VULNERABILITY ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE ON ESTUARINE HABITATS IN THE LOWER HAWKESBURY ESTUARY

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EXECUTIVE SUMMARY

Hornsby Shire Council (HSC) has implemented their Lower Hawkesbury Estuary Management Plan (Hornsby Shire Council, 2008). It identified climate change as a high risk to the management of natural assets within the estuary including estuarine habitats. Climate change will affect all natural habitats and how people will use these natural resources. Management agencies need a means of assessing the extent to which climate changes will affect these habitats. Such assessments need to identify the issues management can address to best conserve natural habitats and also guide how they might prioritise these issues amidst many other responsibilities. Therefore, HSC have commissioned Trade and Investment NSW to undertake a vulnerability assessment of the effects of climate change on the vegetated estuarine habitats in this estuary to provide some of this information. It consisted of hydrological modelling of 15 different climate change scenarios and using the outputs of these scenarios in a four staged assessment process; risk, resilience, vulnerability and priority.

A three-dimensional hydrodynamic model ELCOM (Estuary, Lake and Coastal Ocean Model) was applied to the lower Hawkesbury-Nepean estuary. Baseline (1990) and 32 scenarios of maximum, mean and minimum projections of sea level, sea temperature and air temperature in 2030 and 2050 were then applied. Modelled water levels, salinity and temperature in the baseline and projections were outputted for 18 habitat locations. The results of the 2030 and 2050 scenarios indicate that habitat sites may experience increased frequencies of inundation. Water depth at submerged sites was increased by up to 0.5m, salinity was increased by up to 6 psu, and water temperature was increased by up to 1.0ºC. The locations that are likely to experience the greatest mean change in inundation, depth, temperature and salinity were:

- Brooklyn Oval, which was dry at all times during baseline conditions, experienced inundation for 2% of time during summer and 4% of time during winter in maximum projections of sea level change.
- Cowan Creek at Bobbin Head, Cowan Creek at Smiths Creek, Pumpkin Creek, Popran Creek and Gentlemans Halt experienced the greatest change in salinity. The salinity was increased by up to 6 psu during summer.
- Crosslands and Calna Creek, Gentlemans Halt and Mullet Creek experienced greatest change in temperature of up to 1 ˚C. The increase was greatest during summer.

Four different habitat types were assessed using the data produced from the modelled scenarios; seagrass, mangroves, saltmarsh and floodplain forest. These were assessed at sixteen different sites within the lower Hawkesbury estuary (LHE). Under the worst case scenarios of maximum sea level rise, maximum water and air temperature for 2030 and maximum sea level for 2050 seagrass was at moderate-high risk of loss at all sites during summer and at 60% and 40% of sites, respectively, in these scenarios during winter. Seagrass at the Cowan Creek site had moderate-high levels of resilience to the effects of climate change during summer and winter for the maximum sea level rise scenarios. The remaining sites all had moderate resilience during summer and moderate-high during winter for these same scenarios. Seagrass at Cowan and Patonga had moderate-high levels of vulnerability from non-climatic human stressors under all maximum sea level rise scenarios. The remaining sites all had moderate vulnerability levels.

Mangrove habitats had the lowest level of risk of loss from the effects of climate change. Approximately 50% of sites had moderate levels of risk during summer and 80% of sites had low levels during winter under maximum sea level rise scenarios. Mangroves also had the highest levels of resilience with over 80% of sites having moderate-high levels in both summer and winter.

However, when non-climatic human stressors were added, mangroves had moderate-high to moderate levels of vulnerability to climate change for both summer and winter at most sites.

Saltmarsh habitats had different levels of risk and resilience depending upon the species. *Juncus krausii* had moderate levels of risk of loss in approximately half the sites and low levels in the remaining sites during summer under maximum sea level rise scenarios. During winter risk levels for loss of habitat for this species dropped to low. By contrast, *Sporobolus virginicus* had high to moderate-high levels of risk of loss of habitat in all sites during summer and winter for all maximum sea level rise scenarios. A similar pattern for both species occurs for resilience. *Juncus krausii* had moderate levels of resilience in all sites under all scenarios in both summer and winter, except Popran Creek which had moderate-high resilience. *Sporobolus virginicus* had low resilience in all sites under all scenarios in both summer and winter, except Popran Creek which had moderate resilience. When non-climatic human stressors were added both species had moderate to moderate-high levels of vulnerability to climate change effects.

Floodplain forests were only analysed at the risk assessment stage due to a lack of information about the effects of climate change variables on these habitats. All sites had high levels of risk to being lost at under all maximum sea level rise scenarios in summer and 68% of sites in winter.

Seagrasses at Cowan Creek and Dangar Island sites had the highest priority for management based on the moderate to moderate-high levels of resilience and high concentrations of small and larger scale non-climatic human stressors. One Tree Reach and Farmland sites had the greatest potential for rehabilitation for mangrove and saltmarsh habitats due to the land available for expansion. Mangroves at these sites had moderate-high resilience but also had the greatest concentration of small scale and large scale non-climatic human stressors. Saltmarsh habitats at Courangra Point and Pumpkin Creek would be high priorities for protection due large habitat proportion and low concentration of non-climatic human stressors.

The top three recommendations arising from this project were:

1. Surface elevation studies should be done for mangrove and saltmarsh habitats at One Tree Reach, Courangra, Gentlemans Halt and Pumkin Creek sites.

2. A scientific and economic feasibility study should be undertaken to on the rehabilitation of available land for habitat expansion for mangrove and saltmarsh habitats at One Tree Reach, Farmland and Courangra sites.

3. A detailed study be done on the effects of current human stressors on the condition and ecological function of the seagrass bed at Dangar Island and determine practical and cost-effective ways of minimising their effects.

1. INTRODUCTION

1.1. Purpose

Local governments and regional management agencies are responsible for conserving and managing natural resources. However, they must do so within the context of managing the human activities that interact with natural resources over which they have jurisdiction. One of the greatest challenges facing local governments and regional agencies in fulfilling these dual roles is in responding to the complex effects of climate change. Climate change caused by increasing greenhouse gases will affect all natural habitats and how people will use these natural resources. Therefore, management agencies need a means of assessing the extent to which climate change will affect these habitats. Such assessments need to identify the issues which management can best address to conserve natural habitats and guide how they might prioritise these issues amidst many other responsibilities (Poloczanska et al. 2007). Vulnerability assessment of the effects of climate change on natural habitats is a tool that has been developed for this purpose (e.g. Johnson and Marshall 2007).

Hornsby Shire Council (HSC) has implemented their Lower Hawkesbury Estuary Management Plan (Hornsby Shire Council, 2008). It identifies climate change as a high risk to the management of natural assets within the estuary including estuarine habitats. HSC have commissioned Trade and Investment NSW to undertake a vulnerability assessment of the effects of climate change on the vegetated estuarine habitats of the Hawkesbury River (seagrass, mangroves, saltmarsh and floodplain forest). Specifically there were five objectives to this study:

i) Assess the vulnerability of estuarine habitats in the region covered by the Lower Hawkesbury Estuary Management Plan (Wisemans Ferry to Broken Bay) to the effects of climate change under a range of scenarios
ii) Map the projected vulnerabilities of each habitat in terms of loss, shift or gain of habitat
iii) Assess the level of risk of these vulnerabilities from climate change compared to other human activities within the lower Hawkesbury estuary (LHE)
iv) Recommend appropriate adaptive management action to enhance the ecological resilience of vulnerable habitats

In order to fulfil these objectives we first provide an overview of the potential effects of climate change starting at the global level then working down to the region of the Hawkesbury catchment. We then discuss the range of potential disturbances on estuaries and their habitats from the effects of climate change.

1.2. Potential effects of climate change at the global level and the Australian region

Increasing greenhouses, primarily in the form of increased concentrations of CO_2, is causing the atmosphere to warm (IPCC, 2007). As CO_2 concentrations increase so too does the warming of the atmosphere. The warming atmosphere results in changes to rainfall and storm patterns and warming sea surface temperatures. These in turn affect changes to oceanic circulation and currents, ice sheets, sea level and water chemistry (IPCC, 2007). In addition, increased CO_2 levels in the atmosphere also affect water chemistry by changing the partial pressure of CO_2 in sea water (Fig. 1.1) making it more acidic. The consequences of these global changes on natural and human resources are vast and interacting, most of which are not fully understood (e.g. Hughes, 2003).

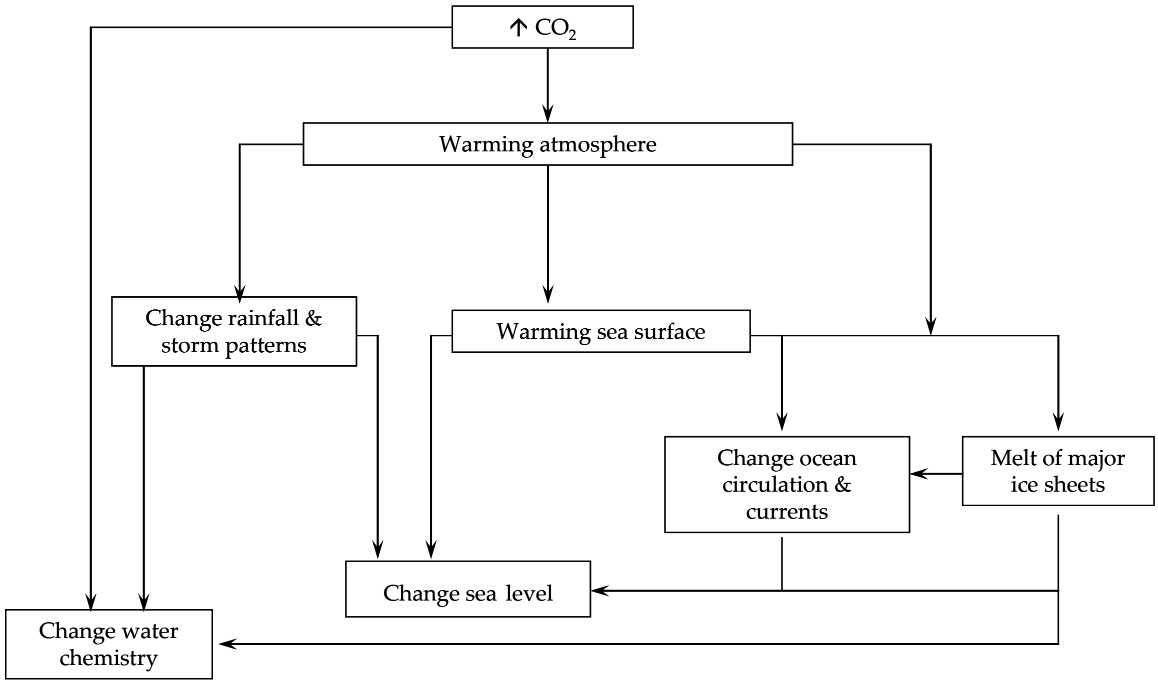


Figure 1.1. Flow diagram showing the connections between the different components and effects of climate change relevant to estuaries.

1.3. Potential effects of climate change on the Hawkesbury estuarine environment

Changes to rainfall patterns and sea level rise will potentially have the most substantial influence on estuarine environments because they will lead to changes in many of their characteristics at large and small spatial and temporal scales. Changes to storms, air temperature and water temperature will also affect estuarine environments but these effects will be mediated through their interaction with the larger influences of rainfall and sea level rise.

All estuaries have four broad biophysical processes – tidal or wave dynamics, hydrology, sediment dynamics and nutrient dynamics. Climate change will potentially affect each of these processes (Najjar, Pyke et al. 2010). The following section discusses the main potential effects of climate change for the Hawkesbury estuary on each of these processes. These sections were based on information obtained from the OzCoasts website (http://www.ozcoasts.gov.au) and representative references for each process were as follows – tidal dynamics, Heggie et al., 1999; hydrology, Kurup et al., 1998; sediment dynamics, Hossain et al., 2001; and nutrient dynamics, Eyre, 1998, 2000.

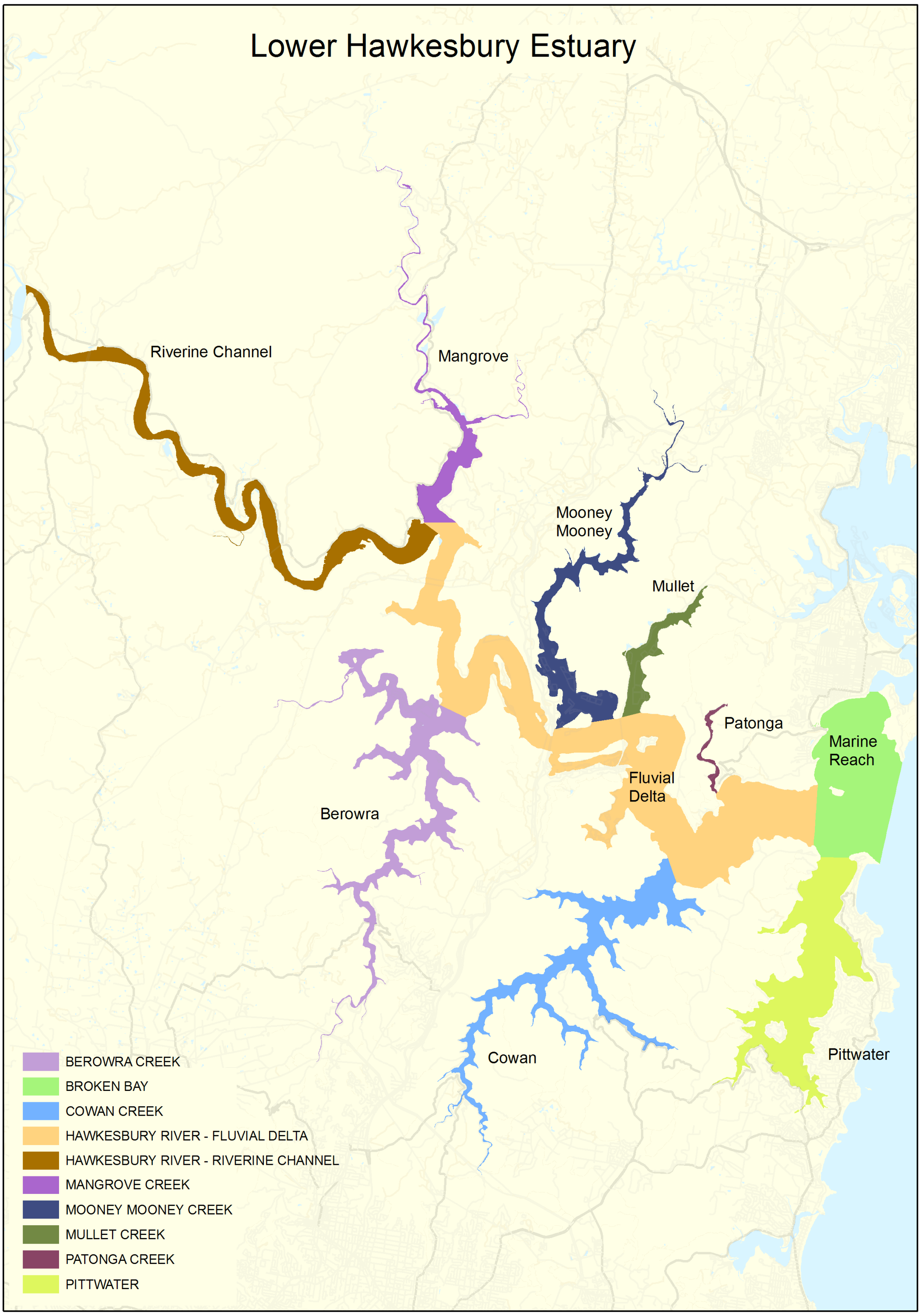


Figure 1.2. Estuarine catchments, reaches and general geomorphic zones of the Lower Hawkesbury River.

1.3.1. Tidal dynamics

1.3.1.1. Sea level rise

The LHE is tidally dominated in its marine reach, Pittwater, fluvial delta and many of its tributaries (Roy, Williams et al. 2001). In these areas changes to sea level rise will have the most significant influence. Tidal amplification occurs as far as Wisemans Ferry which has a tidal range that is approximately 16%

greater than the tidal range at the mouth (maximum range 1.92m, Hughes et al., 1998). Under rising sea level tidal amplification will increase and extend further upstream. Increased tidal amplification may also result in spring tides inundating larger areas of the floodplain and supralittoral shores, such as saltmarsh areas. Tidal currents in the fluvial delta may become stronger as larger volumes of water (restricted by the sandstone cliffs surrounding much of the fluvial delta) are pushed through from the mouth. These tidal currents may result in scouring of deeper channels or erode edges of large habitat patches along tidal channels in the fluvial delta, such as seagrass beds near Dangar Island. Flushing times in the marine reach and lower parts of the fluvial delta may also shorten if tidal currents increase.

1.3.1.2. Rainfall and extreme events

If rainfall decreases, tidal influences will move further upstream. Marine water intrusion (saltwater wedge) will extend further upstream and increase salinity in some areas. Under increased rainfall the saltwater wedge will move further downstream. For extreme events, such as storms, large pulses of freshwater will move downstream increasing the mixing of tidal and riverine water in the fluvial channel and marine reaches, pushing freshwater into the marine reaches. The main tributaries of the LHE, such as Mangrove, Mooney Mooney, Berowra and Cowan, are a significant source of freshwater input to the main river during periods of high rainfall. Increased flows from increased rainfall or storms in these creeks may have a more sustained effect on tidal dynamics increasing mixing with marine water and shifting the saltwater influence downstream.

1.3.1.3. Increased water temperature

Warmer seas will result in the thermal expansion of estuarine waters, further contributing to the effects of sea level rise on tidal dynamics.

1.3.2. Hydrology

1.3.2.1. Sea level rise

Mixing of freshwater inputs from upstream with marine waters in the marine reach, lower fluvial delta and Pittwater areas will increase with larger volumes of coastal water entering the estuary. Flushing times in the marine dominated areas may become shorter if tidal currents increase.

1.3.2.2. Rainfall and extreme events

If rainfall decreases the volume, frequency and extent of freshwater inputs from the catchment will be lower. Therefore, hydrology will be dominated by tidal dynamics under reduced rainfall. If rainfall increases freshwater input from the catchment will increase from multiple locations. Volumes of freshwater input are likely to be highly spatially and temporally variable and this will significantly affect the extent to which freshwater flows counter tidal dynamics. Larger volumes of freshwater entering the fluvial delta from substantial flows from tributaries, such as Mangrove, Mooney Mooney, Mullet, Berowra and Cowan creeks, could cause stratification, with lower salinity water floating over higher salinity sea water. In extreme events, such as storms, there is already clear evidence that the strength of river flow is greater than tidal currents and a greater proportion of this freshwater layer is delivered to the more marine areas of the estuary before undergoing mixing. Under climate change, increased frequency and intensity of storm events may result in freshwater flows penetrating the marine reach more often.

1.3.2.3. Increased water temperature

Warmer seawater, which is less dense, will penetrate further upstream under decreased rainfall as the marine influence is extended with stronger tidal dynamics. Freshwater input from increased rain and storms will counteract warmer seawater, but this will be highly variable due to interactions between the depth of water and increased air temperatures; shallower areas will increase in temperature more than deeper areas under higher air temperatures.

1.3.2.4. Increased air temperature

Evaporation of shallow areas and the surface layer of water will increase under higher air temperatures. Combined with decreased rainfall, this will produce hypersaline water. This may result in reverse stratification in which the denser hypersaline water sinks beneath the marine layer and is transported to the mouth via tidal currents. Increased rainfall will reduce the extent of evaporation and its effect of increasing salinities.

1.3.3. Sediment Dynamics

1.3.3.1. Sea level rise

If tidal currents become stronger sediment re-suspension will increase in shallower areas of the fluvial delta and the tributaries. Net sediment export to the ocean may increase under tidal mixing of these estuarine waters. The location of the deposition of coarse sediment in the fluvial delta may shift up or downstream if the interface between tidal currents and river flow changes. Higher sea level may deposit fine sediments further inland on floodplains and increase delivery of these sediments to saltmarsh and mangrove habitats.

1.3.3.2. Rainfall and extreme events

Decreased rainfall will deliver less sediment from the catchment, slowing infilling of tributaries and the fluvial delta. Increased rainfall will result in larger amounts of fine and coarse sediment entering the estuary from multiple locations across the catchment. The amount and composition of these sediments will vary depending on the volume of rain and the surrounding land-use. The surrounding catchments of Mullet, lower Mooney Mooney, Berowra and Cowan creeks have steep sides and native bushland. Sediment input into these tributaries may have less influence than freshwater input. The land surrounding the riverine channel, Mangrove and the upper reaches of Mooney Mooney creek catchments has a high proportion of agricultural land-use. Sediment input may have a greater influence than freshwater flow in these areas.

Intense rain from storms will deliver larger amounts of sediment from the catchment and re-suspend larger areas of sediment within the estuary, especially in shallower areas. Higher flows from rain will transport sediments from the upper catchment into the fluvial delta and marine reaches. In deeper areas, coarse sediments will be deposited on the floor while finer sediment will be mixed with coastal waters and may be exported offshore. Higher flows will also increase erosion around channels and high energy banks. Increased suspended sediment in fluvial areas due to storm events, may lead to increased deposition of fine sediment on intertidal mudflats and mangroves, as flows dramatically reduce after storms have passed.

1.3.3.3. Increased air temperature

Warmer air temperatures will increase evaporation of soil water. This may result in hypersaline soil, making it less suitable for the establishment of saltmarsh or mangrove seedlings. Drying of supralittoral soil may cause it to shrink, lowering the surface elevation. However, this will be highly dependent on the frequency, magnitude and duration of rainfall and the below-ground biomass of vegetation.

1.3.4. Nutrient Dynamics

1.3.4.1. Sea level rise

If tidal dynamics change with increasing sea level, a greater proportion of particulate nitrogen and dissolved inorganic nitrogen (DIN) will be exported from the estuary to coastal waters. More nutrients may be delivered to supralittoral areas during spring high tides when they bind to fine sediments.

1.3.4.2. Rainfall and extreme events

Decreased rainfall will result in less nutrient input from the catchment. This maybe counter balanced by increased nutrients coming from coastal waters but this will be highly dependent on changes to oceanic and coastal currents such as the EAC (Suthers *et al*., 2011).

Increased rainfall and storm events will provide catchment input of DIN and particulate nitrogen from both point and non-point sources. The amount and rate of nitrogen processing in the water column will depend on the activity of phytoplankton and microalgae present. This will be affected by temperature and light availability. Intense rain periods will increase turbidity, decreasing light penetration making nutrient assimilation and processing less effective by phytoplankton. Particulate nitrogen in sediments is processed by benthic infauna which may be affected by changes in soil salinity from increased freshwater inputs from intense rain.

1.3.4.3. Increased air and water temperature

The root systems of mangroves and seagrasses play an important role in the fixing and denitrification of nitrates. This is dependent on plant productivity which is influenced by temperature and light availability. If air temperature rise above 35^{o}C for extended periods, photosynthesis of mangroves may be severely impaired, decreasing their productivity and ability to process nutrients. Seagrasses in shallow areas may experience more extreme water temperatures under the combined effects of warmer seas and higher air temperatures producing further warming of the upper layers of water. Extreme temperature events such as these may impair photosynthetic processes in seagrass and decrease their ability to take up nutrients and process nitrogen.

1.3.5. Interactions

It should be noted that the various stressors of climate change will have interacting effects. None of the effects described above will occur in isolation and will likely have synergistic effects on all biophysical processes. These in turn will affect estuarine habitats which will also interact with the direct effects of climate change. Due to the uncertainty in the modelling it is not possible to predict the magnitude or the direction of these interacting effects, i.e. whether they are additive, synergistic or antagonistic (Crain et al., 2008).

1.4. Potential effects of climate change on vegetated estuarine habitats

Vegetated estuarine habitats will be affected by the changes to the biophysical processes described above as well as direct effects of climate change. The vegetated estuarine habitats assessed in this study were seagrass, mangroves and saltmarsh. The predicted potential effects of climate change on each of these habitats will be described below. Floodplain forests will also be assessed in this study but these are not strictly estuarine habitats as they generally grow above the spring high water level. There is greater uncertainty about how climate change will affect these habitats in eastern Australia.

1.4.1. Seagrass

1.4.1.1. Increased water and air temperature

Changes in air and water temperature will be most critical to seagrass in shallow subtidal and intertidal areas (e.g. Dangar Island near Bradleys Beach, Cowan, Berowra and Mullet creeks). Water temperature is a major factor controlling photosynthesis. Increased water temperature leads to increased rates of photosynthesis, however, this is countered by increased rates of photorespiration at higher temperatures (Waycott, Collier et al. 2007). In addition, light requirements for tissue growth are greater at higher temperatures. Therefore, species with wider light ranges will be less sensitive to increases in temperature. For intertidal seagrass, increased air temperature will result in more frequent desiccation events, causing burning of the leaves. There is evidence this occurs for *Zostera capricorni* in Mullet Creek (K. Astles, personal observation). More frequent desiccation is expected to favour species that have a faster growth rate and rapid colonisation, such as *Halophila ovalis* (Waycott, Collier et al. 2007). Increased water temperature will also affect the growth of deeper water species, such as *Posidonia australis*. Overall, increased water temperatures will affect growth rates and physiological processes, such as metabolism, in seagrasses which will influence the seasonal patterns of species abundance and distribution (Waycott, Collier et al. 2007).

1.4.1.2. Sea level rise

The two main characteristics of sea level rise important for seagrasses are (i) the elevation of the mean level of ocean surface and (ii) an increase in the tidal variation around the mean. Interactions between tidal height and tidal range affects the availability of light, current velocities, depth and salinity distributions (Waycott, Collier et al. 2007). Increased depth and reduced light will result in decreased productivity and distribution of seagrasses. This could lead to altered bed structure and the functional role of a bed. Maximum depth for plant growth is determined by the depth sufficient for light to penetrate for sustained plant growth. However, depth requirements interact with local geomorphic dynamics, sediment and water quality (e.g. Vacchi et al., 2010). Increased depth from sea level rise will alter the location of this maximum depth for seagrass. These effects will be greatest where increased turbidity occurs. Deeper growing species, such as *P. australis*, may move further into shallower subtidal areas. Thus decreased light may change the composition of seagrasses by enhancing the growth of species with lower light requirements.

