Shallow subtidal species are therefore at greater risk than deeper water species from the adverse effects of increased air temperatures. Intertidal species have the most extreme exposure to warming temperatures. They might suffer not only from warmer water, but also from higher air temperatures which, in combination with expected drier weather conditions, are likely to result in more frequent burning of these seagrasses during exposure at low tide (Seddon et al. 2000).

Carbon Dioxide

Increasing atmospheric CO_2 concentrations are expected to result not only in an increase in dissolved CO_2 concentrations in Australian coastal waters, but also an increase in the relative proportion of dissolved CO_2 to HCO_3^- (Short and Neckles 1999). The effect of this on seagrasses is expected to be positive, with likely increases in productivity and biomass (Poloczanska et al. 2007). While slight increases in HCO_3^- will provide some benefit to a few seagrass species with efficient HCO_3^- uptake systems (e.g. *Zostera* spp.; Beer and Rehnberg 1997), the greatest benefits are expected to occur in species such as *Thalassia hemprichii* which favour uptake of dissolved CO_2 (Abel 1984; Palacios and Zimmerman 2007). Where seagrass is currently carbon limited, species with CO_2 uptake systems will tend to dominate seagrass communities and potentially increase their depth limit (i.e. compensation depth; Poloczanska et al. 2007).

It is likely that the increase in dissolved CO_2 in seawater due to increasing atmospheric CO_2 concentrations will be counteracted by the fact that warmer waters effectively reduce CO_2 solubility (Larkum et al. 1989). In addition, the benefits of increased productivity from elevated CO_2 levels cannot be attained when other factors such as nutrients, light or temperature are limiting (Waycott et al. 2007).

Indirect negative effects of climate change on inorganic carbon availability for Australian seagrasses are also expected. Any increase in eutrophication of coastal waters as a result of an increase in the intensity and possible frequency of extreme weather events such as floods, in combination with drier periods in between, will limit inorganic carbon availability by promoting epiphytic algal growth on seagrass leaf surfaces. Epiphytic algae on seagrass increase the width of the diffusion boundary layer and intercept available carbon for their own requirements (Short and Neckles 1999). Experimental studies have shown that algae are already inorganic carbon saturated under present atmospheric conditions (Beer and Koch 1996), and are therefore unlikely to increase their growth due to an increase of atmospheric CO_2 alone, without the addition of increased nutrient loads.

Nutrients

Climate change is predicted to affect nutrient availability to seagrasses through an increase in the intensity and possible frequency of major storms, floods and cyclones. These events could generate higher nutrient loads and ultimately concentrations in coastal waters, which may either benefit or harm seagrasses.

Seagrass growth and productivity respond positively to low and moderate levels of nutrient enrichment. In the Great Barrier Reef, for example, experimental nutrient addition in oligotrophic sediments of inner islands increased the extent of seagrass meadows on the deeper boundary (Udy et al. 2005). Excessively high nutrient concentrations in the water column, however, adversely affect seagrass growth (Udy and Dennison 1997; Lee and Dunton 2000). This negative effect typically occurs through the stimulation of phytoplankton growth in the water column and epiphytic algal growth on seagrass leaf surfaces, which act to reduce light, inorganic carbon availability and nutrient availability (Short et al. 1995). Algae limit nutrient availability for seagrasses through competitive interactions for nutrient uptake (Walker and McComb 1992). Algae are competitively advantaged in nutrient uptake because, unlike seagrasses, they are inorganic carbon saturated under present day conditions (Beer and Koch 1996). Furthermore, epiphytic algae growing on seagrass leaf surfaces also limit nutrient availability by increasing the diffusion boundary layer and intercepting nutrients for their own requirements (Touchette and Burkholder 2000b).

Substrate for anchoring

An increase in the intensity of major storms and cyclones due to climate change is expected to increase the likelihood of sediment destabilisation and seagrass dislodgment during these events. During these events strong winds create turbulent waters and storm surges which act to scour bottom sediments (Waycott et al. 2007). This scouring effect exposes plant roots, thereby reducing the anchoring capacity of seagrasses and increasing the likelihood of dislodgment (Cabaco et al. 2008). The impact of this is likely to be greater on shallow water species (and particularly intertidal species) as these waters generally experience greater water turbulence than deeper waters, since the greater water depth provides protection by dissipating wind energy (Waycott et al. 2007).

Multiple Stressors

The generally shallow, coastal distribution of seagrasses that makes meadows vulnerable to climate impacts also leaves them vulnerable to coastal urbanisation, agriculture and other human activities. Anthropogenic stressors have been thoroughly recorded as a massive, ongoing source of disturbance to seagrass systems. In Australia, losses, fragmentation and detrimental changes in seagrass health have been documented for over 60 years, and the rate and intensity of these non-climate impacts is still of great concern.