Changes in tidal range will exacerbate the effects of increased depth. An increase in tidal range will restrict the depth seagrasses can grow, resulting in the withdrawal of the deep edge of beds and a loss in total seagrass area. A decrease in tidal range will decrease the amount of intertidal exposure at low tide resulting in shallow edges expanding shorewards (Waycott, Collier et al. 2007). Increases in tidal currents as a result of sea level rise may erode beds and/or create new depositional areas where seagrasses can colonise. The deeper seagrass beds near Dangar Island maybe subject to these effects. Suspended sediments may be sustained for longer periods with increased tidal currents, resulting in decreased light penetration for seagrasses. As noted above, sea level rise may increase the upstream penetration of the saltwater wedge allowing some seagrass to colonise further upstream. However, it may also decrease areas of low salinity (10-20ppt) available for seedling germination (Short and Neckles, 1999).

1.4.1.3. *Storms and rainfall*

The effects of storms on seagrass include erosion from wave action, shading from resuspended sediments and smothering by sediment deposition. For example, Preen et al. (1995) found that a large area of seagrass dies after two major storm events and a cyclone. This was caused by decreased light penetration from suspended sediments and mechanical uprooting. Increased frequency of storms and heavy rain will result in freshwater pulses penetrating further into the estuary. In shallow areas this may decrease seagrass growth through salinity stress (Waycott, Collier et al. 2007). In large floods low salinity regimes may persist for weeks, potentially significantly impacting growth rates. In addition, lower salinities may result in slower recovery of seagrasses after storm events. Recovery may also be hampered by increased frequency of storms because seagrasses such as *Z. capricorni*, need to establish extensive root systems to anchor into the sediment (Waycott, Collier et al. 2007).

1.4.1.4. *Increased CO_2*

Increased CO_2 may cause seagrass productivity to increase. However, experimental work so far has found no long term effects on above ground productivity (Björk, Short . et al. 2008). The productivity and biomass of algae associated with seagrasses, both epiphytic and benthic forms, may increase under elevated CO_2 levels. In the case of epiphytic algae this will increase shading on seagrasses, decreasing the growth rates. These enhancements to algal growth may result in changes in competition between seagrasses and algae, leading to an increase in the abundance of algae within seagrass beds, potentially altering the beds function.

1.4.2. *Mangroves*

1.4.2.1. *Increased water and air temperature*

The effect of high air temperatures on mangrove plants includes, (i) limitation of physiological processes, (ii) death of tissues or whole plants and, (iii) reduction on competitive rigor (Krauss, Lovelock et al. 2008). Growing tissues and seedlings are more susceptible to heat stress than mature plants. Consequently, the success rate of seedling survival and growth to sapling stages of mangroves maybe significantly reduced under higher temperatures. This could have a greater effect on *Avicennia marina* seedlings than those of *Aegiceras corniculatum*. *A. marina* seedlings establish better in open canopy areas, where they would be exposed to full sun. *A. corniculatum* seedlings readily establish under the canopy of other mangroves and can potentially outcompete *A. marina* seedlings for space over time (Clarke 1995). Therefore, increased temperature may result in changes to the species composition, abundance and distribution of mangrove stands over time. Changes in water and air temperature may also change the seasonal patterns of reproduction and length of time between flowering and fall of mature propagules (Krauss, Lovelock et al. 2008).

1.4.2.2. *Sea level rise*

The effects of sea level rise on mangroves will be complex because of its interaction with spatial and temporal geomorphology and hydrology at site specific scales. For example, rapid sea level rise may lead to mangroves extending landward but draw in its seaward edge. Plants in the seaward edge may persist in the short term by extending their pneumatophors to access oxygen upslope. In the Hawkesbury, rapid sea level rise may disproportionately affect *A. corniculatum* mangroves more. This species is usually located in a narrow band on the river edge of large stands of *A. marina*. *A. corniculatum* do not have aerial roots and therefore may die more rapidly than *A. marina* under rapid sea level rise. The presence of small channels running landward through mangrove habitats may provide important avenues for *A. corniculatum* propagules to colonise higher ground.

Surface elevation dynamics will also be important in determining the effect of sea level rise one mangrove habitats. If surface elevation increases at rates equal to or greater than sea level rise mangroves will potentially be able to shift their distribution landward. Soil surface elevation is governed by complex interactions from a number of above- and below-ground processes that feedback into each other. These have been explained in detail by Cahoon et al. (2006). Broadly, soil surface elevation is directly influenced by, (i) tidal waters delivering sediment to mangroves which are accreted, (ii) soil organic matter accumulation (e.g. root growth) and, (iii) groundwater dynamics that affect the shrink-swell capacity of soils. These complex processes will be affected by site specific spatial and temporal characteristics (Wilton, 2002; Rogers et al., 2006).

1.4.2.3. Storms and rainfall

Maximal growth in mangroves is linked to low salinities. If rainfall increases in frequency and intensity it may lead to increases in growth rates, area and species distributions. Lower rainfall will increase salinity in soil, potentially affecting seedling germination and survival (Johnson and Marshall 2007) (Sheaves, Brodie et al. 2007). Increases in the frequency and intensity of storm events will lead to higher rates of erosion around mangrove edges, destabilising trees. Mangroves in narrow sections of high flow areas of the Hawkesbury estuary will be particularly vulnerable to this type of erosion (e.g. Gentlemans Halt, upper Berowra). However, larger flood events will increase the input of sediments into the catchment, potentially leading to higher rates of deposition in mangroves. This would contribute to their capacity to increase their surface elevation to keep pace with sea level rise. Therefore, some patches of mangroves may experience increase erosion whilst others have increased deposition.

Increased rainfall may lead to the erosion of acid sulphate soils surrounding mangroves contributing to the run-off of sulfuric acid into the mangroves and estuarine waters. This could lead to the death of whole plants or degradation of pneumatophors impacting productivity of above- and below-ground biomass. More generally, estuarine acidification can impact all trophic levels resulting in short and long term damage. The Hawkesbury has a high concentration of unexposed acid sulphate soils within the catchment. Therefore, the potential for negative impacts on mangroves is high under high erosional events.

1.4.2.4. Increased CO_2

Increased CO_2 can enhance mangrove seedlings enabling them to establish more rapidly. It decreases seedlings demands for resources such as nutrients and water. Therefore, under poor nutrient availability seedlings may grow more rapidly under increased CO_2 (Krauss, Lovelock et al. 2008). Overall, mangroves growing under conditions of lower salinity and higher nutrients will show the greatest response to increased CO_2. Faster growing and less salt tolerant species, such as *A. corniculatum*, maybe more responsive to elevated CO_2, than slower growing species like *A. marina*, changing species abundance and distribution in mangrove habitats (Lovelock and Ellison 2007).

1.4.3. Saltmarsh

1.4.3.1. Increased water and air temperature

Saltmarsh will show similar responses to increased temperatures to mangroves. It is estimated that a 2^{o}C increase in air temperature could increase plant and soil respiration by 20%. This could result in a net decrease in carbon gain in plant tissue and decrease soil carbon storage. Consequently, the below-ground biomass of saltmarsh habitats maybe negatively affected by increase respiration rates under increased air temperature (Lovelock and Ellison 2007). Increased air temperature may favour saltmarsh species with higher heat tolerances. More succulent species, such as *Sarcocornia quinqueflora* and *Sueada australis*, may decrease in abundance and distribution, changing the composition of saltmarsh habitats. Changes in air temperature may also change seasonal patterns of reproduction and flowering and may enable more subtropical species to colonise in the Hawkesbury as they extend their range southwards (Waycott, Collier et al. 2007).

1.4.3.2. Sea level rise

The effects of sea level rise on saltmarsh are similar to those suggested for mangroves. Surface elevation dynamics will likely be more important in determining the response of saltmarsh to sea level rise than for mangroves. The same complex hydrological processes that govern mangrove habitat elevation apply to saltmarsh and will not be repeated here (see Section 1.4.2.2). However, studies have shown that these processes do not always act uniformly across mangrove and saltmarsh habitats, sometimes resulting in opposite surface elevation trends. For example, Rogers (2010) found that surface elevation rates of mangroves were higher than saltmarsh at some sites. If these trends persist it could lead to mangroves encroaching and eventually overtaking saltmarsh habitat. But these processes vary through time and are site specific (Rogers, 2010). Therefore, it cannot be assumed that saltmarsh will be lost everywhere in the Hawkesbury due to sea-level rise alone and an understanding of the topography and surface elevation dynamics of each habitat site is needed to make an assessment.

If the mean tidal range gradually increases saltmarshes maybe inundated more frequently and for longer periods. This will increase soil salinity, affecting growth rates and inhibit seed germination of saltmarsh species with low salinity ranges. This could lead to gradual changes in species composition, abundance and distribution of saltmarsh habitat.

1.4.3.3. Storms and rainfall

Rainfall influences groundwater inputs which maintain soil surface elevations via swelling of soils and delivers sediment to the surface. Therefore, increased rainfall may enhance surface elevation dynamics enabling saltmarsh habitats to increase their height to keep pace with sea level rise. More frequent rain events will decrease soil salinity and deliver increased nutrients to saltmarshes. This could enhance the productivity of above- and below-ground biomass. However, these same conditions may also favour the establishment of terrestrial plants further into saltmarsh habitats, leading to some terrestrial encroachment of saltmarsh habitat. Wilton (2002) found evidence of terrestrial encroachment into saltmarsh at many sites she studied. Lower salinities from increases rainfall may result in the establishment of non-native saltmarsh species. For example, Greenwood and MacFarlane (2009) have suggested that in areas receiving regular freshwater input the introduced species *Juncus acutus* has the potential to displace native *Juncus kraussii*.

Increased frequency and intensity of storm events may result in erosion of acid sulphate soils surrounding saltmarsh. This would have a significant impact on saltmarshes, most likely leading to its complete loss. This has already occurred in some areas of the Hawkesbury (e.g. One Tree Reach).

1.4.3.4. Increased CO_2

Saltmarsh responses to increased CO_2 will be complex because saltmarsh species are a mixture of C_3 and C_4 plants. Plants with C_3 photosynthetic pathways (e.g. *Juncus kraussii*) have an increased capacity for photosynthesis with elevated CO_2 (Leakey et al., 2009) leading to enhanced growth. In C_4 plants (e.g. *Sporobolus virginicus*) have a photosynthetic pathway that is not directly stimulated by elevated CO_2. However, C_4 plants may be able to increase their growth indirectly from lower water demands as a result of increased CO_2 and therefore enhance their ability to persist in prolonged droughts (Leakey et al., 2009). Salinity has been shown in some studies to modify the effects of elevated CO_2 on saltmarsh species from the northern hemisphere (e.g. Mateos, 2010), by reducing photosynthetic pigments under high salinity. There is currently insufficient information about how increased CO_2 will differentially affect saltmarsh species in Australia and its interactions with other environmental variables (Adam, 2009).

1.4.4. Floodplain forests

Effects of climate change on estuarine floodplain forest species have received less attention in Australia than mangroves and seagrass. Most studies have focused on freshwater wetlands (e.g. de Jong, 2000). However, some general tentative trends can be drawn from the literature. The main floodplain forest species in the Hawkesbury are *Eucalyptus* spp., *Casuarina glauca*, *Melaeuca quinquenervia* and *Melaleuca ericifolia* (Smith and Smith, 2008). Climate change has different effects on these species groups and therefore will be discussed separately below.

1.4.4.1. Eucalyptus floodplain species

Eucalyptus species generally have well defined narrow geographic ranges determined in part by localised soil conditions (Hughes, 2003). An early study by Hughes et al. (1996) found that 53% of *Eucalyptus* species had an annual mean temperature range of <3^{o}C and 23% of species with an annual mean rainfall range of <20% of natural variation. Based on these ranges and the climate change modelling of the time, they estimated that most species would have their geographic distributions completely displaced by the effects of climate change (Hughes et al.; 1996). The swamp mahogany, *Eucalyptus robusta,* in the Hawkesbury could potentially disappear under predicted changes to rainfall and temperature. Experiments on *Eucalyptus robusta* by van der Moezel et al. (1991) found a dramatic reduction in the survival of seedlings grown in 60% seawater waterlogged soils compared to non-saline waterlogged soils (3% and 100% respectively). In addition, seedlings also had a reduced growth rate on saline drained soils compared to non-saline waterlogged soils (18% and 26% respectively). Therefore, if sea level rises to inundate low lying swamp mahogany forests their ability to recruit into new areas may be substantially restricted.

1.4.4.2. Melaleuca and Casurina floodplain species

Increased flooding and soil salinity are likely to have the greatest effect on stands of *Melaleuca* spp. Salter et al. (2010a) found that adult trees of *Melaeuca ericifolia* that were subject to long term flooding (> 30 years) were in poorer condition than intermittently flooded trees. Continuously flooded trees had lower foliage cover, decreasing their capacity to photosynthesise. They also found that lateral asexual expansion in continuously flooded trees was prevented, resulting in an increase in sexual reproduction.

Seedlings of *Melaeuca ericifolia* and *Melaeuca quinquenervia* are expected to be severely impacted by increased inundation and salinity. The percentage survival of seedlings of these two species was substantially reduced in waterlogged saline soils (56% *Melaeuca ericifolia* and 6% *Melaeuca quinquenervia*) (van der Moezel et al., 1991). Salter et al. (2010) also found that seedling growth (height and biomass) was significantly reduced even in low saline soils (e.g. < 15% seawater). Therefore, young seedlings are vulnerable to submergence regardless of salinity levels (Salter et al., 2007). Waterlogged and submerged plants of *Melaeuca ericifolia* produced shorter roots which makes them susceptible to strong winds and decreases their tolerance to drier conditions. Robinson et al. (2006) found low seed viability (c. 6%) in *Melaeuca ericifolia* and that germination was strongly affected by salinity. The optimal conditions for germination are relatively narrow (20^{o}C air temperature, < 2g/L salinity, moist but not flooded soils). Periodic flooding of saline soils by freshwater or heavy rainfall may provide conditions for successful germination (Robinson et al., 2006). Because adult *Melaeuca ericifolia* hold seed on mature branches the persistence of a population is dependent on the continual survival of mature individual trees. Given the narrow conditions required for germination and seedling growth, recruitment of *Melaeuca ericifolia* to new locations in response to climate change maybe limited. Stands of *Melaeuca ericifolia* maybe replaced by the more hardy *Melaeuca quinquenervia* (Gomes and Kozlowski, 1980, McJannet, 2008) but this remains to be investigated.

There have been few studies on the effects of climate change on *Casuarina glauca*. Van der Moezel et al. (1989) found this species to be the third most salt tolerant species of *Casuarina* and the second most tolerant of saline waterlogged conditions. Whilst it is likely that this species may be more hardy to the effects of climate change, equivalent studies like those for *Melaleuca* spp. on reproduction and seedling growth have yet to be done.

1.4.5. Interactions and complexity

All the above potential effects of climate change on estuarine habitats will interact with each other in complex ways. We currently have an inadequate understanding of these interactions. Furthermore, the rate at which the effects of climate change on habitats takes place may be more subtle. Habitat types may still be distinctly identifiable but their location and extent may slowly change over time. Habitats may appear similar but their underlying ecological function maybe substantially different after climate change from before. Such change is likely to be gradual rather than a sudden shift. The diverse and complex biological processes of species that make up estuarine habitats are set within, and linked to, an equally diverse and complex physical environment (e.g. Leoni, et al., 2008; Gillanders et al., 2011). Therefore, any impacts on the physical environment from climate change have the potential to lead to profound changes in estuarine habitats. The interacting and diverse nature of estuarine systems means that the effects of climate change are likely to be complex, pervasive and difficult to predict (Johnson and Marshall, 2007; Sheaves et al. 2007).

2. CLIMATE CHANGE SCENARIOS

2.1. Modelling climate conditions

There are three essential components needed to predict future climate conditions – global climate models, estimates of greenhouse gas concentrations and scenarios of emissions, energy use, technological change and human population trends (Pearce, Holper et al. 2007; Hobday and Lough, 2011). Climate models are mathematical representations of the earth's climate system. Their ability to simulate interactions in the climate system depends on the level of understanding we have of the geophysical and biochemical processes that govern climate. The degree of confidence in climate model outputs will vary with the spatial and temporal scale to which it is applied. Predictions at the largest spatial and temporal scales, such as global means of air temperature, have the highest confidence. Predictions at finer scales, such as sub-continent or regional daily data, have the lowest confidence. This is because local influences on climate become more important at finer spatial scales and our ability to model these local processes in global modelling becomes too difficult. This is exacerbated by the magnitude of natural variability at finer scales. Consequently, in global climate models these local influences are represented by approximations (called model parameterisations) rather than being generated by the modelling process itself (Pearce, Holper et al. 2007; Hobday and Lough, 2011). Therefore, estimates of future climate conditions for the Hawkesbury estuary have a large range in both a positive and negative direction. Management responses to the vulnerability assessment of the Hawkesbury's estuarine habitats will need to be precautionary, to take into account these large ranges.

Greenhouse gas concentrations are estimated using carbon cycle models that convert emissions into atmospheric concentrations of greenhouse gases. CO_2 is continuously cycled between the atmosphere, the oceans and the biosphere. Different types of greenhouse gases have different lengths of duration that they remain in the atmosphere. For example, the rate that emitted CO_2 is removed from the atmosphere decreases by an order of magnitude, with 50% removed in approximately 30 years, another 30% removed in a few hundred years and the remainder stays for thousands of years (Roy, et al., 2011). Carbon cycle models are projecting a reduction in the ability of the oceans and the biosphere (i.e. land) to absorb CO_2, causing it to increase in the atmosphere (Pearce, Holper et al. 2007).

Emission scenarios have been developed by the IPCC based on four basic storylines A1, A2, B1, and B2. (Pearce, Holper et al. 2007). Each storyline predicts what a future world might be like in terms of human population trends, economic development, energy use and technological change for the 21st century. These storylines are summarised in Pearce, Holper et al. (2007). The IPCC has prepared 40 emission scenarios, each one being a variation within one of the four storylines. The A1 storyline has a future world in which economic growth is very rapid, global population peaking mid-century, then declining and rapid introduction of new and more efficient technology. This storyline is used for the middle of the range predictions and scenario A1B has been commonly used in the global climate models for Australia (Pearce, Holper et al. 2007; Hobday and Lough, 2011). The A1B scenario predicts that there will be a balanced reliance on different sources of energy including fossil and non-fossil fuels.

An international database of 23 climate models that run many combinations of emission scenarios has been developed by the Coupled Model Intercomparision Project 3. It provides monthly air temperature and rainfall data for all 23 models, solar radiation levels for 20 models, wind speed for 17 and relative humidity for 14 models. Table 2.1 summarises the global predictions by the IPCC Fourth Assessment Report (AR4) of the ranges of change in the values for the major effects of air temperature, sea level and CO_2 levels.

Table 2.1 Projected global-average sea level rise at the end of the 21st century (2090 to 2099), relative to 1980 to 1999 for the six SRES marker scenarios, given as 5% to 95% ranges based on the spread of model results.

	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		**Sea Level Rise (m at 2090-2099 relative to 1980-1999)**
Scenario	Best estimate	Likely range	Model-based range excluding future rapid dynamic changes in ice flow
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulation Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

Projections of changes in climate variables for the Australian region have been produced by CSIRO based on the IPCC Fourth Assessment Report (Suppiah, Hennessy et al. 2007). Modelling was run for three different years – 2030, 2050 and 2070 but not all variables were determined for each of these years (e.g. sea level rise was not calculated for 2050). The changes in these variables from the base year of 1990 were presented as a best estimate (50th percentile) and as a range of uncertainty (the difference between the 10th and 90th percentile). Table 2.2 is a summary of the projected changes for the major climate variables for the Australian region. Generally, in the eastern region of Australia there will be increases in air temperature, sea surface temperature and average wind speeds. However, projections for rainfall and extreme events are much more diverse. For example, in the southern regions of Australia annual rainfall in 2030 could decrease by 10% or show little change. Winter and spring rainfall in 2030 in the east could decrease from 5-15% but in summer and autumn rainfall could either decrease by as much as 15% or increase by as much as 10%. By 2050 the range of change in rainfall is projected to be -15 to +7.5%. This variability in space and time in the range of changes of rainfall make it difficult to predict how estuaries and their habitats might be affected by climate change given the important role rainfall has in estuarine geomorphology and ecology. Projections for extreme wind events are difficult to predict as they are governed by large and small scale meteorological systems (e.g. cyclones, trade winds) that are hard to incorporate into modelling with consistent precision (Church et al., 2006).

Table 2.2 Climate variables for the Australia region (Suppiah, Hennessy et al. 2007).

Climate Variable	Year	Best Estimate	Range	Notes
Air Temperature	2030	↑ 1.0°C	↑ 0.7-0.9°C	Coastal areas
	2050	↑ 1.2°C	↑ 0.8-1.8°C	Annual all areas
	2070	↑ 1.8°C	↑ 1.0-2.5°C	Annual all areas
Rainfall	2030	↓ 2-5%	↓ 10% to little change	Annual, southern areas
		↓ 15-5%		Winter-spring, east
		↓ 15% to ↑10%		Summer-autumn, east
	2050	↓ 5%	↓ 15% to little change	Annual, south
	2070	↓ 7.5%	↓ 20% to ↑10%	Annual, east
Wind	2030	↑ 2-5%	↓ 2.5% to ↑7.5%	Annual, coastal
	2050/70	↑ 10-15%		Annual, coastal
Sea surface temperature	2030	↑ 0.6-0.9°C	↑ 0.4-1.4°C	South Tasman Sea
	2070	↑ 0.6-1.0°C		South Tasman Sea
Sea level rise	2070	↑ 10cm above global		East coast, south of 30°S

Changes in climate variables for the Hawkesbury catchment are slightly greater than for the Australian region as a whole (Table 2.3). The upper range of average annual air temperatures will be warmer by 0.2 to 2°C. Average rainfall in the catchment could increase up to 7% by 2030 and 20% by 2070 but it could also decrease by these amounts. Extreme rain events could increase by 12% and 10% by 2030 and 2070 respectively. Generally, the ranges of the projected changes in climate variables for the Hawkesbury catchment are larger than for the Australian region. This reflects the greater uncertainty about how the effects of climate change will be manifested at smaller scales. However, there is still sufficient certainty in the projected effects at the regional scale to make an assessment of how these might potentially impact human and natural resources.

Table 2.3 Climate Change Predictions for Hawkesbury (CSIRO, 2007)

Climate Change Predictions for Hawkesbury	**2030**	**2070**
Temperature		
Average	+0.2 to +1.6°C	+0.7 to +4.8°C
Rainfall		
Annual Average Rainfall	-7 to +7%	-20 to +20%
Extreme Rainfall	-3 to +12%	-7 to +10%
Extreme Wind	-5 to +8%	-16 to +24%
Evapotranspiration	+1 to +8%	+2 to +24%

2.2. Climate change scenarios used to assess the effects of climate change in the Hawkesbury

Based on literature research of the potential effects of climate change on the estuarine habitats of seagrass, mangroves, saltmarsh and floodplain forest (see Chapter 1), three variables were chosen to base the development of the climate change scenarios – relative sea level, air temperature and sea surface temperature. Changes to these variables under climate change act as climate stressors on the biology and ecology of estuarine habitats. Sea level affects inundation of floodplain forest and saltmarsh habitats and water depth over seagrass, in turn changing light penetration and affecting photosynthesis, growth and reproduction. Air and water temperature affects evaporation and evapotranspiration rates, photosynthesis, growth, reproduction, germination and seedling growth. The NSW government guidelines for sea level rise was used to calculate relative sea level rise for the Hawkesbury (DECC, 2009). Relative sea level incorporates estimates of global sea level rise, regional differences for the south eastern Australian coast and regional vertical land movement (see Appendix 1 for details of calculation). Sea level was varied as the maximum, minimum and average and air and water temperature was varied as the maximum and average only. Maximum and average values captured both the worst case and conservative scenarios, respectively. Combinations of sea level, air temperature and water temperature were made for the year 2030 and combinations of sea levels only for 2050. Model outputs for air and water temperature were not available for 2050. A baseline year of 1990 for all three variables was included for comparison which is consistent with the year used by the CSIRO modelling. The resulting combinations of variables into 16 climate change scenarios are illustrated in Figure 2.1.

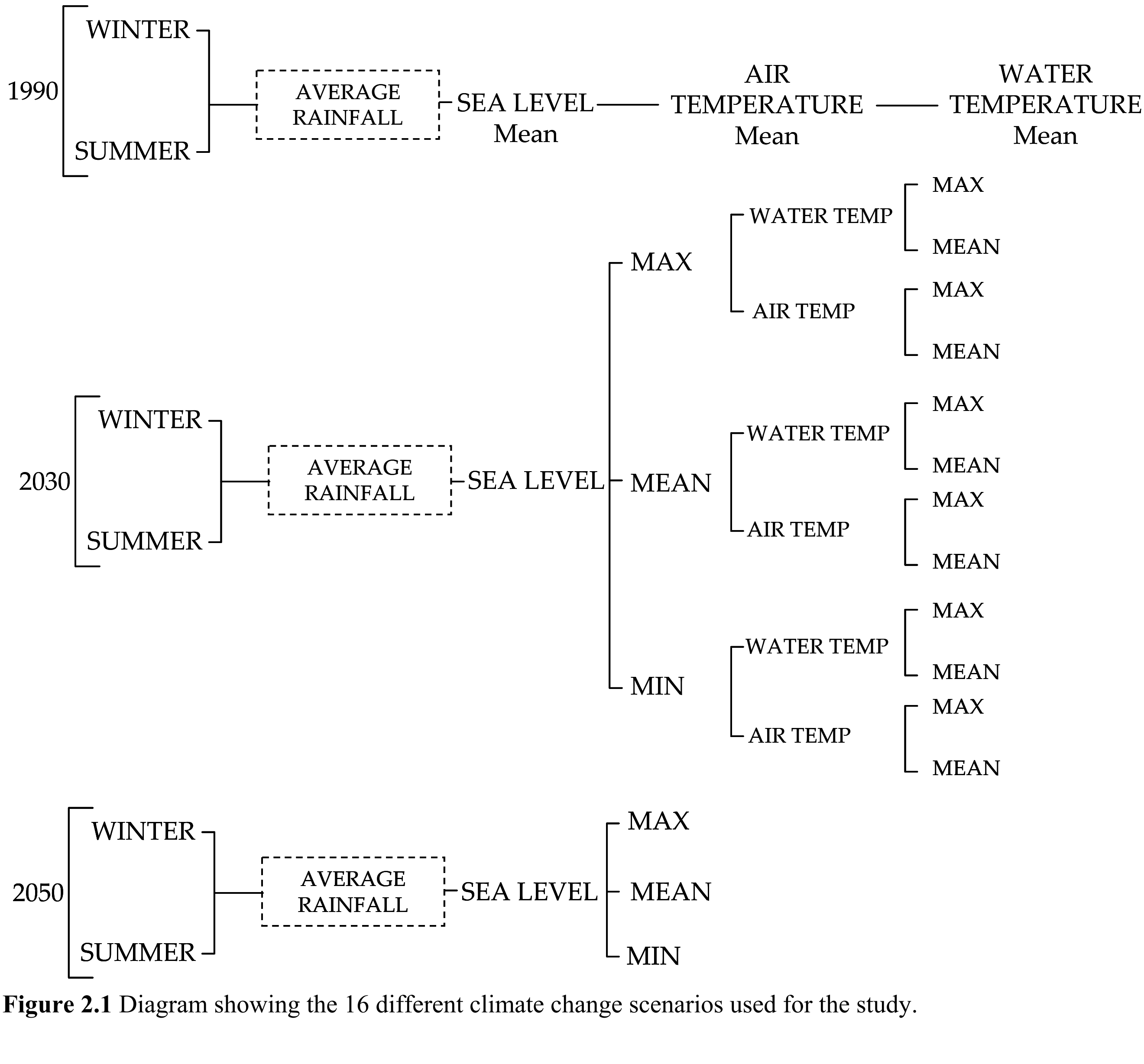


Figure 2.1 Diagram showing the 16 different climate change scenarios used for the study.

For ease of terminology each of these scenarios will be referred to as maximum, minimum or average SLR scenario, with the year included when needed.

Changes in rainfall patterns were not included as part of the scenarios because it would have required a substantial reconfiguring of hydrological model and we did not have access to catchment run-off models that would have provided more accurate modelling of changes to inflows from different rainfall patterns in the surrounding catchments of the estuary. The average rainfall of the base year 1990 was used for all scenarios. Changes in salinity were produced as outputs from the modelling but were not part of the input scenario because there is large variability in how different species respond to salinity which is governed by processes at spatial and temporal scales too small to be modelled by the hydrodynamic model.

3. VULNERABILITY ASSESSMENT METHOD

Vulnerability to climate change in the third IPCC Assessment Report (IPCC, 2001) was defined as follows:

Vulnerability: *The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.*

This definition identifies both external and internal factors that together determine a habitats level of vulnerability to the effects of climate change. Therefore, assessing this vulnerability requires estimating the magnitude of exposure and identifying what characteristics of a habitat contributes to its sensitivity to being exposed to the effects of climate change and what contributes to its capacity to adapt or respond to these effects. An assessment method needs to be able to capture all of these elements. There have been several methods developed over recent years.

3.1. Types of vulnerability assessment methods

There are broadly four different types of vulnerability assessment frameworks that have developed over the past decade – impact assessment, pre-adaptation vulnerability assessment, post-adaptation vulnerability assessment and adaptation policy assessment (Fussel and Klien, 2006). These different frameworks have been applied to assess both natural resources, such as habitats, and human assets, such populations of people living in coastal areas and the built environment. For our purposes, we will only refer to their application to natural resource assessment. The key distinguishing feature of these frameworks is their management or decision context (Table 3.1).

Table 3.1. Summary of the different vulnerability assessment frameworks and their managerial use

Type	What it does	Management use
1. Impact assessment	Evaluates potential effects of climate change scenarios on an area; does not include non-climate change factors	Raises awareness of the potential scale and magnitude of climate change impacts
2. First generation Vulnerability Assessment	Assesses the relative importance of various climate change and non-climatic factors on an area; more comprehensive representation of main stressors affecting a system; considers potential adaptation	Helps prioritise resources and research and determines the need for mitigative and adaptive measures to decrease adverse effects of climate change
3. Second generation Vulnerability Assessment	Assesses the system's ability to effectively respond to climate change through adaptation; identifies limits to adaptation; realistic estimation of vulnerability of a region to climate change based on adaptive capacity	Helps prioritise allocation of resources for most effective adaptation measures
4. Adaptation policy assessment	Examines the available response options for climate change, assesses their feasibility for implementation and compatibility with other policy goals; includes assessment of facilitation (enhance adaptive capacity) and implementation (avoiding adverse impacts) activities of management	Provides specific recommendation to planners and policy makers on specific adaptation strategies including both facilitation and implementation measures

The impact assessment framework focuses only on the consequences of climate change on the natural resource. It combines the level of exposure to climate change effects with the level of sensitivity to the exposure to determine the potential impact. The purpose of this framework is to inform management of the potential scale and magnitude of climate change impacts for particular natural resources or region. However, this framework does not take into account the other factors that may influence the exposure and sensitivity of a resource to the effects of climate change or its ability to adapt to any impacts. These other factors are external things that are not the result of changes to the climate, i.e. non-climatic factors. These non-climatic factors include non-point source pollutants, increased turbidity from runoff and foreshore developments.

The pre-adaptation vulnerability assessment framework assesses the relative importance of climate change and non-climatic factors. Only when all these factors are evaluated can the natural resources vulnerability to climate change be truly estimated. The purpose of this framework is to help management prioritise research and needs for mitigative and adaptative measures to reduce the adverse effects of climate change.

The post-adaptation vulnerability assessment framework goes a step further by taking into account the adaptive capacity of a natural resource to cope with the impacts of climate change. Importantly, it assesses the influence of non-climatic factors/stressors, and their drivers, have on the adaptive capacity, exposure and sensitivity of natural resources to climate change impacts. The purpose of this framework is to identify the limits to adaptation and prioritise allocation of resources to adaptive measures.

The adaptation policy assessment framework assesses the how the application of different adaptation and mitigative policies enhance or diminish the adaptive capacity of a natural resource and the feasibility of implementing such policies. Its purpose is to make recommendations for specific adaptation strategies. This framework has primarily been used in the management of human assets, such as the socio-economic impacts on coastal communities.

The post-adaptive vulnerability assessment framework was adopted for this project as it was the most suitable for the management context. It recognises two important elements in managing natural resources. First, there are multiple human activities that can and do impact on natural resources, not just the effects of climate change, and these multiple activities interact and potentially increase the impacts of climate change on natural resources. Second, management at a local level can do little to mitigate the effects of climate change. It cannot stop sea level from rising, temperatures from increasing or decrease the intensity of storm events. Management at a local level can only influence the non-climatic drivers and their stressors that they do have some control over (e.g. foreshore development). Such influence may take the form of reducing their adverse effects of some non-climatic stressors that increase the exposure or sensitivity of a habitat to climate change effects. It may also take the form of changing a non-climatic stressor to enhance the capacity of a habitat to adapt to the effects of climate change. These elements are illustrated in Figure 3.1. Therefore, the modified framework for the purposes of this project is designed to help give direction to HSC as to where they could best use their resources in maximising the conservation of estuarine habitats amidst all the other human influences on these areas.

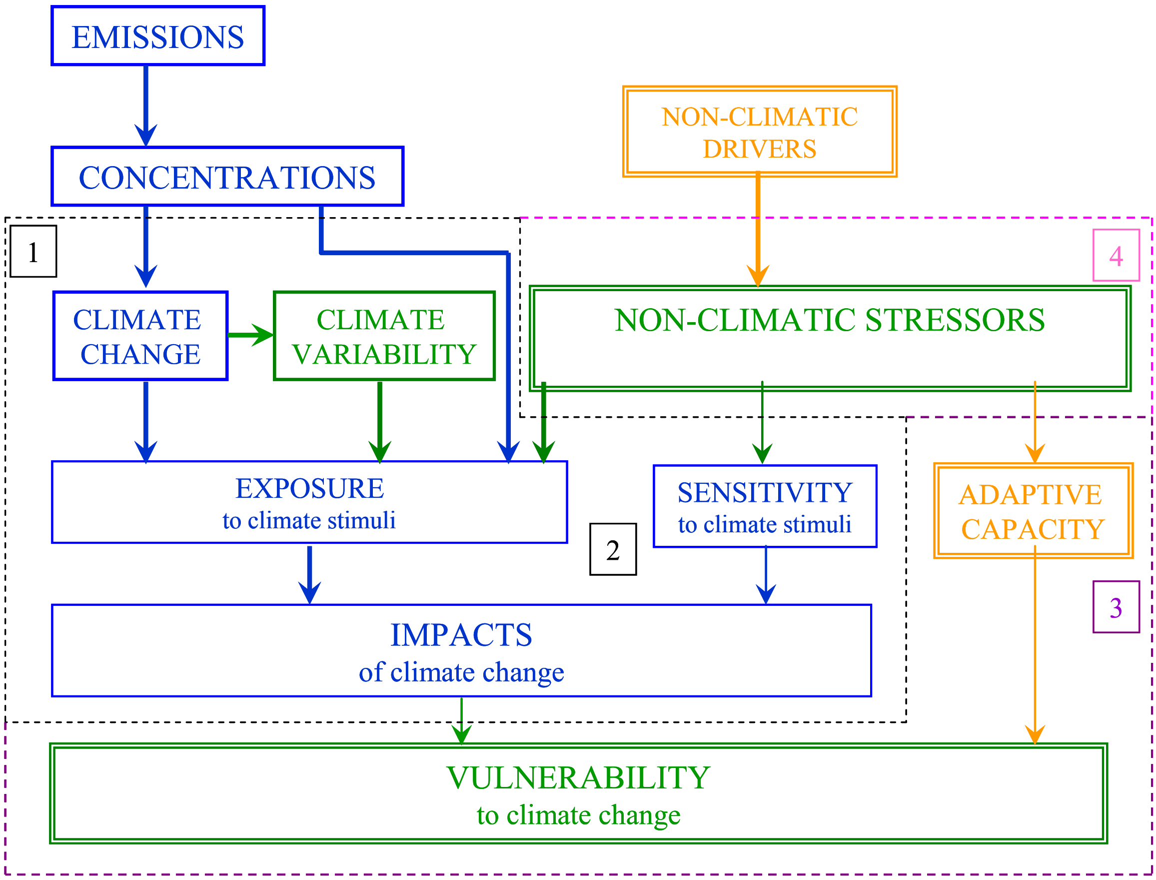


Figure 3.1 Modified post-adaptive vulnerability assessment framework used for the Hawkesbury study. Numbers in boxes refer to the stages of the assessment described in Section 3.2.
Adapted from Fussel and Klien, 2006.

3.2. Application of the modified post-adaptive vulnerability assessment framework to the Hawkesbury estuary

Application of the modified post-adaptive vulnerability assessment framework for the Hawkesbury (PAVAFH) was undertaken using a series of four cascading stages (Figure 3.2). Stage 1 was a risk assessment of the impacts of climate change stressors on a habitat based on exposure and sensitivity. Stage 2 was a resilience assessment based on the risk level and adaptive capacity. Stage 3 was a vulnerability assessment based on the influence of non-climatic human stressors and adaptive capacity. Stage 4 was a priority action assessment that identified which non-climatic human stressors would most influence the exposure and adaptive capacity of habitats to climate change.

3.2.1. Stage 1 – Risk assessment

One of the difficulties in assessing the effects of climate change on estuarine habitats is predicting what the actual impacts will be, due to natural and climatic variability in both space and time and the unknown levels and types of interactions among variables (see Chapter 1). To overcome this problem instead of trying to assess what the impact on a habitat might be, the risk that a specified type of impact (i.e. an undesirable consequence as a result of the effects of climate change) might occur was determined. A standardised qualitative ecological risk assessment (QERA) can then be applied (see examples in Astles, 2010). The potential impacts were simplified into three broad types – loss of habitat (partial or complete), shift (i.e. changed location) or gain (i.e. increase in spatial extent). Loss of habitat at the individual patch level was the most severe potential impact and the risk assessment determined the likelihood that this would occur given predicted levels of exposure to climate change stressors and sensitivities of habitats to these stressors. Exposure is the extent a habitat is subject to climate change stressors. The extent of exposure was based on the duration a habitat was exposed to a stressor above its physiological threshold and the magnitude it exceeded its physiological threshold. Sensitivity is the extent a habitat is potentially affected by climate change stressors, either directly or indirectly. The extent of sensitivity was based of the biological, ecological and/or geomorphological characteristics of habitats that contribute to how susceptible they are to being affected by climate change stressors. How the levels of exposure and sensitivity were calculated is explained in detail in Chapter 6.

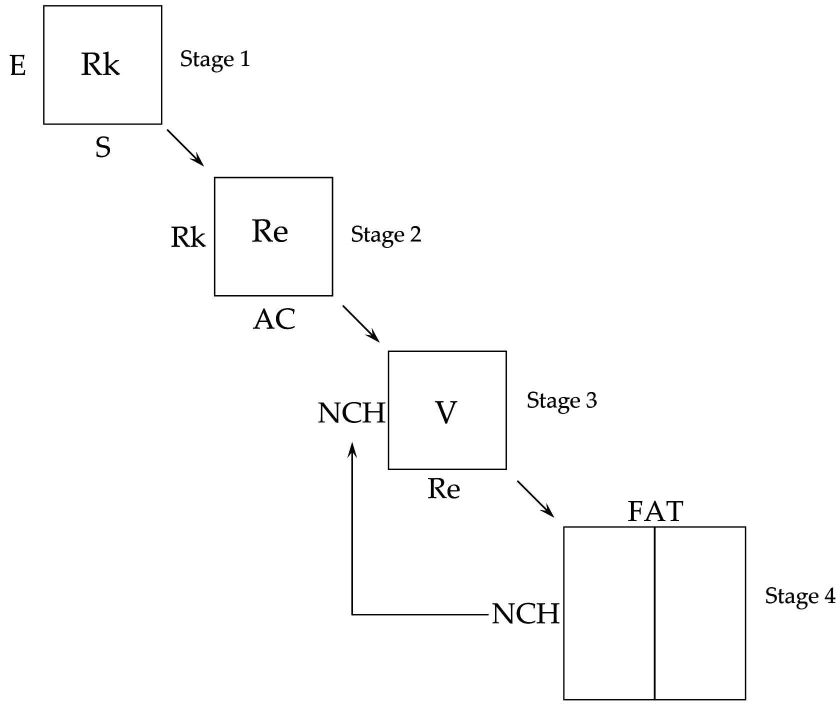


Figure 3.2 Diagram of the four stages of the post-adaptive vulnerability assessment framework for the Hawkesbury. Rk – risk, E – exposure, S – sensitivity, Re – resilience, AC – adaptive capacity, V – vulnerability, NCH – non-climatic human stressor, FAT – focus action table.

3.2.2. Stage 2 – Resilience assessment

Resilience, in a climate change context, is a measure of the magnitude of a perturbation that a habitat can respond to before it is completely degraded or is transformed into a different habitat type (Gallopin, 2006). Therefore, there are two aspects to resilience – the level of the perturbation and the response to that perturbation. The level of risk determined from stage 1 is an indication of the extent of the perturbation to environmental conditions of a habitat patch. The potential of a habitat patch to respond to this perturbation is known as its adaptive capacity (Gallopin, 2006). This capacity may take several forms including moderating the potential damage, taking advantage of opportunities and coping with the consequences. Generally, there are two aspects to this capacity (Gallopin, 2006);

i) A habitat patch being able to maintain or improve its condition in the face of a changed environment. This involves attributes of a habitat that exist prior to the perturbation and is primarily manifested as immediate or short term responses (i.e. within one or two generations of a population) to the changed conditions.

ii) A habitat patch being able to improve its condition in relation to its environment, i.e. extend the range of conditions or environments to which is it able occupy. This can involve evolutionary adaptations of its attributes as its environment changes over time and is primarily manifested as longer term responses (i.e. greater than two generations of a population) to the changed conditions.

Because there was no information available to assess longer term responses of a habitat patch to climate perturbations (e.g. genotypes) the first aspect of adaptive capacity was used in the vulnerability assessment stage. There were four basic ways a habitat patch could respond to the changed conditions (Fig. 3.3); A) contract in spatial extent; B) maintain its extent but shift its location; C) expand its spatial extent; D) translocate to a new location. A habitat patch may respond in any combination of these four basic ways. In addition, these responses may vary over a range of temporal scales, such as seasonally or between dry and wet years.

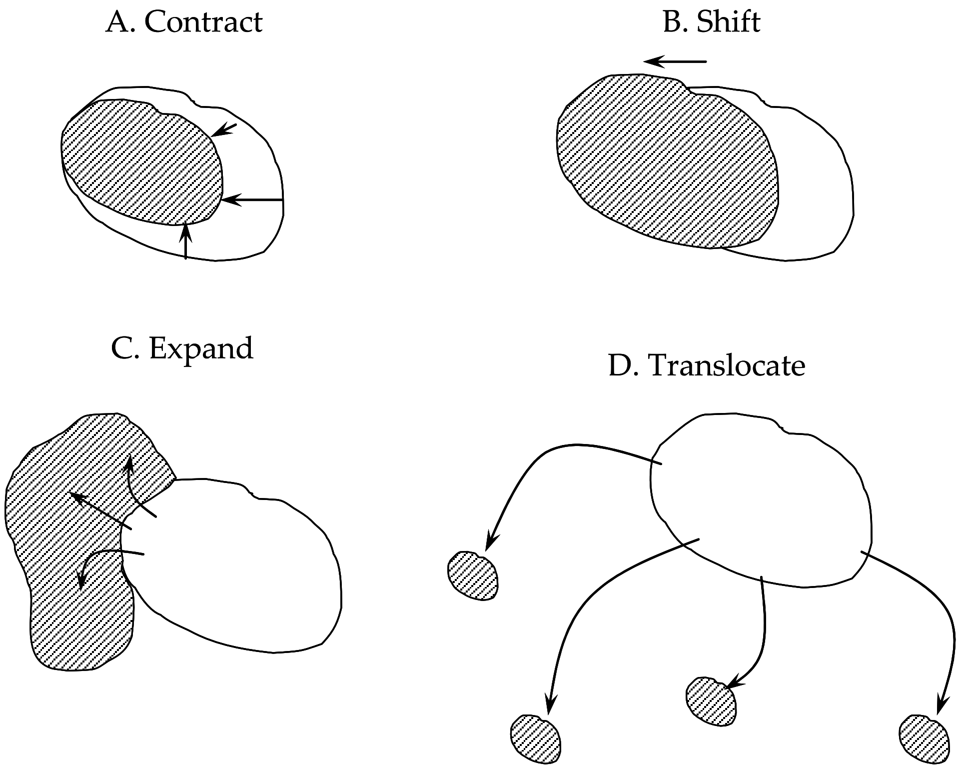


Figure 3.3 Illustration of the four basic ways a habitat patch might respond to the effects of climate change.

The biological, ecological and/or geomorphological characteristics of a habitat patch, that could contribute to its potential to respond in any of these ways to the perturbed conditions, were used to assess its adaptive capacity. How the levels of adaptive capacity were determined is explained in detail in Chapter 5. The level of adaptive capacity for each habitat patch was then combined with its risk level to determine its resilience.

3.2.3. Stage 3 – Vulnerability assessment

A habitat's resilience to the potential effects of climate change can be affected both positively and negatively by non-climatic human (NCH) stressors. These are stressors resulting from human activity that are not directly changing the climatic conditions (as compared to, for example, activities that increase greenhouse emissions). For example, recreational boating within the vicinity of a shallow seagrass bed may cause damage to it from propeller scaring. However, some NCH stressors may be driven by a changing climate, at least in part. For example, extended periods of drought may result in increasing the drawdown of groundwater to supply water to a population. NCH stressors can potentially affect the resilience of a habitat patch in two ways. First, it can either exacerbate or ameliorate the perturbations to environmental conditions. Second, it can either enhance or diminish a habitat's capacity to respond to changed environmental conditions. Such effects can occur over a range of spatial and temporal scales (e.g. Russell et al., 2009). Despite this potentially important interaction there are few studies that have quantitatively examined the relationship between NCH and the effects of climate change on estuarine habitats.

The level of influence of NCH stressors on a habitat patch was determined by identifying which stressors were within two spatial scales of proximity to it and then rating whether it would influence the perturbed environmental conditions and/or the habitat's potential to respond, either positively or negatively. How the levels of NCH stressor were determined is explained in detail in Chapter 5. The level of NCH stressors for each habitat patch was then combined with its resilience level to determine its vulnerability to the effects of climate change.

3.2.4. Stage 4 – Priority action assessment

The level of vulnerability to the effects of climate change for each habitat patch provides the means of prioritising which NCH stressors should be evaluated for management action. This was done by constructing a focus action table (FAT) that lists the NCH stressors that contribute to the vulnerability levels of a habitat patch and beside each an indication of how they are affecting a habitat's potential to respond to climate change stressors (i.e. their adaptive capacity). For example, the increased drawdown of groundwater may affect the soil moisture content of a saltmarsh patch, which in turn may affect below-ground processes that reduce the patch's rate of increase of surface elevation making it unable to keep pace with rising sea level. The FAT enables management to clearly see how their decisions can potentially influence the vulnerability of a habitat patch to the effects of climate change, either positively or negatively. It also enables management to identify where action is most needed and can be most efficacious, thereby assisting in making cost-effective decisions.

3.3. Analysis approach

The analysis approach combined hydrodynamic modelling, habitat threshold evaluation and GIS information about NCH stressor. These were applied to sixteen habitat sites within the estuary.

3.3.1. Habitat sites

Hornsby Shire Council (HSC) identified several sites within the Hawkesbury estuary for which they had particular concern. Other sites were added that were outside HSC jurisdiction that represented significant locations of estuarine habitats. Table 3.2 gives a description of all sites analysed. Field sampling of a representative set of sites was done to document species composition, abundance and distribution. A summary of this data is reported in Appendix 2.

Table 3.2 List of sites and habitats assessed for this study.

		Habitat Types Present				
No.	Site Name	Seagrass[1]	Mangrove	Saltmarsh	Floodplain[2]	Field Inspection
1	One Tree Reach		✓	✓	✓	✓
2	Farmland below Laughtondale			✓		✓
3	Courangra Point		✓	✓		✓
4	Gentleman's Halt		✓	✓		✓
5	Pumpkin Creek		✓	✓		✓
6	Seymores Creek		✓	✓	✓	
7	Brooklyn Oval		✓		✓	
8	Big Bay		✓	✓		✓
9	Coba Bay		✓	✓		
10	Crosslands & Calna Creek		✓	✓		
11	Dangar Is	✓				✓
12	Cowan Creek, below Bobbin Head	✓				✓
13	Cowan Creek, end of Smiths Creek	✓				✓
14	Patonga entrance	✓				✓
15	Mullet, upper	✓				✓
16	Mangrove, Popran Creek		✓	✓		✓

Notes:

1. Seagrasses are present at sites 6 and 10 but were not included in this study.

2. Floodplain forests are present at sites 3 and 10 but were not investigated in this study.

3.3.2. Hydrodynamic modelling

A hydrodynamic model of the Hawkesbury estuary was used to generate data for the climate change stressors. Input data for each of the climate change scenarios were determined using information from the relevant climate change reports from the IPCC and/or CSIRO (Suppiah, Hennessy et al. 2007) and are given in Table 3.3. The hydrodynamic model produced hourly data for air temperature, water temperature, water height and salinity for summer and winter seasons for each scenario. Sea surface temperature was obtained as data for the continental shelf off Sydney. The hydrodynamic model used this data to produce water temperatures at each site. Details and results of the modelling are contained in the following chapter containing the report from Hydronumerics who undertook this part of the project.

Table 3.3 Data for climate change variables used in the hydrodynamic model for each scenario.
RSL – relative sea level rise, SST – sea surface temperature, AT – air temperature, Max – maximum, Min – minimum.

Scenario No.	Year	Time period	Rainfall	Rain mm	Sea Level	RSL rise[1] (mm)	SST	SST rise °C	Air Temp	AT rise °C
Baseline	1990	Annual	Average	801	Average	0	Average	0	Average	0
1	2030	Annual	Average		Max	362.1	Max	1.4	Max	1.5
2	2030	Annual	Average		Max	362.1	Mean	0.9	Max	1.5
3	2030	Annual	Average		Max	362.1	Max	1.4	Mean	0.9
4	2030	Annual	Average		Max	362.1	Mean	0.9	Mean	0.9
5	2030	Annual	Average		Average	138.5	Max	1.4	Max	1.5
6	2030	Annual	Average		Average	138.5	Mean	0.9	Max	1.5
7	2030	Annual	Average		Average	138.5	Max	1.4	Mean	0.9
8	2030	Annual	Average		Average	138.5	Mean	0.9	Mean	0.9
9	2030	Annual	Average		Min	-33	Max	1.4	Max	1.5
10	2030	Annual	Average		Min	-33	Mean	0.9	Max	1.5
11	2030	Annual	Average		Min	-33	Max	1.4	Mean	0.9
12	2030	Annual	Average		Min	-33	Mean	0.9	Mean	0.9
13	2050	Annual	Average		Max	400	Mean	1	Mean	1.5
14	2050	Annual	Average		Average	185	Mean	1	Mean	1.5
15	2050	Annual	Average		Min	120	Mean	1	Mean	1.5

Notes:

1. For procedure used to calculate relative sea level rise and explanation of negative values see Appendix 1

3.3.3. Habitat thresholds

Habitat thresholds were used to evaluate the exposure and sensitivity of habitat types to climate change stressors. These thresholds were for air temperature, water temperature, salinity, exposure to air and inundation (Table 3.4). Values for photosynthesis and growth were also obtained where available to incorporate potential lethal and sub-lethal effects, respectively. An extensive literature search was done to determine the appropriate thresholds to use for the macrophyte species that made up each habitat type. Research into the effects of climate change on the biology and physiology of many estuarine macrophyte species is only just beginning to develop (Short and Neckles 1999). Specific studies on Australian species are even harder to find (Lovelock and Ellison 2007). Consequently, information was taken from a range of studies on the biology and ecology of species. Where there were multiple studies giving a range of values for a variable, an average was taken. In a few cases values were only available for non-Australian species.