Impacts can be direct, through physical modifications or complete removal of seagrass habitats (e.g. shoreline constructions), or via degradation of water and sediment quality (e.g. boating, aquaculture, poor catchment land use practices in agriculture and urban areas). These non-climate stressors are presumed to reduce the resilience of seagrasses to climate change.

Key Points

- Observations of climate change impacts are rare, with just two reported links to warming temperatures, probably due to a lack of long term datasets.
- Evidence of large-scale diebacks of seagrass in the Spencer Gulf, SA, suspected to occur with elevated temperatures during El Niño conditions.
- The sub-tropical seagrass, *Halophila minor*, has recently extended south into Moreton Bay, SE QLD, consistent with a strengthening of the East Australian Current and warming temperatures.

- Elevations in sea-level and increases in the intensity of extreme events such as storms and cyclones will reduce light availability and are expected to negatively impact seagrasses
- Cool-temperate seagrasses in southern Australian waters are expected to be more vulnerable to rising temperatures then tropical species
- Shallow sub-tidal species are more vulnerable to warming temperatures and extreme events then deeper-living seagrasses

Confidence Assessment

Table 1. Summary of observed and expected changes in Australian seagrass habitat and confidence levels about those changes

	Amount of evidence	Degree of consensus	Confidence level
Observed changes			
1. Seagrass loss over 13,000 ha area due to heat stress in single incident in southern Australia.	Low	High	Low
2. Range extension of tropical species (*Halophila minor*) into subtropical waters (300 km shift).	Low	High	Low
Expected changes			
1. Decreased productivity generally. Potentially enhanced productivity due to increased dissolved CO_2 and warmer water overridden by increased water depth, and pulsed turbidity from more extreme rainfall and thus river plumes. Local exceptions in clear, still water (where CO_2 is currently limiting).	Medium	Medium	Medium
2. Local (to large) scale loss due to decreased light (increased water depth, turbidity, storm intensity), increased storm intensity and water temperature. Shallow water seagrass extremely vulnerable.	High	High	High
3. Seagrass community change to heat tolerant species (and/or species favouring CO_2 uptake).	High	High	High

4.	Long-term decline of seagrass health and extent in some places, species changes in other places.	High	High	High
5.	Distribution changes to seagrass species. Recolonisation higher on shore, and southward shift (where not prevented by physical barriers or unsuitability of substrate), and especially favouring species with seed dispersal. Diminished range in some species, or lost altogether, especially with synergistic effects of other, non-climate stressors.	Medium	High	Medium
6.	Reduction or loss of ecosystem services provided by seagrass, such as support of dugong and turtle populations, and fisheries productivity reliant on seagrass (and attached algae) either as nursery habitat or for nutrition in adjacent habitats.	Medium	Medium	Medium

Adaptation Responses

Historically, seagrasses have adjusted to large scale changes in CO_2 concentration and sea level. The predicted climate change over the next century will, however, be more rapid than in the past. What adaptation measures can be taken to limit the impact on seagrasses? Given the massive, adverse existing consequences for seagrass from urbanisation and agriculture, the main strategy should be to minimise the impact of non-climate related stressors on seagrass. This will ensure that seagrass is in optimum health and is therefore more likely to show greater resistance and adaptive capacity to the rapid rate of climate change.

It will be important to maintain species diversity, and genetic diversity within species. As for other marine systems, early evidence is emerging that the breadth of diversity in a seagrass plant community is directly related to its resilience to external perturbations. In laboratory experiments into the effects of warm water on *Zostera marina*, it was shown that containers that included diverse genotypes of this species were more resilient than those lacking genetic diversity (Elhers et al. 2008). This theoretical maxim, that diversity provides a degree of protection for ecological systems, should be at the forefront whenever future management strategies are being considered.

One other management intervention has been discussed in the literature. Seagrass growth is increased when dissolved CO_2 concentrations are increased experimentally. The possibility of pumping CO_2 into the water column to encourage seagrass growth at critical or vulnerable stages has been suggested (Palacios and Zimmerman 2007). Such a remediation action would seem, however, to contradict International efforts to reduce carbon emissions.

Knowledge Gaps

Some of the key knowledge gaps that need addressing are:

- Better defined thermal tolerances for Australian seagrass species
- Informative modelling of changes in coastal catchment runoff at a local scale under climate change
- Dispersal and recolonisation information for seagrasses and their associated fauna – how will seagrass communities respond to a higher rate of habitat fragmentation?

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