Table 3.4 Thresholds of climate variables used to assess exposure levels under the different climate change scenarios of the study.

G - growth, PS - photosynthesis, Opt - optimal, ad - adult, germ - germination, grw – growth, HR - hour

		Air Temp °C		**Opt Water Temp °C**		**Salinity (psu)**		**Light (%SI)**			
Habitat	**Species/Grp**	Max	Min	G	PS	Max	Min	Max	Min	**Exposure**	**Inundation**
Seagrass (SG)[1]	*Posidonia australia*	35	-	19	23		13-19		11	1HR @ 35°C	
	Zostera capricornia	35		15.3	23.3	30-40			11	1HR @ 35°C	
	Halophila ovalis	35		25	27.6				11	1HR @ 35°C	
	SG Average	35		19.77	24.63	40	13		11	1HR @ 35°C	
Mangroves (Mn)[2]	*Avicennia marina* (ad)	40	16	24		35					
	Avicennia marina (seedling germ)	30				35					
	Avicennia marina (seedling grw)	30				5					
	Aegiceras corniculatum (ad)	40	16	24		35					
	Aegiceras corniculatum (seedling germ)	30				15					
	Aegiceras corniculatum (seedling grw)	30				5					
	Mn Average	33.33	16	24		35	5				
Saltmarsh (SM)[3]	*Juncus kraussii* (ad)	40				40	0				5cm for 10wk
	Juncus kraussii (seedling germ)	30	15			15	10				
	Juncus kraussii (seedling grw)	30	15			20					
	Sporobolus virginus (ad)	40				7	0				
	Phragmites australis	40				30	5				
	*Sarcocornia spp.**	35				35					5cm for 6wk
	SM Average	35.83	15			24.50	5				5cm for 6wk
Floodplain forest (FPF)[4]	*Melaleuca ericifolia* (ad)	40				30	25				continuous >5 yr
	Melaleuca ericifolia (seedlings germ)	40				0.2					10cm 50 days
	Melaleuca ericifolia (seedlings grw)	40				0.2					10cm 50 days
	Melaleuca ericifolia (seedlings germ)	40				4					0 cm, 0 days
	Melaleuca ericifolia (seedlings grw)	40				8					0 cm, 0 days
	Melaleuca quinquenervia (ad)	40				0					waterlogged > 30 days
	Melaleuca quinquenervia (seedling germ)	40				0					waterlogged > 30 days
	Melaleuca quinquenervia (seedling grw)	40				0					waterlogged > 30 days
	Eucalyptus robusta (ad)	40				0					0 cm, 0 days
	Casuarina glauca (seedlings germ)	25				31					waterlogged > 12 weeks
	Casuarina glauca (seedlings grw)	25				31					
	FPF Average	40	25			30	0				waterlogged > 12 weeks

Notes:

* data is for non-Australian species

1. References: Abal et al. (1994), Bite et al. (2007), Brenchley and Probert (1998), Cambridge and Hocking (1997), Dennison (1987), Larkum (1976), Tyerman, et al. (1984).

2. References: Ball, 1988, Ball and Anderson (1986), Ball and Critchley, (1982), Ball and Farquhar (1984), Burchett et al. (1984, 1989), Downton (1982), Krauss et al. (2008), Saintilan (1998), Youssef and Saenger (1998).

3. References: Adams and Bate (1994), Bell and O'Leary (2003), Clarke and Hannon (1967), Clarke and Hannon (1969), Clarke and Hannon (1970), Greenwood and MacFarlane (2006), Greenwood and MacFarlane (2009), Laegdsgaard (2002), Naidoo and Naidoo (1998), Naidoo and Kift (2006).

4. References: Hughes et al. (1996), Ladiges et al. (1981), MacJannet (2008), Marcar (1993), Salter et al. (2007, 2010a,b), Van der Moezel et al. (1989), Van der Moezel et al. (1991).

It is important to note that the thresholds used for the analyses are only indicative of the potential effects of climate change stressors on these habitats. They should not be seen as definitive predictions of how the different habitat types might be impacted. Habitat patches will have specific site characteristics that will moderate how any of these variables will act on the species. To provide more accurate estimates of these thresholds, manipulative experiments specifically designed to test hypotheses about the how estuarine habitats respond to changes in a range of variables relevant to climate change stressors are required.

3.3.4. GIS information and LIDAR data

Non-climatic human stressors that were potentially affecting each habitat site were obtained from GIS information. The number and types of NCH stressors within 10m of a habitat were collated. In addition, groundwater condition, which can affect saltmarsh and mangrove habitats, was obtained from the 2010 State of the Catchment reports for the Sydney metropolitan area. Table 3.5 lists the NCH stressors used.

Table 3.5 List of non-climatic human stressors assessed for each habitat type at each site in the study.

Human disturbances within 10m of a sites	Rationale
No. public parks	Provides access to habitats which may result in trampling & gross pollution
No. marinas	Recreational boating , including boat maintenance, and instream infrastructure
No. boat ramps	Indication of recreational boating activity
Length of artificial rockwall	Indication of changes to hardness and slope of foreshore
Length of farmland boundary closest to site	Indication of agriculture landuse
No. unsewered housing blocks	Diffuse pollutants, increase nitrogen and phosphorous loads
No. wharves	Recreational boating and instream infrastructure
No. stormwater outlets	Point source pollutants, gross pollution, freshwater input
Proportion of farmland to habitat area	Indication of agriculture landuse

3.3.4.1. LiDAR data analysis issues

It was originally intended that LiDAR data would be used for this project to analyse the potential elevation change in mangrove and saltmarsh habitats as a result of sea level rise. Unfortunately, the LiDAR data had significant problems that prevented it being used. There were three major issues that neither HSC nor NSW Department of Primary Industries anticipated.

First, the elevations of on the LiDAR of the different habitats did not match the current distribution maps produced by NSW Department of Primary Industries. When the elevation ranges (above AHD) for mangroves, saltmarsh and mangrove/saltmarsh mixed habitats were entered into the LiDAR data, it did not identify the habitats correctly. Whole areas of habitat are missing and it identified habitat where it does not occur (e.g. in the middle of the river). Figure 3.4 is an example of the problem for the Big Bay site. The coloured lines are the actual distributions of the habitats that have been mapped by NSW Department of Primary Industries. The different coloured shaded areas are what the LiDAR data identifies as the different habitat types based on their elevations. It shows saltmarsh where we know there are mangroves, mixed habitat where only mangroves occur, some mangroves and saltmarsh are not identified at all where it is present and patches of mangrove and saltmarsh where there are none. The consequence of this issue is that it was not possible to construct a base set of habitat distributions with their current real elevations. Without such a base set it was not possible to generate any predictions in changes to the habitat distributions under different sea level rise scenarios.

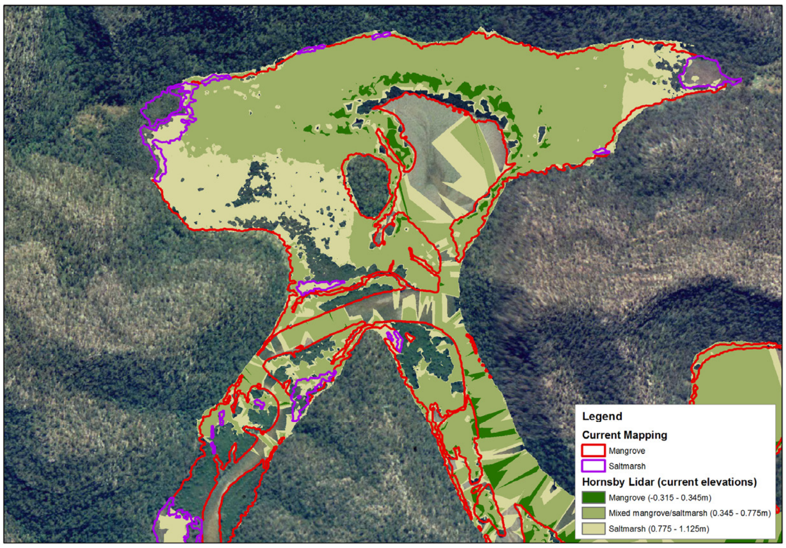


Figure 3.4 Example of LiDAR data supplied compared to NSW Department of Primary Industries habitat maps for Big Bay in the Hawkesbury estuary.

Second, elevations on the LiDAR for habitat patches did not appear to be real. For example, the elevation for saltmarsh in Popran Creek was given as 8m and mangroves go as high as 38m in some locations. Part of the problem is that possibly the LiDAR was picking up the canopy rather than the ground level. But even correcting for vegetation height does not explain all the anomalies. Furthermore, vegetation height varies widely among sites and among species and without specific height data for each species and site such corrections cannot be made on the LiDAR data. Therefore, the accuracy of the elevation data for the areas where these habitats occur is not reliable enough to use to predict changes in distribution from sea level rise.

Third, the original producers of the LiDAR clipped the data to the Department of Lands waterline, which removed about 90% of the mangrove habitats. Therefore, there were whole areas where elevation data for mangroves was completely missing. A complete set of corrected data that removed the clipped waterline, was not forthcoming from the original producers of the LiDAR.

LiDAR data can be very useful to examine changes in elevation. However, the key principle is to ensure that LiDAR is collected for the specific purpose for which it will be used. Only then can the elevations be developed and ground truthed accurately with appropriate confidence intervals for the specific areas of concern. LiDAR that has been collected for one purpose is very difficult to adapt for another unless it is for exactly the same area.

4. HYDRODYNAMIC MODELLING

Dr Alicia Loveless

See separate document of original report received from Hydronumerics.

5. INTEGRATED VULNERABILITY ASSESSMENT

5.1. Stage 1 – Risk Assessment

5.1.1. Exposure levels

Using the data generated from the hydrodynamic modelling four variables were used to determine the level of exposure – air temperature, water temperature, salinity, water depth (mean, and daily maximum, minimum, range). The mean and standard deviation of a whole season for each variable was calculated. The values of all variables were able to vary naturally in the hydrodynamic model. Under natural variability thresholds for habitat would be breached. To determine whether such breaches would lead to increased exposure for a habitat, the duration and magnitude of these breaches under each climate change scenario was compared to the duration and magnitude of breaches in 1990 (base year). Duration assessed whether unfavourable conditions for a habitat were occurring more often under each climate change scenario compared to 1990. Magnitude assessed whether unfavourable conditions for a habitat were getting worse under each climate change scenario compared to 1990. Table 5.1 explains how duration and magnitude were calculated for each variable.

Table 5.1 Tables describing how the A) duration and B) magnitude of exposure for each climate change variable was calculated.

A. Duration:		**Example – air temperature, threshold 35°C**		
i) The number of hours in a season that the variable was greater than the threshold for each scenario	ii) Percentage difference in the number of hours from 1990 = (Number hours from (i) – Number hours from 1990)/ Number hours from 1990)		i) # Hours > 35°C	ii) % Difference
		Scenario 1	40	((40-24)/24)*100 = 66.7
		1990	24	

B. Magnitude:			**Example – air temperature, threshold 35°C**			
i) The value a variable was greater than the threshold for each hour in each scenario	ii) Average of all values from (i) for each variable for a season for each scenario	iii) Difference between the average from (ii) for a scenario and the average for 1990 scenario		i)	ii)	iii)
			Scenario 1	0.5 3.476 4.508 5.5 5.5 3.488 1.988 0.488	3.81	3.81-0.91 = 2.27
			1990	0 0 0 0 0.984 2.008 3 1.271	0.91	

5.1.1.1. Exposure metrics

To determine an overall level of exposure from all variables to a habitat the duration and magnitude of each variable were scored using the principle of biological significance rather than statistical significance (univariate statistical analysis of the data was not possible due to the data being autocorrelated and non-independent, making the use of statistical significance unviable). Under natural variability climate variables will exceed thresholds. Under climate change scenarios these exceedances will be biologically significant if they are outside the natural variability occurring in the base year 1990 (Table 5.2). This will be referred to as "biologically significant" throughout the results section. A set of decision criteria were then developed to determine how to score different combinations of biologically significant duration and magnitude. These criteria were developed by integrating information from the scientific literature about the effects of the different variables on habitats (see summary of this information in Appendix 3). Scores for all variables relevant to each habitat type were summed and expressed as a proportion of all possible scores across all relevant variables.

Table 5.2 Decision criteria used to determine the metric score for duration and magnitude of each exposure variable.

Metric	Measure	High Exposure	Low exposure
Duration	Percentage difference in the number of hours from 1990 (from Table 5.1 A(ii))	% difference in the number of hours > than threshold is ≥ 10%	% difference in the number of hours > than threshold is < 10%
Magnitude	Difference between the average for a scenario and the average for 1990 scenario (from Table 5.1 B(iii))	Difference in the average value of exceedance is > than standard deviation of the average value of variable in 1990	Difference in the average value of exceedance is ≤ than standard deviation of the average value of variable in 1990

5.1.2. Sensitivity levels

Sensitivity levels were based on the biological, ecological and geomorphological characteristics of habitat types. Each characteristic was scored according to how it contributed to a habitat's responsiveness to climate change stressors. The scores were then summed and expressed as a proportion of the total number of maximum possible scores. Sensitivity levels were determined on a habitat basis only and differences among sites were not incorporated. Whilst it is acknowledged that individual sites may have characteristics that could moderate the sensitivity of individual habitat patches, there was insufficient information available that could be used to determine this. Table 5.3 gives the decision criteria for each habitat type.

Table 5.3 Decision criteria for determining sensitivity levels to climate change variables for estuarine habitats.

		Sensitivity to effects of climate change		
Habitat	**Characteristics**	High	Meduim	Low
Seagrass	Morphological/ physiological plasticity	low plasticity		high plasticity
	Rhizome persistence	long term, plant age >3 years	mediul-long term, plant age < 3 >1 year	short/ephemeral term, plant age <= 1 year
	Environmental variability	grows in low variable envirnomental conditions	grows in medium variable envirnomental conditions	grows in high variable envirnomental conditions
Mangroves	Growth	Slow ,>2yrs		Fast 1-2yr
	Salinity tolerance	narrow salinity range within optimum range 3-27ppt		wide salinity range outside optimum range 3-27ppt
	CO2 Increase	less responsive due to high metabolic demands		responsive under low nutrient availability
Saltmarsh	Salinity range	narrow,< 7ppt	medium, 7-25ppt	large, >35
	Air T max	maximum 35	maximum 40	
	Inundation period		not used insufficient information	
Floodplain forests	Salinity Inundation period		insufficient information, all species assessed as high sensitivity due they are rarely inundated by estuarine waters	

5.1.3. Results - risk

Results are presented for each site for each scenario, with the exception of scenarios 4 (maximum sea level), 7 and 8 (mean sea level), and 11 and 12 (minimum sea level). The outputs from these scenarios showed that mean air temperature did not change with changes in sea level and also did not change water temperatures. Therefore, they produced data that was the same as the other scenarios within each sea level group. Consequently, results for scenarios 4, 7, 8, 11 and 12 have been omitted.

5.1.3.1. Seagrass habitat

Exposure

In summer seagrass habitats at all sites had a medium to high level of exposure to climate change variables under all maximum sea level rise (SLR) scenarios (Table 5.4). These exposure levels were due to biologically significant increases in the duration of air temperature and water temperature above their thresholds rather than an increase in the magnitude (see Tables in Appendix 4). However, for water depth there was a biologically significant increase in the average hourly water depth and in the daily maximum and minimum water depths. In all sites, except Mullet Creek, minimum depths increased more than maximum depths. Thus at low tide, under maximum SLR scenarios, seagrass is likely to be in deeper water at these sites. At the two sites with intertidal seagrass habitats, Mullet and Smiths Creeks, there was a decrease in the duration that these beds were out of water under maximum SLR scenarios.

All sites in summer had a low-medium to medium exposure to climate change variables under average and minimum SLR scenarios. As for the maximum SLR scenarios these levels were due to a biologically significant increase in the duration of air and water temperature above their thresholds. Water depths did not show any biologically significant change under these scenarios. However, in the 2050 average and minimum SLR scenarios, Mullet Creek had a biologically significant increase in the average hourly water depth and Patonga had biologically significant increases in the maximum and minimum water depths.

In winter all sites had a medium to medium-high exposure to climate change variables under all maximum SLR scenarios. This was primarily due to a biologically significant increase in the duration of water temperatures above the threshold for growth for *Z. capricorni* and an increase in the daily maximum and minimum water depths. In 2050 there was a biologically significant increase in the average hourly water depth. In Mullet Creek there was an increase in the average daily range in water depth. This occurred because the maximum depth increased but there was no corresponding increase in the minimum water depth, hence the range was larger. Also at this site, during winter under minimum sea level rise, exposure was negative because the minimum water depth in 2030 was less than the minimum water depth in 1990.

Table 5.4 Summary of exposure levels for seagrass habitats in the Hawkesbury estuary.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	Site	1	2	3	5	6	9	10	13	14	15
Summer	Cowan Bobbin Head	0.64	0.64	0.64	0.44	0.44	0.44	0.44	0.75	0.50	0.44
	Smiths Creek, Cowan	0.87	0.87	0.87	0.67	0.67	0.40	0.40	0.94	0.67	0.67
	Dangar Island	0.63	0.63	0.63	0.46	0.46	0.33	0.33	0.65	0.56	0.46
	Mullet Creek upper	0.94	0.94	0.94	0.50	0.50	0.09	0.09	0.94	0.73	0.50
	Patonga	0.79	0.79	0.79	0.55	0.55	0.55	0.55	0.79	0.69	0.55
Winter	Cowan Bobbin Head	0.50	0.50	0.50	0.25	0.25	0.25	0.25	0.64	0.40	0.25
	Smiths Creek, Cowan	0.71	0.71	0.71	0.45	0.45	0.30	0.11	0.79	0.50	0.50
	Dangar Island	0.50	0.50	0.50	0.33	0.17	0.46	0.46	0.53	0.43	0.33
	Mullet Creek upper	0.71	0.71	0.71	0.36	0.36	-0.10	-0.10	0.71	0.62	0.09
	Patonga	0.58	0.58	0.58	0.22	0.22	0.22	0.00	0.58	0.36	0.22

Sensitivity

All the sites examined predominantly consisted of the seagrass *Z. capricorni*. This species had a medium sensitivity to climate change variables as it can tolerate a range of salinities and variable environmental conditions (Table 5.5). *H. ovalis* had a low sensitivity to climate change variables due to its ephemeral life history and ability to grow in a range of salinity environments. *Posidonia australis* was not present in any of the sites in this study but it is present within the estuary in small to medium sized patches in deeper water off beaches in the marine and fluvial reaches. *P. australis* has a high sensitivity to climate change variables due to it primarily occurring in relative constant environmental conditions (Carruthers, Dennison et al. 2007) (Table 5.5).

Table 5.5 Summary of sensitivity results for seagrass species (Carruthers et al., 2007).

L – low; M – moderate; MH – moderate-high; H – high

		Characteristics				
Habitat	**Species**	**Morphological/ physiological plasticity**	**Rhizome persistence**	**Environmental variability**	**Overall Sensitivity**	**Reason**
Seagrass	*H. ovalis*	H	L	H	Low	high plasticity, ephemeral life strategy (rhizome persistence) can withstand high environmental varaibility
	Score	1	1	1	3	0.20
	Z. capricornia	MH	ML	MH	Medium-high	Moderate to high plasticity, moderate persistence, high environmental varaibility tolerances
	Score	4	2	4	10	0.67
	P. australis	L	H	L	High	low plasticity, long-term presistence, low environmental variability tolerances
	Score	5	5	5	15	1.00

Risk Levels

The exposure and sensitivity levels of each seagrass species were combined in the risk matrix (see Appendix 5) to determine the level of risk a habitat patch will be lost due to the potential effects of climate change (i.e. excluding the capacity of habitats to respond to these effects) at each site. For scenarios with maximum SLR, *Z. capricorni* habitat patches had a moderate-high level of risk of loss during summer (Table 5.6). Under average and minimum climate change scenarios the risk of loss drops to moderate during summer for all sites except Smiths Creek and Patonga, which remained at moderate-high risk. Dangar Island was the only seagrass patch to have a low risk of loss under minimum SLR scenarios in summer. During winter, all sites had a moderate to low risk of loss, except for the two sites with intertidal seagrass patches (Mullet Creek and Smiths Creek). These sites continued to have a moderate-high risk of loss under maximum SLR scenarios and average SLR in 2050 in Mullet Creek. Interestingly, even under minimum SLR scenarios *Z. capricorni* habitat patches remained at moderate levels of risk, indicating that water and air temperature have a substantial influence (Table 5.6). Figures 5.1-5.10 are maps of each site showing the risk levels for seagrass represented by *Z. capricorni.*

Table 5.6 Summary of risk levels for the seagrass species *Z. capricorni,* i.e. level of risk a habitat patch will be lost due to the potential effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	Cowan Bobbin Head	MH	MH	MH	M	M	M	M	MH	M	M
	Smiths Creek, Cowan	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Dangar Island	MH	MH	MH	M	M	M	M	MH	M	M
	Mullet Creek upper	MH	MH	MH	M	M	L	L	MH	MH	M
	Patonga	MH	MH	MH	M	M	M	M	MH	MH	M
Winter	Cowan Bobbin Head	M	M	M	M	M	M	M	MH	M	M
	Smiths Creek, Cowan	MH	MH	MH	M	M	M	L	MH	M	M
	Dangar Island	M	M	M	M	L	M	M	M	M	M
	Mullet Creek upper	MH	MH	MH	M	M	L	L	MH	MH	L
	Patonga	M	M	M	L	L	L	L	M	M	L

H. ovalis had a moderate level of risk of loss during summer at the two intertidal sites, Mullet and Smiths Creeks, under all scenarios. All other sites had low levels of risk for this species. During winter, the risk of loss of *H. ovalis* was low in all sites (Table 5.7).

Table 5.7 Summary of risk levels for the seagrass species *H. ovalis,* i.e. level of risk a habitat patch will be lost due to the potential effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	Cowan Bobbin Head	L	L	L	L	L	L	L	L	L	L
	Smiths Creek, Cowan	M	M	M	L	L	L	L	M	L	L
	Dangar Island	L	L	L	L	L	L	L	L	L	L
	Mullet Creek upper	M	M	M	L	L	L	L	M	L	L
	Patonga	L	L	L	L	L	L	L	L	L	L
Winter	Cowan Bobbin Head	L	L	L	L	L	L	L	L	L	L
	Smiths Creek, Cowan	L	L	L	L	L	L	L	L	L	L
	Dangar Island	L	L	L	L	L	L	L	L	L	L
	Mullet Creek upper	L	L	L	L	L	L	L	L	L	L
	Patonga	L	L	L	L	L	L	L	L	L	L

The following pages contain Figures 5.1 – 5.10 which are the maps of risk levels for seagrass sites*,* i.e. level of risk a habitat patch will be lost due to the potential effects of climate change. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 5.1 Map of Cowan Creek site showing risk levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.2 Map of Cowan Creek site showing risk levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.3 Map of Smiths Creek site showing risk levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.4 Map of Smiths Creek site showing risk levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.5 Map of Danger Island site showing risk levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.6 Map of Dangar Island site showing risk levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.7 Map of Mullet Creek site showing risk levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.8 Map of Mullet Creek site showing risk levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.9 Map of Patonga site showing risk levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

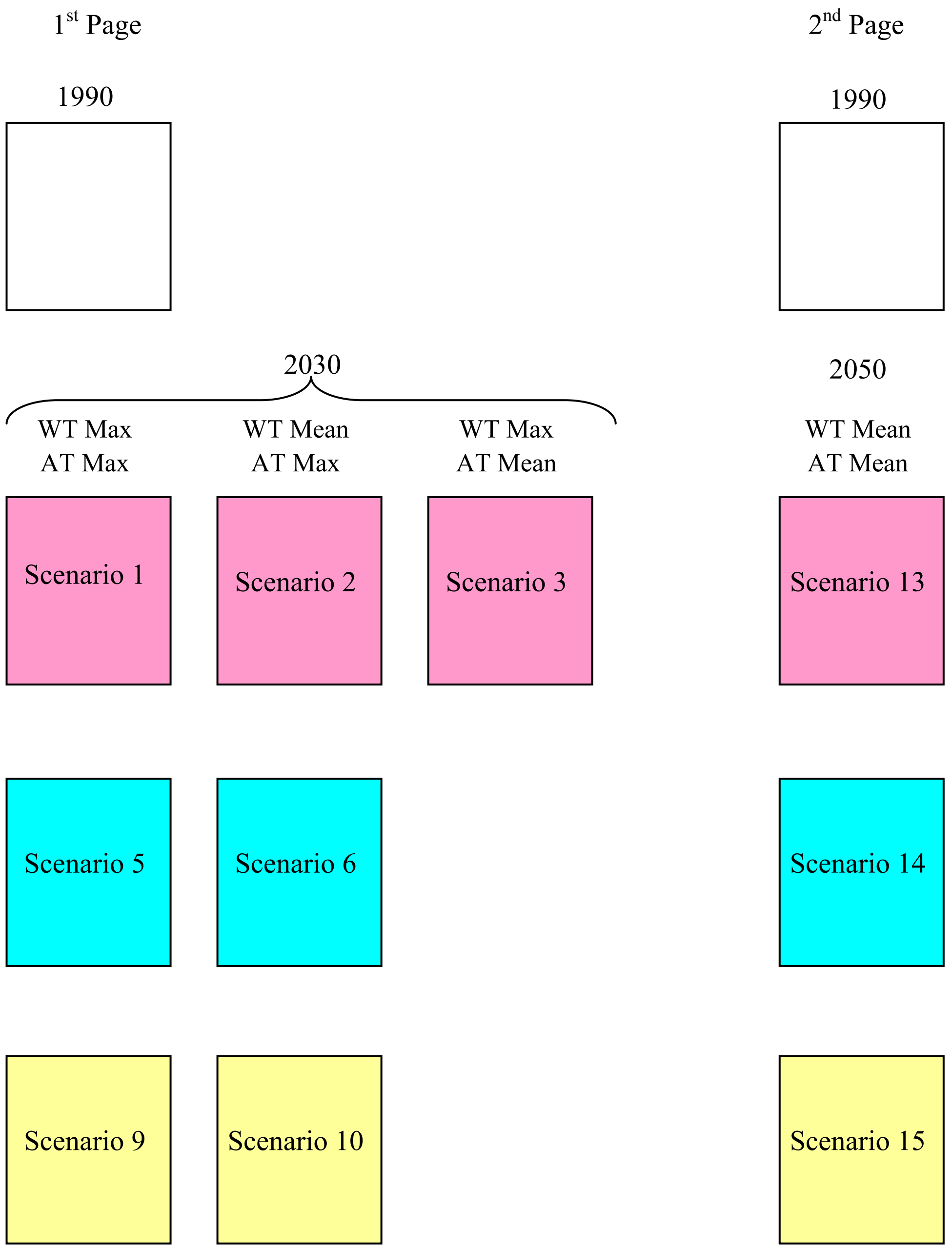
Figure 5.10 Map of Patonga site showing risk levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



5.1.3.2. Mangrove habitat

Exposure

In summer five mangrove sites, Courangra, Brooklyn, Coba Bay, Crosslands/Calna Creek and One Tree Reach, had medium-high levels of exposure to climate change variables and three sites had medium levels under all maximum SLR scenarios (Table 5.8). These exposure levels were due to three factors. First, there was a biologically significant increase in the duration of air and water temperatures above the thresholds for mangroves. For example, the optimum water temperature for mangrove growth (24^{o}C) was exceeded more often under maximum climate change scenarios than in 1990. Second, there was an increase in the mean hourly water depth and in the daily maximum and minimum water depth. Only Courangra did not have an increase in its minimum water depth under all maximum SLR scenarios. Five sites, Courangra, Brooklyn, Coba Bay, Crosslands/Calna Creek and One Tree Reach, also had an increase in the mean daily water depth range. Third, two sites, Brooklyn and One Tree Reach had biologically significant increases in their duration and magnitude of salinity above the threshold for salinity for the growth of mangrove seedlings.

Under average and minimum SLR scenarios during summer these same five sites remained at medium-high to high exposure levels but dropped to low-medium to medium for all other sites. Gentlemans, Popran Creek, Pumpkin Creek and Seymores Creek did not have a biologically significant increase in the duration of salinity above the threshold for seedling growth. Water height above 1990 levels only increased for Brooklyn in the average SLR scenario in 2050 and daily water depth range increased above 1990 at Courangra and Brooklyn in the same scenario.

During winter only Big Bay and Brooklyn had medium-high levels of exposure under all maximum SLR scenarios. The remaining sites had medium to low-medium levels of exposure under these scenarios. These levels were due to two factors - a biologically significant increase in the duration salinity was above the threshold for seedling growth and a biologically significant increase in the duration the sites were inundated with water compared to 1990. The latter occurred in Big Bay, Gentlemans, Popran Creek, Pumpkin Creek and Seymores Creek. There were also biologically significant increases in all water depth variables in most sites under all maximum SLR scenarios. Under minimum SLR scenarios during winter exposure levels were low to medium-low in all sites.

Table 5.8 Summary of exposure levels for mangrove habitats in the Hawkesbury estuary.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
SEASON	Site	1	2	3	5	6	9	10	13	14	15
Summer	One Tree Reach	0.94	0.94	0.91	0.75	0.75	0.50	0.50	0.94	0.80	0.75
	Courangra	0.91	0.91	0.87	0.79	0.79	0.43	0.76	0.94	0.81	0.79
	Gentlemans	0.69	0.69	0.63	0.50	0.50	0.50	0.50	0.69	0.54	0.50
	Pumpkin	0.69	0.69	0.63	0.50	0.50	0.50	0.50	0.69	0.54	0.50
	Seymores	0.72	0.72	0.67	0.50	0.50	0.50	0.50	0.72	0.58	0.50
	Brooklyn Oval	0.98	0.98	0.95	0.94	0.94	0.43	0.43	0.98	0.97	0.91
	Coba Bay	0.94	0.94	0.87	0.79	0.79	0.50	0.50	0.97	0.80	0.79
	Crosslands & Calna	0.88	0.88	0.84	0.79	0.79	0.50	0.50	0.94	0.79	0.79
	Poporan	0.64	0.64	0.58	0.50	0.50	0.50	0.50	0.69	0.54	0.50
Winter	One Tree Reach	0.70	0.70	0.70	0.64	0.64	0.25	0.25	0.70	0.64	0.58
	Courangra	0.75	0.75	0.75	0.60	0.60	0.16	0.16	0.75	0.69	0.58
	Gentlemans	0.52	0.52	0.52	0.25	0.25	0.16	0.16	0.56	0.32	0.25
	Pumpkin	0.52	0.52	0.52	0.25	0.25	0.16	0.16	0.56	0.32	0.25
	Seymores	0.56	0.50	0.56	0.25	0.25	0.16	0.16	0.56	0.36	0.25
	Brooklyn Oval	0.83	0.83	0.83	0.64	0.64	0.16	0.16	0.85	0.74	0.64
	Big Bay	0.82	0.82	0.82	0.11	0.11	0.11	0.11	0.82	0.11	0.11
	Coba Bay	0.72	0.72	0.72	0.64	0.58	0.06	0.06	0.71	0.65	0.58
	Crosslands & Calna	0.72	0.72	0.72	0.58	0.58	0.16	0.16	0.76	0.65	0.58
	Poporan	0.67	0.67	0.63	0.25	0.25	0.16	0.16	0.63	0.29	0.25

Sensitivity

Avicennia marina had a low sensitivity to climate change variables due to its slow growth rate (temperature) and in being less responsive to increases CO_2 due to its high metabolic demands (Table 5.9). *Aegiceras corniculatum* had a medium-low sensitivity to climate change variables due to its faster growth rate and greater positive response to increased CO_2. However, the sensitivity levels for both these species are dependent on the availability of nutrients, which can vary widely across the estuary in time and location. When more specific information is available on the nutrient dynamics at each site, these sensitivity levels may change up or down (Table 5.9).

Table 5.9 Summary of sensitivity results for mangrove species (Ye et al., 2005; Krauss et al., 2008)

	Characteristics				
Species	**Growth**	**Salinity tolerance**	**CO2 Increase**	**Overall Sensitivity**	**Reason**
Avicennia marina	slow	large	less responsive due to high metabolic demands	Low	able to tolerate wide range of salinities outside the optimum range of 3-27ppt
Score					0.2
Aegeceras corniculatum	fast	small	more responsive	Medium-Low	narrow salinity range, within the optimum range, 5-15
Score					0.4

Risk Levels

The exposure and sensitivity levels for each mangrove species for each site were combined in the risk matrix to determine the levels of risk for loss of habitat. *Avicennia marina* mangrove habitats will have a moderate risk of loss due to the potential effects of climate change under all maximum SLR scenarios for five sites in summer and two sites in winter (Table 5.10). Under average and minimum SLR scenarios the risk of loss is low for both summer and winter. Brooklyn was the only exception, which remained at a moderate risk of loss in summer under average SLR in 2030 and 2050 and under minimum SLR in 2050. In winter only Big Bay and Brooklyn had a moderate risk of loss of mangrove habitat under all maximum SLR scenarios (Table 5.10). Figures 5.11-5.29 are maps of each site showing the risk levels for mangroves represented by *Avicennia marina.*

Table 5.10 Summary of risk levels for the mangrove species *A. marina*, i.e. level of risk a habitat patch will be lost due to the potential effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Nil – no results due to the grid cell not being covered by water; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	One Tree Reach	M	M	M	L	L	L	L	M	L	L
	Courangra	M	M	M	L	L	L	L	M	M	L
	Gentlemans	L	L	L	L	L	L	L	L	L	L
	Pumpkin	L	L	L	L	L	L	L	L	L	L
	Seymores	L	L	L	L	L	L	L	L	L	L
	Brooklyn Oval	M	M	M	M	M	L	L	M	M	M
	Big Bay	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	Coba Bay	M	M	M	L	L	L	L	M	L	L
	Crosslands & Calna	M	M	M	L	L	L	L	M	L	L
	Poporan	L	L	L	L	L	L	L	L	L	L
Winter	One Tree Reach	L	L	L	L	L	L	L	L	L	L
	Courangra	L	L	L	L	L	L	L	L	L	L
	Gentlemans	L	L	L	L	L	L	L	L	L	L
	Pumpkin	L	L	L	L	L	L	L	L	L	L
	Seymores	L	L	L	L	L	L	L	L	L	L
	Brooklyn Oval	M	M	M	L	L	L	L	M	L	L
	Big Bay	M	M	M	L	L	L	L	M	L	L
	Coba Bay	L	L	L	L	L	L	L	L	L	L
	Crosslands & Calna	L	L	L	L	L	L	L	L	L	L
	Poporan	L	L	L	L	L	L	L	L	L	L

Aegiceras corniculatum had a moderate level of risk of loss at all sites under all SLR scenarios in summer (Table 5.11). During winter, the risk of loss to *Aegiceras corniculatum* remained moderate for all sites under maximum SLR scenarios. However, the risk reduced to low for fives sites, Gentlemans, Pumpkin Creek, Seymores, Big Bay and Popran Creek, under all average and minimum SLR scenarios. All sites were at low risk for *Aegiceras corniculatum* under the minimum SLR scenarios for 2030.

Table 5.11 Summary of risk levels for the mangrove species *A. corniculatum.* i.e. level of risk a habitat patch will be lost due to the potential effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Nil – no results due to the grid cell not being covered by water; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	One Tree Reach	M	M	M	M	M	M	M	M	M	M
	Courangra	M	M	M	M	M	M	M	M	M	M
	Gentlemans	M	M	M	M	M	M	M	M	M	M
	Pumpkin	M	M	M	M	M	M	M	M	M	M
	Seymores	M	M	M	M	M	M	M	M	M	M
	Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
	Big Bay	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
	Poporan	M	M	M	M	M	M	M	M	M	M
Winter	One Tree Reach	M	M	M	M	M	L	L	M	M	M
	Courangra	M	M	M	M	M	L	L	M	M	M
	Gentlemans	M	M	M	L	L	L	L	M	L	L
	Pumpkin	M	M	M	L	L	L	L	M	L	L
	Seymores	M	M	M	L	L	L	L	M	L	L
	Brooklyn Oval	M	M	M	M	M	L	L	M	M	M
	Big Bay	M	M	M	L	L	L	L	M	L	L
	Coba Bay	M	M	M	M	M	L	L	M	M	M
	Crosslands & Calna	M	M	M	M	M	L	L	M	M	M
	Poporan	M	M	M	L	L	L	L	M	L	L

The following pages contain Figures 5.11 – 5.31 which are the maps of risk levels for mangrove sites. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 5.11 Map of One Tree Reach site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.12 Map of One Tree Reach site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.13 Map of Couranga Point site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.14 Map of Couranga Point site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.15 Map of Gentlemans Halt site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.16 Map of Gentlemans Halt site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.17 Map of Pumpkin Creek site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.18 Map of Pumpkin Creek site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.19 Map of Seymores Creek site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.20 Map of Seymores Creek site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.21 Map of Brooklyn Oval site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.22 Map of Brooklyn Oval site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.23 Map of Big Bay site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.24 Map of Coba Bay site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.25 Map of Coba Bay site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.26 Map of Crosslands site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.27 Map of Crosslands site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.28 Map of Popran Creek site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.29 Map of Popran Creek site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.30 Map of Calna Creek site showing risk levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

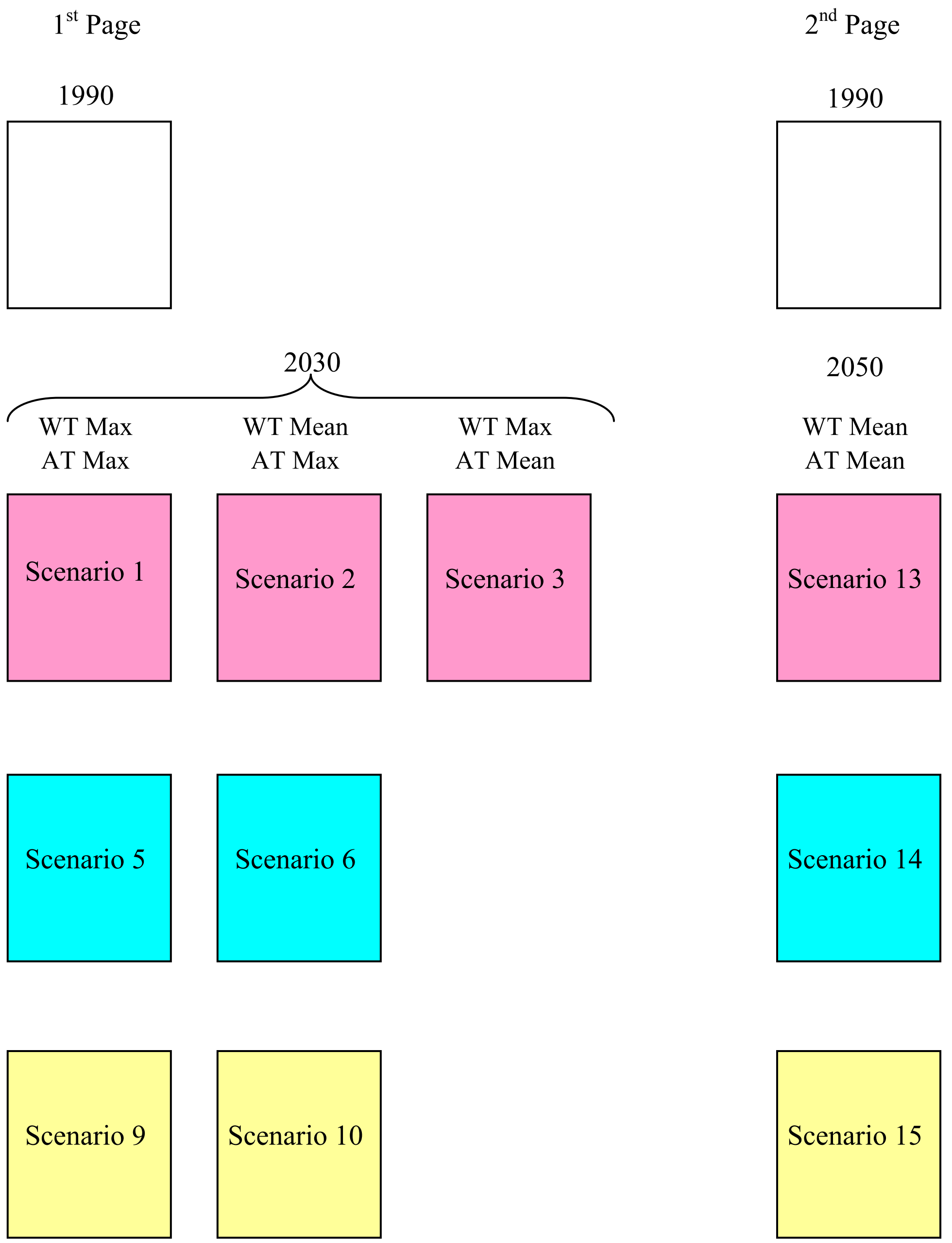
Figure 5.31 Map of Calna Creek site showing risk levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



5.1.3.3. Saltmarsh habitat

Exposure

During summer four saltmarsh sites, Courangra, Brooklyn, Coba Bay and Crosslands/Calna Creek, had medium-high levels of exposure to climate change variables and three sites had medium levels under all maximum SLR scenarios (Table 5.12). Biologically significant increases in the duration of air temperatures for saltmarsh above their average growing threshold and *Casurina* spp. seedling growth threshold occurred in all maximum SLR scenarios. In addition, saltmarsh were exposed to air temperatures greater than 40^{o}C for longer periods under all these scenarios compared to 1990. There were also biologically significant increases in the duration of salinity above thresholds for suitable for *Sporobolus virginicus* and seedling germination and growth of *Juncus krausii*. The duration saltmarsh will be inundated with water greater than 5cm also increased under all maximum SLR scenarios. Changes to water depth were the same for mangroves with an increase in the mean hourly water depth and in the daily maximum and minimum water depth.

Under average and minimum SLR scenarios during summer four saltmarsh sites, Courangra, Brooklyn, Coba Bay and Crosslands/Calna Creek, remained at medium-high to high exposure levels but dropped to low-medium to medium for all other sites (Table 5.12). All sites had the same pattern of an increase in the duration of air temperatures above saltmarsh thresholds. For salinity, there was no biologically significant increase in the duration above the threshold for *J. krausii* seedling germination at Gentlemans, Popran Creek, Pumpkin Creek and Seymores Creek sites under average SLR scenarios. But in 2030 under average water temperature there was a significant increase in the duration of salinity above the threshold for *J. krausii* seedling germination at these sites. The threshold for salinity for *J. krausii* seedling growth was exceeded for longer under all average SLR scenarios in four sites, Courangra, Brooklyn, Coba Bay and Crosslands/Caln Creek.

During winter, only Big Bay and Brooklyn had medium-high levels of exposure under all maximum SLR scenarios (Table 5.12). The remaining sites had medium to low-medium levels of exposure under these scenarios. The most notable change during winter was a biologically significant increase in both the duration and magnitude of inundation greater than 5 cm for all maximum SLR scenario in five sites, Big Bay, Courangra, Brooklyn, Coba Bay and Crosslands/Caln Creek. Under the average and minimum SLR scenarios only duration increased for inundation but not in all these sites. There were also biologically significant increases in all water depth variables in most sites under all maximum SLR scenarios. Under minimum SLR scenarios during winter, exposure levels were low to medium-low in all sites.

Table 5.12 Summary of exposure levels for saltmarsh habitats in the Hawkesbury estuary

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	Courangra	0.91	0.91	0.87	0.79	0.79	0.43	0.76	0.94	0.81	0.79
	Gentlemans	0.69	0.69	0.63	0.50	0.50	0.50	0.50	0.69	0.54	0.50
	Pumpkin	0.69	0.69	0.63	0.50	0.50	0.50	0.50	0.69	0.54	0.50
	Seymores	0.72	0.72	0.67	0.50	0.50	0.50	0.50	0.72	0.58	0.50
	Brooklyn Oval	0.98	0.98	0.95	0.94	0.94	0.43	0.43	0.98	0.97	0.91
	Coba Bay	0.94	0.94	0.87	0.79	0.79	0.50	0.50	0.97	0.80	0.79
	Crosslands & Calna	0.88	0.88	0.84	0.79	0.79	0.50	0.50	0.94	0.79	0.79
	Poporan	0.64	0.64	0.58	0.50	0.50	0.50	0.50	0.69	0.54	0.50
Winter	Courangra	0.75	0.75	0.75	0.60	0.60	0.16	0.16	0.75	0.69	0.58
	Gentlemans	0.52	0.52	0.52	0.25	0.25	0.16	0.16	0.56	0.32	0.25
	Pumpkin	0.52	0.52	0.52	0.25	0.25	0.16	0.16	0.56	0.32	0.25
	Seymores	0.56	0.50	0.56	0.25	0.25	0.16	0.16	0.56	0.36	0.25
	Brooklyn Oval	0.83	0.83	0.83	0.64	0.64	0.16	0.16	0.85	0.74	0.64
	Big Bay	0.82	0.82	0.82	0.11	0.11	0.11	0.11	0.82	0.11	0.11
	Coba Bay	0.72	0.72	0.72	0.64	0.58	0.06	0.06	0.71	0.65	0.58
	Crosslands & Calna	0.72	0.72	0.72	0.58	0.58	0.16	0.16	0.76	0.65	0.58
	Poporan	0.67	0.67	0.63	0.25	0.25	0.16	0.16	0.63	0.29	0.25

Sensitivity

J. krausii had the lowest sensitivity to climate change variables due its large salinity range and high maximum air temperature tolerance (Table 5.13). *Phragmites australis* had medium-low sensitivity due to its slightly shorter salinity range. *Sarcocornia quinqueflora* had a medium sensitivity due to its moderate range of salinity tolerances and lower maximum air temperature. *Sporobolus virginicus* was given the highest sensitivity to climate change variables because of its narrow salinity range.

Table 5.13 Summary of sensitivity results for saltmarsh species (Naidoo and Kift, 2006; Laegdsgaard, 2002; Greenwood and MacFarlane, 2006).

	Characteristics			
Species	**Salinity range**	**Air T max**	**Overall Sensitivity**	**Reason**
Juncus kraussi	large (40ppt)	40	Low	large salinity range
Phragmites	mod-large (25ppt)	40	Medium-Low	moderate salinity range
Sarrcacornia	moderate	35	Medium	lower salinity tolerance and air temperature maximum
Sporobulus	narrow (7ppt)	40	High	narrow salinity range

Risk Levels

Based on field inspections, most of the saltmarsh habitats were predominantly made up of *J. krausii* and *S. virginicus* (Table 5.14). The risk of loss of habitat for saltmarsh where *J. krausii* dominates was moderate in four sites under all maximum SLR scenarios during summer and only in two sites during winter. However, where *S. virginicus* spp dominates, the risk of loss is high-moderate to high under all scenarios in all sites. Only in winter under minimum SLR scenario in 2030 is the risk low for this species. The less dominant saltmarsh species *Sarcocornia quinqueflora* had a moderate to moderate-high level of risk of loss in all sites under all scenarios. *Phragmites australis*, consistently had a moderate level of risk of loss in all sites under all scenarios during summer. Both *S. quinqueflora* and *Phragmites australis* have a low risk of loss in winter under minimum SLR scenario in 2030. Figures 5.30-5.46 are maps of each site showing risk levels for *J. krausii* saltmarsh habitats. Figures 5.47-5.64 show risk levels for *S. virginicus* saltmarsh habitats.

Table 5.14 Summary of risk levels for the saltmarsh species, i.e. level of risk a habitat patch will be lost due to the potential effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Nil – no results due to the grid cell not being covered by water; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

			Scenario									
Species	**SEASON**	**Site**	1	2	3	5	6	9	10	13	14	15
Juncus	Summer	Courangra	M	M	M	L	L	L	L	M	M	L
		Gentlemans	L	L	L	L	L	L	L	L	L	L
		Pumpkin	L	L	L	L	L	L	L	L	L	L
		Seymores	L	L	L	L	L	L	L	L	L	L
		Brooklyn Oval	M	M	M	M	M	L	L	M	M	M
		Big Bay	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
		Coba Bay	M	M	M	L	L	L	L	M	L	L
		Crosslands & Calna	M	M	M	L	L	L	L	M	L	L
		Poporan	L	L	L	L	L	L	L	L	L	L
	Winter	Courangra	L	L	L	L	L	L	L	L	L	L
		Gentlemans	L	L	L	L	L	L	L	L	L	L
		Pumpkin	L	L	L	L	L	L	L	L	L	L
		Seymores	L	L	L	L	L	L	L	L	L	L
		Brooklyn Oval	M	M	M	L	L	L	L	M	L	L
		Big Bay	M	M	M	L	L	L	L	M	L	L
		Coba Bay	L	L	L	L	L	L	L	L	L	L
		Crosslands & Calna	L	L	L	L	L	L	L	L	L	L
		Poporan	L	L	L	L	L	L	L	L	L	L
Sporobulus	Summer	Courangra	H	H	H	H	H	MH	H	H	H	H
		Gentlemans	H	H	MH	MH	MH	MH	MH	H	MH	MH
		Pumpkin	H	H	MH	MH	MH	MH	MH	H	MH	MH
		Seymores	H	H	H	MH	MH	MH	MH	H	MH	MH
		Brooklyn Oval	H	H	H	H	H	MH	MH	H	H	H
		Big Bay	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
		Coba Bay	H	H	H	H	H	MH	MH	H	H	H
		Crosslands & Calna	H	H	H	H	H	MH	MH	H	H	H
		Poporan	H	H	MH	MH	MH	MH	MH	H	MH	MH
	Winter	Courangra	H	H	H	MH	MH	L	L	H	H	MH
		Gentlemans	MH	MH	MH	M	M	L	L	MH	M	M
		Pumpkin	MH	MH	MH	M	M	L	L	MH	M	M
		Seymores	MH	MH	MH	M	M	L	L	MH	M	M
		Brooklyn Oval	H	H	H	MH	MH	L	L	H	H	MH
		Big Bay	H	H	H	L	L	L	L	H	L	L
		Coba Bay	H	H	H	MH	MH	L	L	H	H	MH
		Crosslands & Calna	H	H	H	MH	MH	L	L	H	H	MH
		Poporan	H	H	MH	M	M	L	L	MH	M	M
Sarccocornia	Summer	Courangra	MH	MH	MH	MH	MH	M	MH	MH	MH	MH
		Gentlemans	MH	MH	M	M	M	M	M	MH	M	M
		Pumpkin	MH	MH	M	M	M	M	M	MH	M	M
		Seymores	MH	MH	M	M	M	M	M	MH	M	M
		Brooklyn Oval	MH	MH	MH	MH	MH	M	M	MH	MH	MH
		Big Bay	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
		Coba Bay	MH	MH	MH	MH	MH	M	M	MH	MH	MH
		Crosslands & Calna	MH	MH	MH	MH	MH	M	M	MH	MH	MH
		Poporan	M	M	M	M	M	M	M	MH	M	M
	Winter	Courangra	MH	MH	MH	M	M	L	L	MH	MH	M
		Gentlemans	M	M	M	L	L	L	L	M	M	L
		Pumpkin	M	M	M	L	L	L	L	M	M	L
		Seymores	M	M	M	L	L	L	L	M	M	L
		Brooklyn Oval	MH	MH	MH	M	M	L	L	MH	MH	M
		Big Bay	MH	MH	MH	L	L	L	L	MH	L	L
		Coba Bay	MH	MH	MH	M	M	L	L	MH	M	M
		Crosslands & Calna	MH	MH	MH	M	M	L	L	MH	M	M
		Poporan	M	M	M	L	L	L	L	M	M	L
Phragmites	Summer	Courangra	M	M	M	M	M	M	M	M	M	M
		Gentlemans	M	M	M	M	M	M	M	M	M	M
		Pumpkin	M	M	M	M	M	M	M	M	M	M
		Seymores	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
		Big Bay	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
		Coba Bay	M	M	M	M	M	M	M	M	M	M
		Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
		Poporan	M	M	M	M	M	M	M	M	M	M
	Winter	Courangra	M	M	M	M	M	L	L	M	M	M
		Gentlemans	M	M	M	L	L	L	L	M	L	L
		Pumpkin	M	M	M	L	L	L	L	M	L	L
		Seymores	M	M	M	L	L	L	L	M	L	L
		Brooklyn Oval	M	M	M	M	M	L	L	M	M	M
		Big Bay	M	M	M	L	L	L	L	M	L	L
		Coba Bay	M	M	M	M	M	L	L	M	M	M
		Crosslands & Calna	M	M	M	M	M	L	L	M	M	M
		Poporan	M	M	M	L	L	L	L	M	L	L

The following pages contain Figures 5.32 – 5.50 which are the maps of risk levels for *J. krausii* saltmarsh habitat. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 5.32 Map of Courangra Point site showing risk levels for *Juncus krausii* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.33 Map of Courangra Point site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.34 Map of Gentlemans Halt site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.35 Map of Gentlemans Halt site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.36 Map of Pumpkin Creek site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.37 Map of Pumpkin Creek site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.38 Map of Seymores Creek site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.39 Map of Seymores Creek site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.40 Map of Brooklyn site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.41 Map of Brooklyn site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.42 Map of Big Bay site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.43 Map of Coba Bay site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.44 Map of Coba Bay site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.45 Map of Crosslands site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.46 Map of Crosslands site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.47 Map of Popran Creek site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.48 Map of Popran Creek site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.49 Map of Calna Creek site showing risk levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

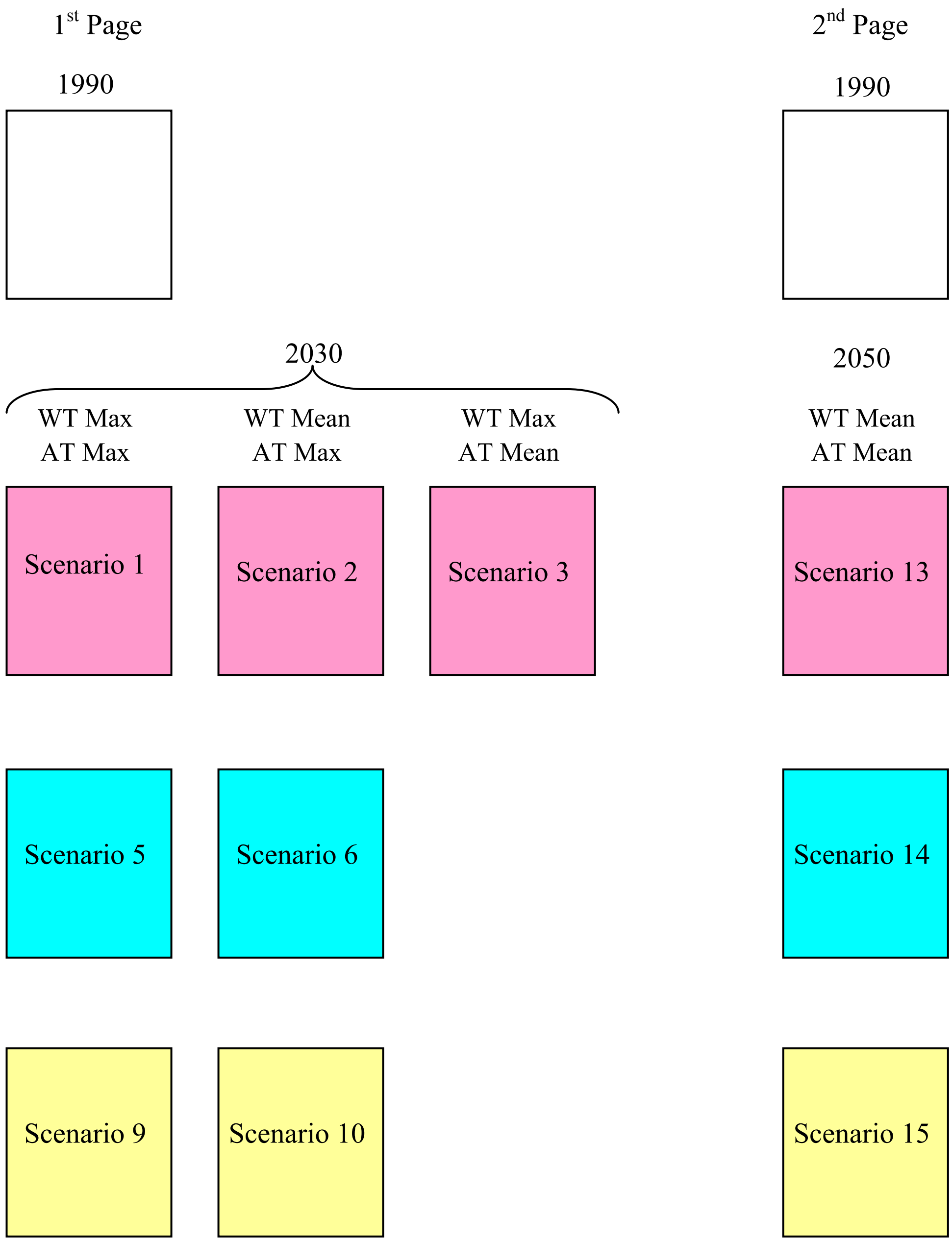
Figure 5.50 Map of Calna Creek site showing risk levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



The following pages contain Figures 5.51 – 5.70 which are the maps of risk levels for *S. virginicus* saltmarsh habitat. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 5.51 Map of Courangra Point site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.52 Map of Courangra Point site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.53 Map of Gentlemans Halt site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.54 Map of Gentlemans Halt site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.55 Map of Pumpkin Creek site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.56 Map of Pumpkin Creek site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.57 Map of Seymores Creek site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.58 Map of Seymores Creek site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.59 Map of Brooklyn site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.60 Map of Brooklyn site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.61 Map of Big Bay site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.62 Map of Big Bay site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.63 Map of Coba Bay site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.64 Map of Coba Bay site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.65 Map of Crosslands site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.66 Map of Crosslands site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.67 Map of Popran Creek site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.68 Map of Popran Creek site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 5.69 Map of Calna Creek site showing risk levels for *S. virginicus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

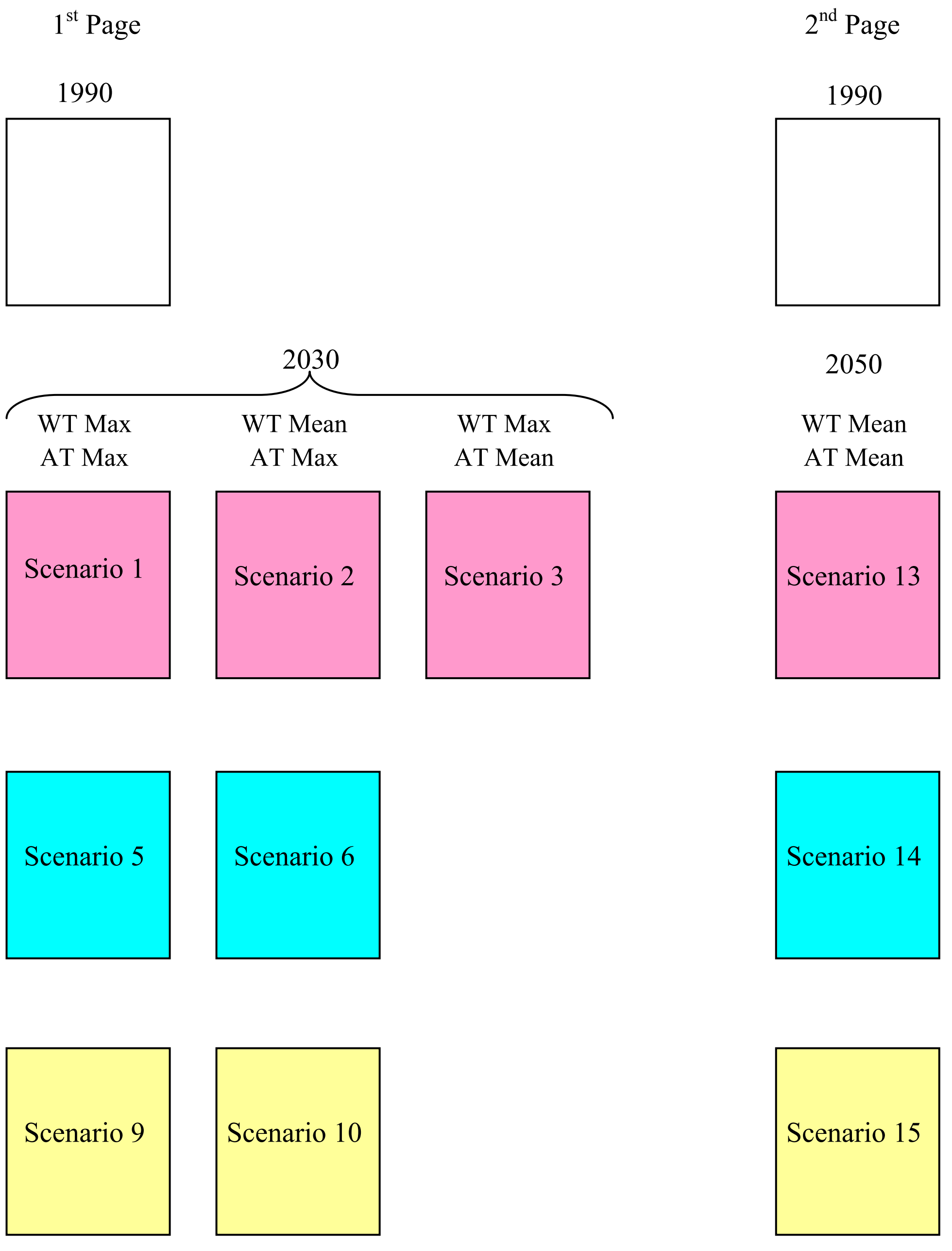
Figure 5.70 Map of Calna Creek site showing risk levels for *S. virginicus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



5.1.3.4. *Floodplain forest habitat*

Exposure

Floodplain forest habitat had a high level of exposure during summer at Brooklyn and One Tree Reach and medium-high at Seymores Creek under all maximum SLR scenarios (Table 5.15). This was due to three factors. There was a biologically significant increase in the duration of air temperature greater than 40oC. Salinity exceeded the thresholds for *Melaleuca* adult and seedling growth for a biologically significant longer period than in 1990. At Brooklyn the magnitude of the exceedance of salinity for *Melaleuca* seedlings was also biologically significant. Average daily water depth, daily maximums and minimums all had a biologically significant increase in magnitude. Only Seymores Creek had an increase in the duration it was inundated by water. This site also did not have an increase in the magnitude of water depth range, unlike the other two sites. Under all average SLR scenarios and minimum 2050 SLR scenario Brooklyn maintained a high level of exposure. Exposure levels drop to medium-high and medium for the two other sites due to an increase in the duration of salinity above the threshold for *Melaleuca* seedling growth but no change to any of the water depth or inundation variables.

During winter floodplain forest habitat at Brooklyn had a medium-high to medium level of exposure for all scenarios except minimum 2030 SLR where it dropped to low (Table 5.15). These higher levels were due to biologically significant increases in the duration of salinity above the thresholds for *Melaleuca* adults and seedlings and increases in water depth variables. Exposure levels during winter for One Tree Reach and Seymores Creek were reduced to medium and medium-low for all maximum SLR scenarios and low exposure for minimum SLR scenarios.

Table 5.15 Summary of exposure levels for floodplain habitats in the Hawkesbury estuary

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	Brooklyn Oval	0.98	0.98	0.95	0.94	0.94	0.43	0.43	0.98	0.97	0.91
	One Tree Reach	0.94	0.94	0.91	0.75	0.75	0.50	0.50	0.94	0.80	0.75
	Seymores	0.72	0.72	0.67	0.50	0.50	0.50	0.50	0.72	0.58	0.50
Winter	Brooklyn Oval	0.83	0.83	0.83	0.64	0.64	0.16	0.16	0.85	0.74	0.64
	One Tree Reach	0.70	0.70	0.70	0.64	0.64	0.25	0.25	0.70	0.64	0.58
	Seymores	0.56	0.50	0.56	0.25	0.25	0.16	0.16	0.56	0.36	0.25

Sensitivity

There was little information available about the how floodplain species respond to climate change variables. Therefore, a precautionary approach was taken with this habitat and was given a high level of sensitivity. This was based on the fact that these habitats are not usually inundated by estuarine waters over a long time period and therefore are less likely to be able to withstand increased exposure to these stressors.

Risk Levels

As would be expected, floodplain forest habitat had a moderate-high to high level of risk to being lost as a result of the effects of climate change under all scenarios in both summer and winter (Table 5.16). The only scenario in which the risk is below this level for all three sites is in winter for the minimum 2030 SLR scenario, where the risk is moderate for One Tree Reach and low for Brooklyn and Seymores Creek. Interestingly, Seymores Creek had consistently lower levels of risk during winter than the other two sites for all scenarios due to its lower exposure levels. Because there was little information about the effects of climate variables on estuarine floodplain forest species and the characteristics relevant to their potential capacity to respond to these effects, these habitats were not assessed in the remaining three stages. No maps were produced showing risk levels to floodplain forest because of the limited availability of GIS expertise (from Industry and Investment NSW) to produce them.

Table 5.16 Summary of risk levels for the floodplain forest habitat. , i.e. level of risk a habitat patch will be lost due to the potential effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
Season	**Site**	1	2	3	5	6	9	10	13	14	15
Summer	One Tree Reach	H	H	H	H	H	MH	MH	H	H	H
	Seymores	H	H	H	MH	MH	MH	MH	H	MH	MH
	Brooklyn Oval	H	H	H	H	H	MH	MH	H	H	H
Winter	One Tree Reach	H	H	H	MH	MH	M	M	H	MH	MH
	Seymores	MH	MH	MH	M	M	L	L	MH	M	M
	Brooklyn Oval	H	H	H	MH	MH	L	L	H	H	MH

5.2. Stage 2 – Resilience Assessment

5.2.1. Adaptive capacity

The adaptive capacity of each habitat type for each site was assessed using the biological, ecological and geomorphic characteristics that contribute to the way a habitat could potentially respond to the changed condition as a result of the effects of climate change. Characteristics were based on how they might contribute to a habitat responding in the four ways described in Chapter 3 (i.e. contracting, expanding, shifting and/or translocating). The characteristics were different for each type of habitat and incorporated site based factors that might interact with a habitat (e.g. size of a habitat patch at a site). A set of decision criteria was then developed to determine whether a characteristic made a positive or negative contribution to the capacity of a habitat to respond to changed environmental conditions. The overall adaptive capacity level was determined by summing the number of characteristics with positive contributions and expressing this as a proportion of the total number of all characteristics. It should be noted that the assessment of adaptive capacity assumed that species have sufficient nutrients and light for their physiological and reproductive processes to function. Thus the level of adaptive capacity will change if these elements are limiting.

5.2.2. Results - resilience

5.2.2.1. Seagrass

Adaptive capacity

Three species specific and two site specific characteristics were identified that would be most influential in enabling seagrass habitat patches to respond to altered environmental conditions as a result of climate change (Larkum et al., 2006). Vegetative growth enables seagrasses to expand their patch size into surrounding areas or regrow into bare or sparsely covered areas within patches created by damaged leaves or plants. The responsive capacity of vegetative growth is most commonly measured by its biomass production and rhizome extension rate. *Z. capricorni* has a moderate to fast above ground biomass production rate and is greater in summer than winter, and higher in high light conditions such as in intertidal beds. Its rhizome extension rate is also considered moderate. *H. ovalis* has a rapid biomass and rhizome extension rate and *P. australis* the slowest in both characteristics (Table 5.17).

Sexual reproduction can enable seagrasses to colonise new habitat patches away from the source bed (i.e. a translocation response) or larger bare patches within beds created by natural die of plants or damage. *H. ovalis* is known to colonise bare patches rapidly (McMahon, 2003) but it is an ephemeral species, mainly occurring in summer. However, if warmer conditions persist during winter as a result of climate change this species may be more able to take advantage of these conditions than either *Z. capricorni* or *P. australis*. *Z. capricorni* and *P. australis* have elevated flowering positions which enables their seeds to be dispersed further from the parent beds via tides and currents, enabling them to potentially colonise new areas of suitable habitat. However, both species have a low percentage of flowering shoots and low seedling survival (Inglis, 2000; Inglis and Lincoln Smith, 1998). *H. ovalis* has sub-surface flowering which limits its ability to colonise new areas further from the parent bed (Table 5.17). Table 5.18 gives the decision criteria used to assess the contribution all these characteristics made to a species capacity to respond.

Table 5.17 Biological characteristics of seagrass species used to assess their capacity to respond to the effects of climate change

References: Kirkman et al. (1982), Inglis (2000), Inglis and Lincoln Smith (1998), Larkum et al. (2006), Meehan and West (2004), Olesen et al. (2004), Peterken and Conacher (1997).

Characteristic	Measure	*Z. capricornia*	*H. ovalis*	*P. australis*
Vegetative growth	Biomass production	higher above ground in high light conditions	1.5-8g/m^2/day, high	Spring-Summer > Winter
	Rhizome extention rate	moderate	300cm/yr, 1-8m/yr, fast, intertidal > subtidal	2.5cm/yr, slow
Reproduction	Flowering	not annual intertidal, Aug - Mar; peak Dec, decreased light decreases flowering success	Oct-Dec	infrequent, about August but not always annual, associated with decrease in water temperature
	Seeds	Fruit and seeds develop on spadix, seed bank transient, moderate buoyancy	seed bank transient-persistent,	rapid settlement when shed from fruit, seed bank indistinct, large
	Dispersal	Pollen released in linear strands or whole reproductive shoots drift in currents, fruit and seed released directly from spadix	low, fruit/seeds sub-surface	large fleshy fruit long dispersal distance
	Recruitment	unknown	high within patches	seeds important for initial establishment, bed develop via
	Flowering position	elevated	sub-surface - at or below	top canopy, pollen dispersal distance long
	Number of seeds per fruit	1 but large number produced	7-60	1
	% flowering shoots	<5% at peak times in Nov, max in low intertidal and creeks	high, 570 fruits m^2	small, larger in shallow than deeper water
Colonisation	Seedling survival	40% max	unknown	20% max

Table 5.18 Decision criteria used to determine the contribution a biological characteristic made to a species of seagrass capacity to respond to the effects of climate change,

	Positive contribution		Negative contribution
		Score	
Characteristic	**2**	**1**	**-1**
Biomass prod'n		High, su-sp	Low
Patch size	>50%	25-50%	<25%
Rhisome extention rate	Fast	Mod	slow
Flowering		Annual	water temperature dependent
Seeds		buoyant/large/indeterminant seed bank	small/persistent seed bank
Dispersal		Long	sub-surf
Recruitment new patch		sexual - primary	very little-none
Recruitment within patch		rapid vegetative	very little-none
Flowering position		high	sub-surface
# seeds per fruit		>5	1
% flowering shoots		>=5%	<5%
Seedling survival	>40%	20-40	<20
Genetic diversity	High	Low	

The patch size of each seagrass bed as a proportion of seagrass habitat within the sub-catchment or reach of each site was a site specific measure. This measure was an approximation of the relative contribution the habitat patch at a site potentially makes to the genetic diversity and source of propagules for reproduction with other seagrass beds in the sub-catchment or reach. The larger proportions made a relative larger contribution. Seagrass beds at Dangar Island and Mullet Creek had the largest patch sizes of all the sites (Table 5.19). Natural barriers (e.g. steep sloping land or vertical cliff) to patch expansion were present at all sites. Cowan Creek below Bobbin Head had the most potential to expand further upstream or into nearby side creeks if conditions became suitable.

Table 5.19 Characteristics of sites used to assess the capacity of seagrass habitats to respond to the effects of climate change.

	Characteristic	
	Patch size	Barriers
Site	Proportion of habitat in sub-catchment/reach	Natural barriers - potential to expand or shift
Cowan, Bobbin Head	0.199	Long fluvial channel, side creeks
Smiths Creek, Cowan	0.057	upstream narrow channel
Dangar Island	0.424	rocky reef east of beach
Patonga Creek entrance	0.046	Mobile sand barrier at entrance, wide channel then long channel, steep one side, fringed by mangroves,
Mullet	0.863	bushland, narrow creek upstream

Resilience levels

Resilience levels were determined by combining the risk levels from stage 1 with each species/site specific adaptive capacity. These are presented in Table 5.20 and the following maps are for *Z. capricorni* species only because this was the dominant species at all sites. The results show that during summer *Z. capricorni* had a moderate-high level of resilience under all scenarios only at Cowan Creek, except the highest SLR scenario in 2050. This was due to its lower risk of loss at this site compared to other sites. During winter *Z. capricorni* had moderate-high levels of resilience at more sites under all scenarios. Interestingly, *Z. capricorni* at Smiths Creek and Patonga remained at moderate resilience levels under all maximum SLR scenarios in both seasons. Mullet Creek was the only site during winter at which *Z. capricorni* had a high level of resilience under the lowest SLR 2030 scenario (Table 5.20). Figures 6.1-6.10 are maps of each site showing resilience levels for *Z. capricorni* for all seagrass sites. *H. ovalis* had moderate levels of resilience under all scenarios in both summer and winter at Dangar Island but moderate-high resilience at Patonga Creek only under average and minimum SLR scenarios during summer and all scenarios during winter (Table 5.20).

Table 5.20 Resilience levels of seagrass species for sites in the Hawkesbury, i.e. resilience to the effects of climate change.

L – low; M – moderate; MH – moderate-high; H – high; Blank – species not present in abundance; Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

			Scenario									
Species	**Season**	**Site**	1	2	3	5	6	9	10	13	14	15
Zostera	Summer	Cowan Bobbin Hd	MH	MH	MH	MH	MH	MH	MH	M	MH	MH
		Smiths Creek	M	M	M	M	M	MH	MH	M	M	M
		Dangar Is	M	M	M	MH	MH	MH	MH	M	M	MH
		Mullet upper	M	M	M	MH	MH	MH	MH	M	MH	MH
		Patonga	M	M	M	MH	MH	MH	MH	M	M	MH
	Winter	Cowan Bobbin Hd	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Smiths Creek	M	M	M	MH	MH	MH	MH	M	MH	MH
		Dangar Is	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Mullet upper	MH	MH	MH	MH	MH	H	H	MH	MH	MH
		Patonga	M	M	M	MH	MH	MH	MH	M	MH	MH
Halophila	Summer	Cowan Bobbin Hd										
		Smiths Creek										
		Dangar Is	M	M	M	M	M	M	M	M	M	M
		Mullet upper										
		Patonga	M	M	M	MH	MH	MH	MH	M	MH	MH
	Winter	Cowan Bobbin Hd										
		Smiths Creek										
		Dangar Is	M	M	M	M	M	M	M	M	M	M
		Mullet upper										
		Patonga	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH

The following pages contain Figures 6.1 – 6.10 which are the maps of resilience levels for *Z. capricorni* seagrass habitat. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 6.1 Map of Cowan Creek site showing resilience levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.2 Map of Cowan Creek site showing resilience levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.3 Map of Smiths Creek site showing resilience levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.4 Map of Smiths Creek site showing resilience levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.5 Map of Dangar Island site showing resilience levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.6 Map of Dangar Island site showing resilience levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.7 Map of Mullet Creek site showing resilience levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.8 Map of Mullet Creek site showing resilience levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.9 Map of Patonga site showing resilience levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

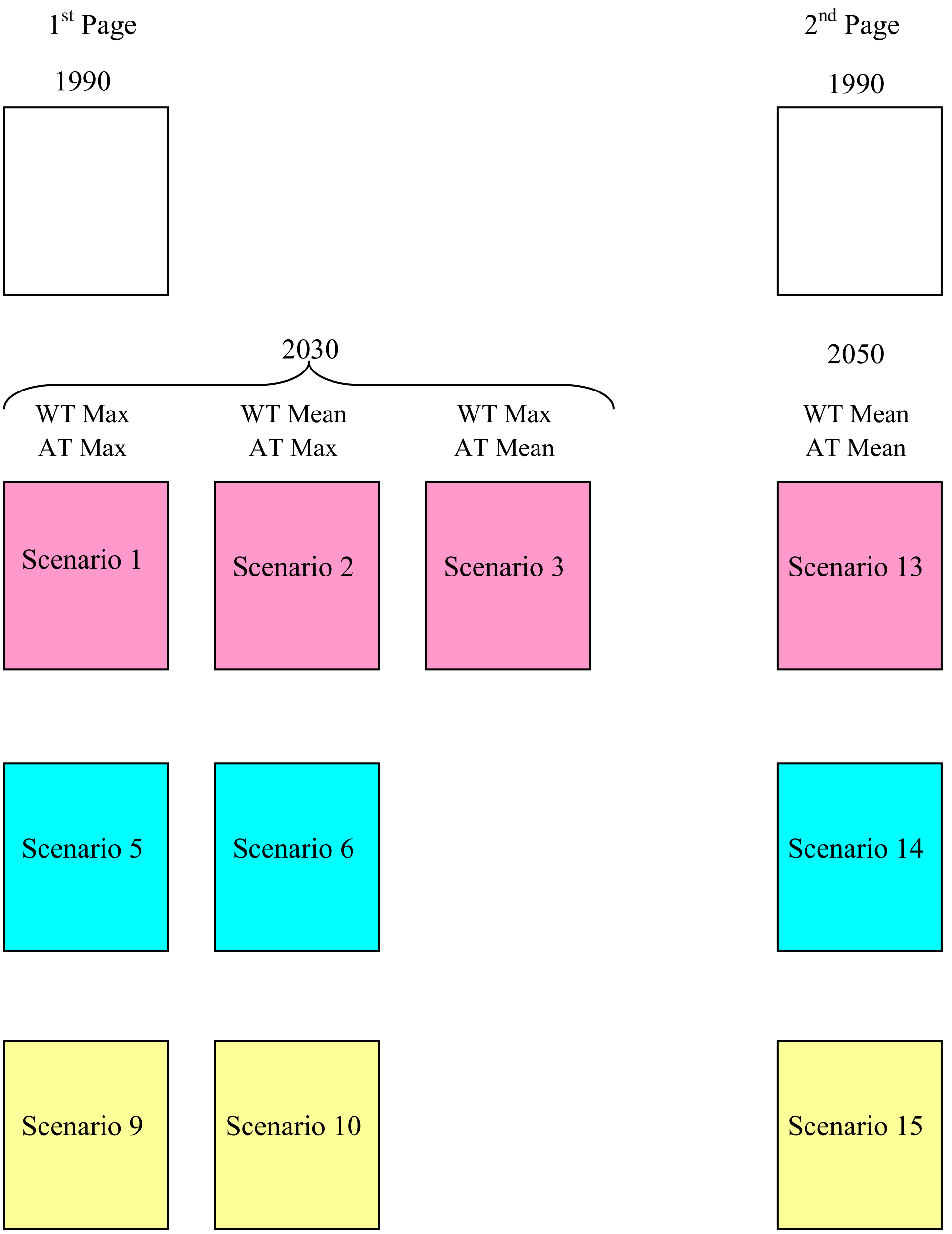
Figure 6.10 Map of Patonga site showing resilience levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



5.2.2.2. Mangroves

Adaptive capacity

Four species specific characteristics were identified that would be most influential in enabling mangrove habitat patches to respond to altered environmental conditions as a result of climate change Table 5.21). Establishment related to propagules being able to colonise either within a mangrove habitat patch or in a new area. This characteristic was measured by components such as propagule buoyancy, seedling establishment, disturbance and canopy requirements. *A. marina* propagules are buoyant for up to 4 days in 100% seawater, whilst *A. corniculatum* propagules can remain buoyant for longer. Seedling establishment takes much longer in *A. corniculatum* than *A. marina* and a smaller proportion succeed. However, *A. marina* requires large scale sediment disturbance and canopy gaps to establish in new habitat areas. Seed predation can be higher for *A. corniculatum* than *A. marina*.

Sexual reproduction is the only means mangroves have available to colonise new habitat patches away from the source patch (i.e. a translocation response). Reproduction was measured by flowering properties and dispersal of propagules. Flowering is annual in both species of mangrove, however, not all trees of *A. marina* in a mangrove patch will flower every year. In the Hawkesbury, the percentage of trees flowering is 60-100% for patches but patches alternate between flowering and non-flowering among years (Clarke and Myerscough, 1991a,b). Dispersal distance is longer in *A. marina* than *A. corniculatum*.

Intra- and interspecific competition can affect the success of seedling establishment. Intraspecific competition among saplings for light and sediments in canopy gaps is high in *A. marina* but is not known to what extent this occurs in *A. corniculatum*. *A. marina* can respond to disturbances more quickly than *A. corniculatum* and can outcompete them under these conditions. However, in stable environments *A. corniculatum* can establish better under the canopy of *A. marina* and over time inhibit the recruitment of further *A. marina* (Clarke, 1995).

Plasticity (i.e. the ability to adjust to changed climate conditions) enables mangroves to grow and reproduce under variable environmental conditions (Feller et al., 2010). Such plasticity is known for *A. marina* but only small scale variability is evident for *A. corniculatum* (Clarke, 1994). The density of pneumatophores of *A. marina* aids in the surface accretion of sediment and this was incorporated into the site specific characteristics.

Table 5.21 Biological characteristics of mangrove species used to assess their capacity to respond to the effects of climate change

References: Clarke (1993, 1994, 1995), Clarke and Myerscough (1991a, b), Saintilan (1997).

Characteristics	Measure	*Avicennia marina*	*Aegerceras corniculatum*
Establishment	Propagule buoyancy	100% SW float 1-3days 10% SW sink then refloat	100% SW float longer than Av <5% SW sink quickly
	Length seedling estab.	4 weeks, 80%	3 months, <1%
	Propagule predation	Low-mod	High
	Disturbance required	Yes, large sed disturbance - small scales	No
	Canopy	Large gaps, e.g. tree	Understory establishment
Reproduction	Flowering	Annual but not every tree	Annual, all trees
	Propagule release	Summer	Autumn
	Dispersal distance	10-500m	0-10m
	% Trees flowering	Hawk 60-100% altn yrs	100%
	% Trees flower mature fruit	1.7-2.1%	8%
Climate plasticity	Growth & reproductive attribute variability	Yes	No, but at local scales some variability
Competition	Intraspecific	competition between seedlings for light and seds in canopy gaps to	unknown
	Interspecific	Responds to distrurbance quickly and inhibits recruitment of Aeg.	Settlement in stable conditions in understorey of Av. Inhibiting Av seedling recruitment over time
Sediment accretion	Density of pneumatophores		NA

Three site specific characteristics that would contribute to the capacity of mangrove habitats to respond to altered environmental conditions were patch size, geomorphic conditions and wetland hydrologic conditions (Table 5.22). The patch size of each mangrove stand (both species combined) was determined as a proportion of mangrove habitat within the sub-catchment or reach of each site. This was an approximation of the relative contribution the habitat patch at a site potentially made to the genetic diversity and source of propagules for reproduction with other mangrove patches in the sub-catchment or reach. Big Bay, Pumpkin Creek, Gentleman's Halt and Courangra had the largest patch sizes.

Geomorphic conditions examined the landward potential for mangroves to move inland or further upslope. The proportion of potential expandable area was the area of land (excluding built structures, e.g. buildings) between the current landward edge of a mangrove patch and the first 10m contour line (taken from the relevant 1:25 000 topographic map) or to the first human modified barrier that ran the length of the habitat (e.g. road). This area was then expressed as the proportion of the combined total of mangrove habitat and expandable land area at a site. One Tree Reach, Farmland below Laughtondale and Popran Creek had the largest potential area for mangrove expansion and Brooklyn and Seymores Creek the least (Table 5.22). Landward barriers, such as the slope of land after the 10m contour and the type of terrestrial edge were also noted at each site. Five of the sites had a road as their terrestrial edge and only Coba Bay had a slope of less than 10%.

Wetland hydrologic conditions were the above- and below-ground processes that contribute to the capacity of mangroves and saltmarsh habitats to alter their surface elevation (Cahoon et al., 2011). Cahoon et al. (2006) and Rogers et al. (2006) provide a comprehensive description of these processes in relation to mangroves and saltmarsh. If these conditions are favourable, then over time increasing surface elevations maybe able to keep pace with sea level rise. Above and below-ground processes that are involved in wetland hydrologic conditions are complex and site specific (Rogers et al. (2006). To determine these processes requires data to be collected over a long time period (e.g. Wilton, 2002). Consequently, information was only available for a few sites within the study area. Groundwater condition can also affect these processes by changing the water level which influences soil wetness and salinity. Groundwater condition was very poor for all sites except Popran Creek which was fair to poor (NSW Government, 2010).

Table 5.22 Characteristics of sites used to assess the capacity of mangrove habitats to respond to the effects of climate change.

ND – no data; VP – very poor; P – poor; F – fair; VG – very good; Gw - groundwater

Characteristics	Component	Measure	One Tree Reach	Farmland	Couranga Point	Gentlemans Halt	Pumpkin Creek	Seymores Creek	Brooklyn Oval
Patch size	Proportion of habitat in reach or sub-catchment		0.01	0.01	0.22	0.25	0.24	0.02	0.02
Geomorphic conditions	Landward barriers	Prop'n potential expandable area	0.92	0.83	0.58	0.23	0.29	0.12	0.00
		% slope	100.00	100.00	13.50	16.70	13.70	100.00	100.00
		Terrestial edge	Modified	Modified	Bush	Bush	Bush	Modified	Modified
Wetland hydrologic conditions	Above ground processes	Sediment input -							
		Catchment delivery	ND	ND	ND	ND	ND	ND	ND
		Estuarine delivery	ND	ND	ND	ND	ND	ND	ND
		Deposition rate (density of pneumatophors, m^2)	165.6		142.4		223.2		
		Erosion rate	ND	ND	ND	ND	ND	ND	ND
		Organic matter input -							
		Accumulation	ND	ND	ND	ND	ND	ND	ND
		Decomposition	ND	ND	ND	ND	ND	ND	ND
		Vertical accretion trajectory m/y	ND	ND	ND	ND	ND	ND	ND
	Below ground processes	Root production							
		Aerated layer -							
		Shallowest depth of ground water level	ND	ND	ND	ND	ND	ND	ND
		Shrink-swell capacity -							
		Tidal water infiltration/drainage	ND	ND	ND	ND	ND	ND	ND
		Rainfall	ND	ND	ND	ND	ND	ND	ND
		Evapotranspiration rate	ND	ND	ND	ND	ND	ND	ND
		Soil depth	ND	ND	ND	ND	ND	ND	ND
		Flow regulation effect on water table	ND	ND	ND	ND	ND	ND	ND
		Groundwater condition-							
		Region Gw Level	VP	VP	VP	VP	VP	VP	VP
		Local Gw Level	VP	VP	VP	VP	VP	VP	VP
		Aquifer integrity	VP	VP	VP	VP	VP	VP	VP
		Surface elevation trajectory m/yr	ND	ND	ND	ND	ND	ND	ND

Table 5.22 cont'd

Characteristics	Component	Measure	Big Bay	Coba Bay	Crosslands & Calna	Poporan Creek
Patch size	Proportion of habitat in reach or sub-catchment		0.34	0.12	0.01	0.09
Geomorphic conditions	Landward barriers	Prop'n potential expandable area	0.19	0.37	0.68	0.74
		% slope	11.79	7.27	40.00	40.00
		Terrestial edge	Bush	Bush	Bush	Modified
Wetland hydrologic conditions	Above ground processes	Sediment input -				
		Catchment delivery	ND	ND	ND	ND
		Estuarine delivery	ND	ND	ND	ND
		Deposition rate (density of pneumatophors, m^2)				346.8
		Erosion rate	ND	ND	ND	ND
		Organic matter input -				
		Accumulation	ND	ND	ND	ND
		Decomposition	ND	ND	ND	ND
		Vertical accretion trajectory m/y	ND	ND	ND	ND
	Below ground processes	Root production				
		Aerated layer -				
		Shallowest depth of ground water level	ND	ND	ND	ND
		Shrink-swell capacity -				
		Tidal water infiltration/drainage	ND	ND	ND	ND
		Rainfall	ND	ND	ND	ND
		Evapotranspiration rate	ND	ND	ND	ND
		Soil depth	ND	ND	ND	ND
		Flow regulation effect on water table	ND	ND	ND	ND
		Groundwater condition-				
		Region Gw Level	VP	VP	VP	P
		Local Gw Level	VP	VP	VP	F
		Aquifer integrity	VP	VP	VP	VG
		Surface elevation trajectory m/yr	0.00259	ND	0.00069	ND

Resilience levels

By combining the risk levels from stage 1 with each species/site specific adaptive capacity resilience levels were determined for both species of mangrove. These results are presented in Table 5.23 and the following maps are for *A. marina* species only because this was the dominant species at all sites. Resilience levels were calculated for *A. corniculatum* and presented in Table 5.23 so that where this species is present in less abundance as assessment of their resilience can be made. The results show that during summer and winter *A. marina* stands at all sites, except Seymores and Brooklyn, have a moderate-high level of resilience under all SLR scenarios. At Seymores Creek resilience drops to moderate for both maximum SLR scenarios. Brooklyn had a moderate resilience in all scenarios except for minimum 2030 SLR, where it was moderate-high. This was maintained in both seasons. In winter Gentlemans is the only site to have high resilience level under average and minimum SLR scenarios. Figures 6.11-6.32 are maps of each site showing resilience levels for *A. marina* for all mangrove sites.

A. corniculatum mangrove habitat during summer had a moderate resilience level under all scenarios in all sites except Gentlemans and Popran Creek. At Gentlemans *A. corniculatum* had an increased level of resilience to moderate-high under average and minimum SLR scenarios. At Popran Creek a moderate-high level of resilience was maintained under all SLR scenarios for *A. corniculatum*. During winter the resilience levels remained unchanged in five sites. The other sites increased their resilience levels to moderate-high only under average 2030 SLR and minimum 2030 and 2050 SLR (Table 5.23).

Table 5.23 Resilience levels of mangrove species for sites in the Hawkesbury.

H – high, MH – moderate-high, M – moderate, L – low, Blank – not present, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

			Scenario									
Species	**Season**	**Site**	1	2	3	5	6	9	10	13	14	15
Avicennia	Summer	One Tree Reach	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Farmland	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Couranga Point	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Gentlemans Halt	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Seymores Creek	M	M	MH	MH	MH	MH	MH	M	MH	MH
		Brooklyn Oval	M	M	M	M	M	MH	MH	M	M	M
		Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Coba Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Winter	One Tree Reach	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Farmland	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Couranga Point	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Gentlemans Halt	MH	MH	MH	H	H	H	H	MH	H	H
		Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Brooklyn Oval	M	M	M	MH	MH	MH	MH	M	M	MH
		Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Coba Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
Aegiceras	Summer	One Tree Reach	M	M	M	M	M	M	M	M	M	M
		Farmland	M	M	M	M	M	M	M	M	M	M
		Couranga Point	M	M	M	M	M	MH	M	M	M	M
		Gentlemans Halt	M	M	MH	MH	MH	MH	MH	M	MH	MH
		Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
		Seymores Creek	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
		Big Bay	M	M	M	M	M	M	M	M	M	M
		Coba Bay	M	M	M	M	M	M	M	M	M	M
		Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
		Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Winter	One Tree Reach	M	M	M	M	M	MH	MH	M	M	M
		Farmland	M	M	M	M	M	M	M	M	M	M
		Couranga Point	M	M	M	MH	MH	MH	MH	M	MH	MH
		Gentlemans Halt	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
		Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
		Seymores Creek	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
		Big Bay	M	M	M	MH	MH	MH	MH	M	MH	MH
		Coba Bay	M	M	M	M	M	MH	MH	M	M	M
		Crosslands & Calna	M	M	M	M	M	MH	MH	M	M	M
		Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH

The following pages contain Figures 6.11 – 6.34 which are the maps of resilience levels for mangrove habitat. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 6.11 Map of One Tree Reach site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.12 Map of One Tree Reach site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.13 Map of Couranga Point site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.14 Map of Couranga Point site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.15 Map of Gentlemans Halt site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.16 Map of Gentlemans Halt site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.17 Map of Pumpkin Creek site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.18 Map of Pumpkin Creek site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.19 Map of Seymores Creek site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.20 Map of Seymores Creek site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.21 Map of Brooklyn Oval site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.22 Map of Brooklyn Oval site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.23 Map of Big Bay site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.24 Map of Big Bay site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.25 Map of Coba Bay site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.26 Map of Coba Bay site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.27 Map of Crosslands site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.28 Map of Crosslands site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.29 Map of Popran Creek site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.30 Map of Popran Creek site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.31 Map of Farmland site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.32 Map of Farmland site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.33 Map of Calna Creek site showing resilience levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

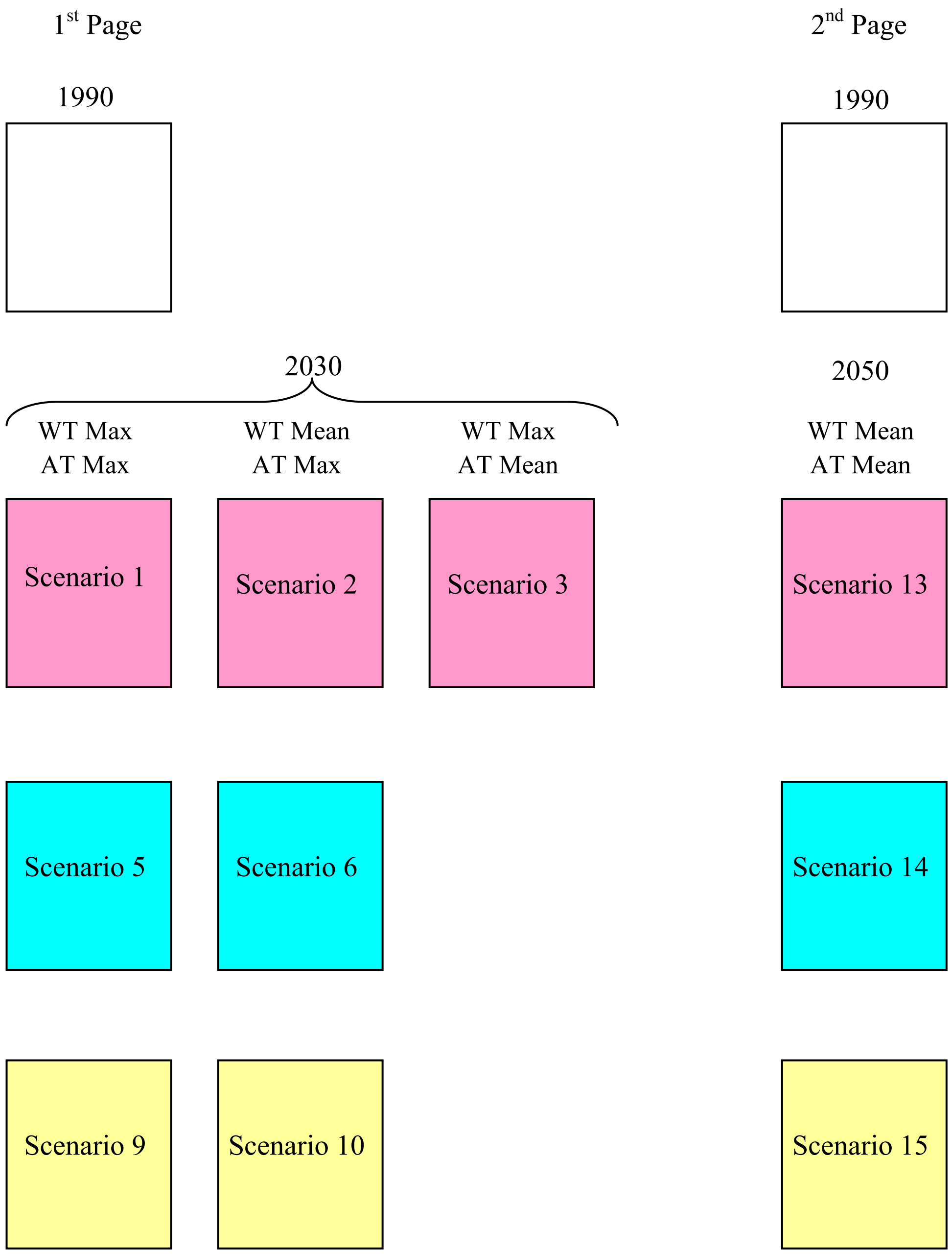
Figure 6.34 Map of Calna Creek site showing resilience levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



5.2.2.3. Saltmarsh

Adaptive capacity

A similar set of species specific characteristics were identified that would be most influential in enabling saltmarsh habitat patches to respond to altered environmental conditions as a result of climate change (Table 5.24). However, unlike mangroves, there was less specific information available for the most dominant saltmarsh species in the Hawkesbury. Soil condition was added for saltmarsh as some species require some specific conditions for germination and flowering (Table 5.24). *J. krausii* flowers throughout the year, and *S. virginicus* and *Sarcocornia quinqueflora* only flower during summer months. However, there is no information on the proportion of plants flowering within a patch for any of these species. *S. virginicus* and *Sarcocornia quinqueflora* expand primarily via vegetative growth, however, the former takes longer to recolonise bare areas than the latter. *J. krausii* is less competitive with the non-native invasive saltmarsh *J. acutus* under increased freshwater inputs.

Table 5.24 Biological characteristics of mangrove species used to assess their capacity to respond to the effects of climate change

References: Clarke and Hannon, (1970), Adam (1990), Naidoo and Naidoo (1998), Laegdsgaard (2002), Saintilan (2009).

ND – no data; Unk - unknown

Characteristics	Measure	*Juncus kraussi*	*Sporobolus*	*Sarcocornia q.*
Reproduction	Flowering season	All year	Summer , hastened by water logging	Nov-Feb, triggered by high salinity
	% plants flowering	ND	ND	ND
	Dispersal method	wind & floating	wind primary, floating 2nd	floating
Sediment condition	Soil specificity:			
	salinity	10-15	low	low for germination, high for flowering
	soil water content	ND	high	access to tidal inundation
	Soil waterlogging affect growth	ND	under constant inundation little or no growth	ND
Establishment	Seed predation	ND	ND	ND
	Canopy	ND	yes for vegetative growth	ND
	Length of seedling establishment	ND	ND	germination after rain
Recruitment	Primary mode of expansion	Sex reproduction primary	vegetative growth primary,	vegetative growth primary,
	Recovery rate to 80% after disturb	ND	slow, 5-6yr to reach 80-100%	2yr to reach 80-100% in low marsh, >5yr in mid-high marsh
Competition	Interspecific competition with:			
	mangroves	poor	poor	poor
	terrestial plants	ND	ND	ND
	other SM	ND	more competitve on moist sites	more competitve on saline sites
	invasives	with J. acutus in increasing FW > Jk	ND	poor
Climate plasticity	Response to CO_2 increase	Unk	Unk	Unk

Site specific characteristics were the same as for mangrove habitats, excluding sediment accretion via the presence of pneumatophors (Table 5.25). Popran and Crosslands/Calna Creek sites had the largest proportion of potential expandable area for saltmarsh habitat.

Table 5.25 Characteristics of sites used to assess the capacity of mangrove habitats to respond to the effects of climate change.

ND – no data; VP – very poor; P – poor; F – fair; VG – very good; Gw - groundwater

Characteristics	Component	Measure	Couranga Point	Gentlemans	Pumpkin Creek	Seymores Creek	Brooklyn Oval
Patch size	Proportion of habitat in reach or sub-catchment		0.369	0.040	0.424	0.023	0.025
Geomorphic conditions	Landward barriers	Prop'n potential expandable area	0.439	0.229	0.260	0.115	0.000
		% slope	13.500	16.700	13.700	100.000	100.000
		Terrestial edge	Bush	Bush	Bush	Modified	Modified
Wetland hydrologic conditions	Above ground processes	Sediment input:					
		Catchment delivery	ND	ND	ND	ND	ND
		Estuarine delivery	ND	ND	ND	ND	ND
		Deposition rate	ND	ND	ND	ND	ND
		Erosion rate	ND	ND	ND	ND	ND
		Vertical accretion trajectory m/yr	ND	ND	ND	ND	ND
	Below ground processes	Aerated layer:					
		shallowest depth of ground water level	ND	ND	ND	ND	ND
		Shrink-swell capacity:					
		tidal water infiltration/drainage	ND	ND	ND	ND	ND
		rainfall	ND	ND	ND	ND	ND
		evapotranspiration rate	ND	ND	ND	ND	ND
		soil depth	ND	ND	ND	ND	ND
		flow regulation effect on water table	ND	ND	ND	ND	ND
		Groundwater condition:					
		Region Gw Level	VP	VP	VP	VP	VP
		Local Gw Level	VP	VP	VP	VP	VP
		Aquifer integrity	VP	VP	VP	VP	VP

Table 5.25 Cont'd.

Characteristics	Component	Measure	Big Bay	Coba Bay	Crosslands & Calna	Popran Creek
Patch size	Proportion of habitat in reach or sub-catchment		0.268	0.092	0.107	0.230
Geomorphic conditions	Landward barriers	Prop'n potential expandable area	0.180	0.350	0.517	0.512
		% slope	11.800	7.270	40.000	40.000
		Terrestial edge	Bush	Bush	Modified	Modified
Wetland hydrologic conditions	Above ground processes	Sediment input:				
		Catchment delivery	ND	ND	ND	ND
		Estuarine delivery	ND	ND	ND	ND
		Deposition rate	ND	ND	ND	ND
		Erosion rate	ND	ND	ND	ND
		Vertical accretion trajectory m/yr	0.00062	ND	0.00146	ND
	Below ground processes	Aerated layer:				
		shallowest depth of ground water level	ND	ND	ND	ND
		Shrink-swell capacity:				
		tidal water infiltration/drainage	ND	ND	ND	ND
		rainfall	ND	ND	ND	ND
		evapotranspiration rate	ND	ND	ND	ND
		soil depth	ND	ND	ND	ND
		flow regulation effect on water table	ND	ND	ND	ND
		Groundwater condition:				
		Region Gw Level	VP	VP	VP	P
		Local Gw Level	VP	VP	VP	F
		Aquifer integrity	VP	VP	VP	VG

Resilience levels

By combining the risk levels from stage 1 with each species at each site, specific adaptive capacity resilience levels were determined for three species of saltmarsh (*J. krausii, S. virginicus, Sarcocornia quinqueflora)*. These results are presented in Table 5.26 and the following maps are for *J. krausii* and *S. virginicus* species only because these was the most dominant species at all sites. During summer *J. krausii* had a moderate level of resilience under all SLR scenarios in all sites except Popran Creek where it increased to moderate-high under all scenarios. During winter the pattern of resilience was the same except at Gentlemans under the minimum 2030 SLR scenario where its resilience was moderate-high. *S. virginicus*, by contrast, had low resilience levels under all scenarios in almost all sites during summer. Again Popran was an exception with *S. virginicus* having a moderate level of resilience under all scenarios except maximum 2050 SLR. At Courangra and Coba Bay *S. virginicus* also had moderate resilience but only under minimum 2030 SLR scenario. During winter *S. virginicus* increased its resilience level to moderate under average and minimum SLR scenarios at four sites, with Popran increasing to moderate-high resilience under minimum 2030 SLR scenario. *Sarcocornia quinqueflora* had a moderate level of resilience during summer at all sites under all scenarios with two exceptions, Brooklyn and Popran. At Brooklyn, resilience was low for all scenarios except minimum 2030 SLR, due to its high risk of loss at this site. At Popran, *Sarcocornia quinqueflora* had an increased level of resilience (moderate-high) under average and minimum SLR scenarios. The summer pattern at all sites was repeated in winter with Brooklyn increasing to moderate and Gentlemans Halt increasing to moderate-high resilience (Table 5.26). Figures 6.33-6.50 are maps of each site showing resilience levels for *J. krausii* saltmarsh habitats. Figures 6.51-6.68 show resilience levels for *S. virginicus* saltmarsh habitats.

Table 5.26 Resilience levels of saltmarsh species for sites in the Hawkesbury.

H – high, MH – moderate-high, M – moderate, L – low, Blank – not present, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

			Scenario									
Species	**Season**	**Site**	1	2	3	5	6	9	10	13	14	15
Juncus	Summer	Couranga Point	M	M	M	M	M	M	M	M	M	M
		Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
		Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
		Seymores Creek	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
		Big Bay	M	M	M	M	M	M	M	M	M	M
		Coba Bay	M	M	M	M	M	M	M	M	M	M
		Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
		Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Winter	Couranga Point	M	M	M	M	M	MH	MH	M	M	M
		Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
		Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
		Seymores Creek	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
		Big Bay	M	M	M	M	M	M	M	M	M	M
		Coba Bay	M	M	M	M	M	M	M	M	M	M
		Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
		Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
Sporobulus	Summer	Couranga Point	L	L	L	L	L	M	L	L	L	L
		Gentlemans Halt	L	L	L	L	L	L	L	L	L	L
		Pumpkin Creek	L	L	L	L	L	L	L	L	L	L
		Seymores Creek	L	L	L	L	L	L	L	L	L	L
		Brooklyn Oval	L	L	L	L	L	L	L	L	L	L
		Big Bay	L	L	L	L	L	L	L	L	L	L
		Coba Bay	L	L	L	L	L	M	M	L	L	L
		Crosslands & Calna	L	L	L	L	L	L	L	L	L	L
		Poporan Creek	M	M	M	M	M	M	M	L	M	M
	Winter	Couranga Point	L	L	L	M	M	M	M	L	L	M
		Gentlemans Halt	L	L	L	M	M	M	M	L	M	M
		Pumpkin Creek	L	L	L	M	M	M	M	L	M	M
		Seymores Creek	L	L	L	L	L	M	M	L	L	L
		Brooklyn Oval	L	L	L	L	L	M	M	L	L	L
		Big Bay	L	L	L	M	M	M	M	L	M	M
		Coba Bay	L	L	L	L	L	M	M	L	L	L
		Crosslands & Calna	L	L	L	L	L	M	M	L	L	L
		Poporan Creek	L	L	M	M	M	MH	MH	M	M	M
Sarccocornia	Summer	Couranga Point	M	M	M	M	M	MH	M	M	M	M
		Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
		Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
		Seymores Creek	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	L	L	L	L	L	M	M	L	L	L
		Big Bay	M	M	M	M	M	M	M	L	M	M
		Coba Bay	M	M	M	M	M	M	M	M	M	M
		Crosslands & Calna	M	M	M	M	M	M	M	L	M	M
		Poporan Creek	M	M	M	MH	MH	MH	MH	M	MH	MH
	Winter	Couranga Point	M	M	M	M	M	MH	MH	M	M	M
		Gentlemans Halt	M	M	M	MH	MH	MH	MH	M	MH	MH
		Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
		Seymores Creek	M	M	M	M	M	M	M	M	M	M
		Brooklyn Oval	M	M	M	M	M	M	M	M	M	M
		Big Bay	M	M	M	M	M	M	M	M	M	M
		Coba Bay	M	M	M	M	M	MH	MH	M	M	M
		Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
		Poporan Creek	M	M	M	MH	MH	MH	MH	M	MH	MH

The following pages contain Figures 6.35 – 6.58 which are the maps of resilience levels for *J. krausii* saltmarsh habitat. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 6.35 Map of One Tree Reach site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.36 Map of One Tree Reach site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.37 Map of Courangra Point site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.38 Map of Courangra Point site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.39 Map of Gentlemans Halt site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.40 Map of Gentlemans Halt site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.41 Map of Pumpkin Creek site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.42 Map of Pumpkin Creek site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.43 Map of Seymores Creek site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.44 Map of Seymores Creek site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.45 Map of Brooklyn site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.46 Map of Brooklyn site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.47 Map of Big Bay site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.48 Map of Big Bay site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.49 Map of Coba Bay site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.50 Map of Coba Bay site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.51 Map of Crosslands site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.52 Map of Crosslands site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.53 Map of Popran Creek site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.54 Map of Popran Creek site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.55 Map of Farmalnd site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.56 Map of Farmland site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.57 Map of Calna Creek site showing resilience levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

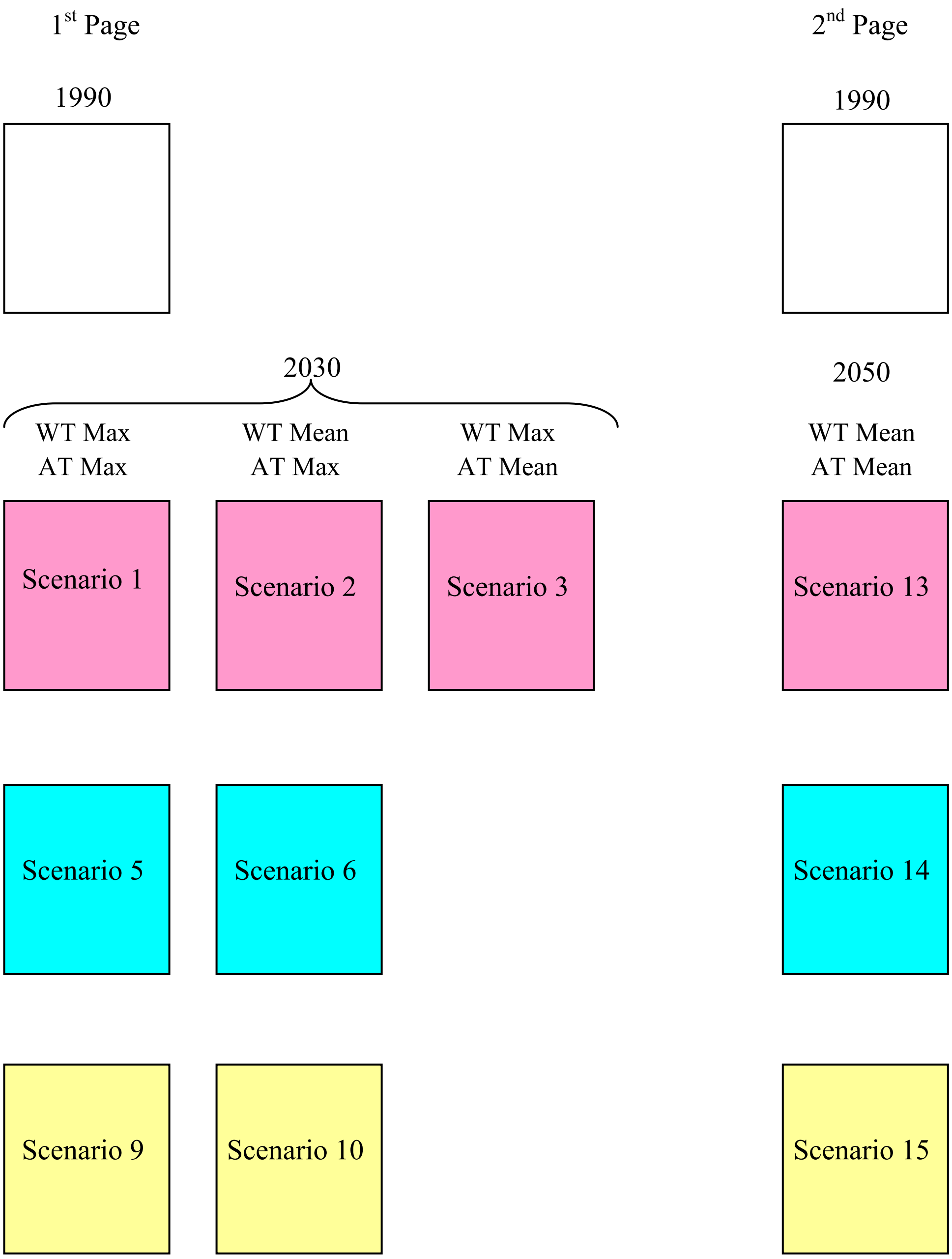
Figure 6.58 Map of /Calna Creek site showing resilience levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



The following pages contain Figures 6.59 – 6.82 which are the maps of resilience levels for *S. virginicus* saltmarsh habitat. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 6.59 Map of One Tree Reach site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.60 Map of One Tree Reach site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.61 Map of Courangra Point site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.62 Map of Courangra Point site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.63 Map of Gentlemans Halt site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.64 Map of Gentlemans Halt site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.65 Map of Pumpkin Creek site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.66 Map of Pumpkin Creek site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.67 Map of Seymores Creek site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.68 Map of Seymores Creek site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.69 Map of Brooklyn site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.70 Map of Brooklyn site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.71 Map of Big Bay site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.72 Map of Big Bay site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.73 Map of Coba Bay site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.74 Map of Coba Bay site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.75 Map of Crosslands site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.76 Map of Crosslands site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.77 Map of Popran Creek site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.78 Map of Popran Creek site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.79 Map of Farmland site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.80 Map of Farmland site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.81 Map of Calna Creek site showing resilience levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 6.82 Map of Calna Creek site showing resilience levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

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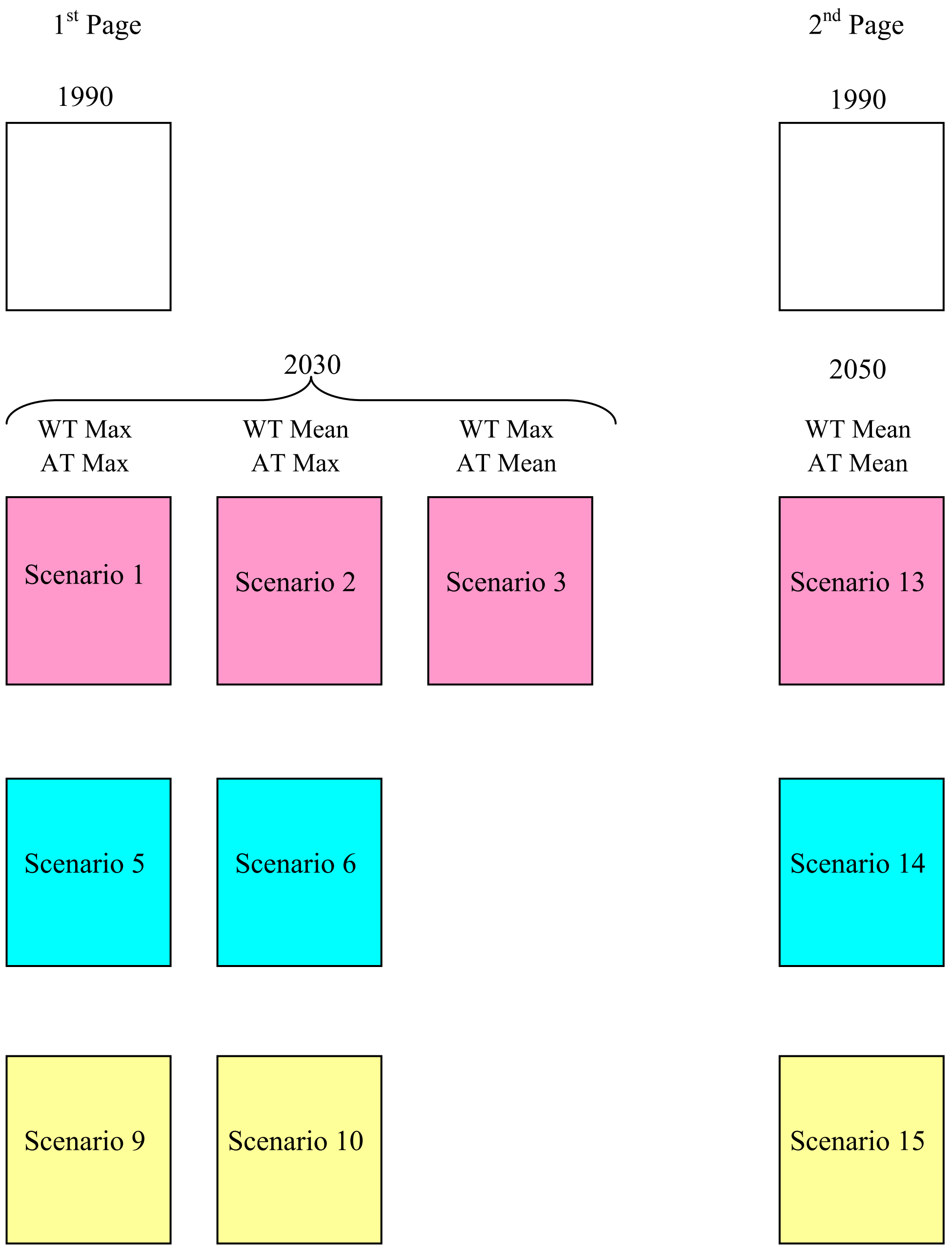
Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



5.3. Stage 3 – Vulnerability Assessment

5.3.1. Non-climatic human stressors

Non-climatic human stressors (NCHS) were assessed at two spatial scales - small and large. At the small spatial scale human activities that occurred within 10m of a habitat patch were assessed to determine the potential level of pressure occurring in the immediate vicinity of a habitat. These pressures could affect a habitat's capacity to expand or shift in response to the effects of climate change or exacerbate its contraction or complete loss. At the larger spatial scale of sub-catchment or reach, human activities were assessed for their potential to affect biochemical, physical and geomorphic processes. Human pressures occurring at this wider scale could affect a habitat's capacity to translocate to more favourable habitats in response to the effects of climate change as well as interact with human stressors at smaller spatial scales. The level of non-climatic human stressors was determined for each site separately.

A previous ecological risk assessment study on estuarine habitats in the Hawkesbury estuary (Astles et al. 2010) identified eight major human activities that could potentially affect habitats (recreational fishing, aquatic recreation, commercial fishing, foreshore development, sewage treatment, stormwater and catchment run-off, dredging and sedimentation, commercial vessels). Each human activity had a number of human stressors that made a habitat either susceptible or not susceptible to being degraded. These are explained in detail in Astles et al. (2010). These activities and stressors formed the basis of the NCHS assessed in this study. At the small spatial scale the number of NCHS within 10m of the habitat patch was calculated using GIS data. This included the number of wharves, marinas and stormwater outlets. The length of artificial rockwalls and farmland boundaries was also recorded. These values were then expressed as a proportion of the total number or length of NCHS for all sites to assess the relative pressure from these stressors among sites. Four sites (One Tree Reach, Farmland below Laughtondale, Courangra Point, Crosslands) had large farm or parkland bordering their habitats. The area of each of these land types was expressed as a proportion of the area of mangrove or saltmarsh habitat at these sties.

Results from the ecological risk assessment study were used to assess the pressure from NCHS at the large spatial scale. For each reach and sub-catchment, corresponding to the location of the sites of this study, the number of human activities that had stressors which contributed to habitats being susceptible to degradation were extracted. These were then expressed as a proportion of all human activities operating in the catchment or reach. In addition, the number of individual susceptible human stressors for all activities was also extracted and expressed as a proportion of the total number of possible stressors. Keeping the human activities and their stressors separate enables the evaluation of both the sources and type of the pressures being exerted on habitats in Stage 4 of the assessment.

Two other factors were incorporated into the large scale assessment. Groundwater pressures, as measured by the latest State of the Catchments report (Department of Environment, Climate Change and Water, 2010), were included as this can affect below-ground processes associated with surface elevation changes, which affect saltmarsh and mangrove habitats. The percentage loss of habitat between 1940 and 2000 was extracted from Williams and Thiebaud (2007). This was mainly used for seagrass and saltmarsh habitats. Whilst there were significant increases in mangrove habitats during this period, it was not clear what proportion of saltmarsh habitat it replaced at every site and was not included (Saintilan and Williams, 1999).

The results of the NCHS at both spatial scales for each site are summarised in Table 5.27. The levels of NCHS discussed in the following section are given separately for each scale and as an overall level of NCHS as the total of both scales.

Table 5.27 Summary of the results of the NCHS data used to assess vulnerability of habitats to the effects of climate change.

ND – no data, NA – not applicable, Ha – hectare, Unsew – unsewered, Prop'n – proportion, Struct – structure, Entitl – entitlement, LTAAEL – long term annual average extraction limit, Entitl:LTAAEL – current level of ground water extraction relative to LTAAEL, suscpt – susceptible.

Spatial Scale	Habitat	Non-climatic human stressors	One Tree Reach	Farmland	Courangra Point	Gentleman's Halt	Pumpkin Creek	Seymores Creek	Brooklyn Oval	Kangaroo Pt	Big Bay	Coba Bay
10m	All	Prop'n public parks	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
		Prop'n marinas complexes	0.00	0.00	0.00	0.00	0.00	0.20	0.10	0.10	0.00	0.00
		Prop'n boat ramps	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00
		Prop'n artifical rockwall	0.00	0.00	0.00	0.00	0.00	0.38	0.42	0.00	0.00	0.00
		Prop'n closesfarmland boundary to site	0.14	0.11	0.68	0.00	0.03	0.00	0.00	0.00	0.00	0.00
		Prop'n unsewered housing blocks	0.00	0.03	0.00	0.00	0.00	0.18	0.22	0.00	0.00	0.00
		Prop'n wharves	0.14	0.07	0.00	0.00	0.00	0.00	0.07	0.14	0.00	0.00
		Prop'n stormwater outlets	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
		Farm/park (F/P) area (Ha)	12.10	12.74	19.67	ND	ND	ND	ND	NA	NA	NA
	Mangroves (Mn)	Prop'n F/P to mangroves	0.78	0.86	0.27	ND	ND	ND	ND	NA	NA	NA
	Saltmarsh (SM)	Prop'n F/P to saltmarsh	ND	ND	0.33	ND	ND	ND	ND	NA	NA	NA
	Mangroves (Mn)	Mn Wharf # per Ha	0.57	0.49	0.00	0.00	0.00	0.00	0.31	NA	0.00	0.00
		Mn Unsew Housing # per Ha	0.00	0.99	0.00	0.00	0.00	2.48	4.59	NA	0.00	0.00
		Mn Boat ramps # per Ha	0.00	0.00	0.00	0.00	0.00	0.21	0.31	NA	0.00	0.00
		Mn Marina # per Ha	0.00	0.00	0.00	0.00	0.00	0.41	0.31	NA	0.00	0.00
		Mn Stormwater # per Ha	0.00	0.00	0.00	0.00	0.00	0.00	2.45	NA	0.00	0.00
	Saltmarsh (SM)	SM Wharf # per Ha	ND	ND	0.00	0.00	0.00	0.00	2.09	NA	0.00	0.00
		SM Unsew Housing # per Ha	ND	ND	0.00	0.00	0.00	27.08	31.32	NA	0.00	0.00
		SM Boat ramps # per Ha	ND	ND	0.00	0.00	0.00	2.26	2.09	NA	0.00	0.00
		SM Marina # per Ha	ND	ND	0.00	0.00	0.00	4.51	2.09	NA	0.00	0.00
		SM Stormwater # per Ha	ND	ND	ND	0.00	0.00	ND	16.71	NA	0.00	0.00
	Seagrass (SG)	SG Wharf # per Ha	NA	NA	NA	NA	NA	NA	NA	2.68	ND	ND
		SG Unsew Housing # per Ha	NA	NA	NA	NA	NA	NA	NA	0.00	ND	ND
		SG Boat ramps # per Ha	NA	NA	NA	NA	NA	NA	NA	0.00	ND	ND
		SG Marina # per Ha	NA	NA	NA	NA	NA	NA	NA	1.34	ND	ND
		SG Stormwater # per Ha	NA	NA	NA	NA	NA	NA	NA	0.00	ND	ND

Spatial Scale	Habitat	Non-climatic human stressors	Woolwash, Berowra Ck	Crosslands	Calna Creek	Dangar Is	Cowan Ck,, Bobbin Hd	Smiths Ck, Cowan	Patonga entrance	Dangar Is beach	Mullet, upper	Popran Ck
10m	All	Prop'n public parks	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
		Prop'n marinas complexes	0.00	0.00	0.00	0.50	0.10	0.00	0.00	0.00	0.00	0.00
		Prop'n boat ramps	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
		Prop'n artifical rockwall	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
		Prop'n closesfarmland boundary to site	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Prop'n unsewered housing blocks	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.24	0.00	0.00
		Prop'n wharves	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00
		Prop'n stormwater outlets	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Farm/park (F/P) area (Ha)	NA	2.65	ND	NA	NA	NA	NA	NA	NA	NA
	Mangroves (Mn)	Prop'n F/P to mangroves	NA	0.80	ND	NA	NA	NA	NA	NA	NA	NA
	Saltmarsh (SM)	Prop'n F/P to saltmarsh	NA	0.98	ND	NA	NA	NA	NA	NA	NA	NA
	Mangroves (Mn)	Mn Wharf # per Ha	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	0.00
		Mn Unsew Housing # per Ha	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	0.00
		Mn Boat ramps # per Ha	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	0.00
		Mn Marina # per Ha	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	0.00
		Mn Stormwater # per Ha	NA	0.00	0.00	NA	NA	NA	NA	NA	NA	0.00
	Saltmarsh (SM)	SM Wharf # per Ha	NA	0.00	0.00	NA	NA	NA	NA	NA	0.00	0.00
		SM Unsew Housing # per Ha	NA	0.00	0.00	NA	NA	0.00	NA	NA	0.00	0.00
		SM Boat ramps # per Ha	NA	0.00	0.00	NA	NA	0.00	NA	NA	0.00	0.00
		SM Marina # per Ha	NA	0.00	0.00	NA	NA	0.00	NA	NA	0.00	0.00
		SM Stormwater # per Ha	NA	0.00	0.00	NA	NA	0.00	NA	NA	0.00	0.00
	Seagrass (SG)	SG Wharf # per Ha	0.00	NA	ND	ND	0.00	0.00	4.76	0.00	0.00	NA
		SG Unsew Housing # per Ha	0.00	NA	ND	ND	0.00	0.00	13.10	1.31	0.00	NA
		SG Boat ramps # per Ha	0.00	NA	ND	ND	0.00	0.00	0.60	0.00	0.00	NA
		SG Marina # per Ha	0.00	NA	ND	ND	0.36	0.00	0.00	0.00	0.00	NA
		SG Stormwater # per Ha	0.00	NA	ND	ND	0.00	0.00	0.00	0.00	0.00	NA

Table 5.27 Cont'd

ND – no data, NA – not applicable, Ha – hectare, Unsew – unsewered, Prop'n – proportion, Struct – structure, Entitl – entitlement, LTAAEL – long term annual average extraction limit, Entitl:LTAAEL – current level of ground water extraction relative to LTAAEL, suscpt – susceptible, H – high, L – low, M – medium, VH – very high, VL – very low.

		Sub-catchment/Reach:	**Riverine**	**Riverine**	**Riverine**	**Fluvial**	**Fluvial**	**Fluvial**	**Fluvial**	**Fluvial**	**Berowra**	**Berowra**
Spatial Scale	**Habitat**	**Non-climatic human stressors**	**One Tree Reach**	**Farmland**	**Courangra Point**	**Gentleman's Halt**	**Pumpkin Creek**	**Seymores Creek**	**Brooklyn Oval**	**Kangaroo Pt**	**Big Bay**	**Coba Bay**
Sub-catchment/ Reach[1]	Seagrass	Propn NCHP	0.00	0.00	0.00	0.86	0.86	0.86	0.86	0.86	0.86	0.86
		Proportion Suscpt	0.00	0.00	0.00	0.23	0.23	0.23	0.23	0.23	0.18	0.18
	Mangroves	Propn NCH	0.71	0.71	0.71	0.86	0.86	0.86	0.86	0.86	0.86	0.86
		Proportion Suscpt	0.23	0.23	0.23	0.30	0.30	0.30	0.30	0.30	0.23	0.23
	Saltmarsh	Propn NCH	0.43	0.43	0.43	0.57	0.57	0.57	0.57	0.57	0.71	0.71
		Proportion Suscpt	0.07	0.07	0.07	0.09	0.09	0.09	0.09	0.09	0.16	0.16
	Seagrass	SG % Change	0.00	NA	0.00	NA	100.00	ND	0.00	ND	0.00	ND
	Mangrove	Mn % Change	0.00	NA	75.24	ND	218.53	ND	31.63	ND	22.56	ND
	Saltmarsh	SM % Change	0.00	NA	-37.26	ND	-85.18	ND	-80.81	ND	-80.98	ND
	Groundwater pressures	Landuse	H	H	H	H	H	H	H	H	H	H
		Regional impact	L	L	L	L	L	L	L	L	L	L
		Localised impact	M	M	M	M	M	M	M	M	M	M
		Aquifer struct	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH
		Entitl:LTAAEL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

		Sub-catchment/Reach:	**Berowra**	**Berowra**	**Berowra**	**Fluvial**	**Cowan**	**Cowan**	**Patonga**	**Fluvial**	**Mullet**	**Mangrove**
Spatial Scale	**Habitat**	**Non-climatic human stressors**	**Woolwash, Berowra Ck**	**Crosslands**	**Calna Creek**	**Dangar Is**	**Cowan Ck, Bobbin Hd**	**Smiths Ck, Cowan**	**Patonga entrance**	**Dangar Is beach**	**Mullet, upper**	**Popran Ck**
Sub-catchment/ Reach[1]	Seagrass	Propn NCHP	0.86	0.86	0.86	0.86	0.71	0.71	0.86	0.86	0.71	0.14
		Proportion Suscpt	0.18	0.18	0.18	0.23	0.20	0.20	0.33	0.23	0.14	0.02
	Mangroves	Propn NCH	0.86	0.86	0.86	0.86	0.71	0.71	0.86	0.86	0.71	0.57
		Proportion Suscpt	0.23	0.23	0.23	0.30	0.16	0.16	0.21	0.30	0.18	0.19
	Saltmarsh	Propn NCH	0.71	0.71	0.71	0.57	0.57	0.57	0.57	0.57	0.43	0.43
		Proportion Suscpt	0.16	0.16	0.16	0.09	0.09	0.09	0.10	0.09	0.07	0.10
	Seagrass	SG % Change	ND	-87.04	ND	390.39	-100.00	ND	-1.67	ND	74.52	0.00
	Mangrove	Mn % Change	ND	63.31	ND	0.00	7.69	ND	30.73	ND	55.70	0.00
	Saltmarsh	SM % Change	ND	-69.83	ND	0.00	-100.00	ND	-62.84	ND	-100.00	-55.88
	Groundwater pressures	Landuse	H	H	H	H	H	H	H	H	H	H
		Regional impact	L	L	L	L	L	L	L	L	L	L
		Localised impact	M	M	M	M	M	M	M	M	M	M
		Aquifer struct	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH
		Entitl:LTAAEL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

Note 1. See Astles et al. (2010) for method of calculation of NCHS.

5.3.1.1. Seagrass

Seagrass had low levels of NCHS at the small spatial scale at all sites except Patonga, where it was medium (Table 5.28). At the small spatial scale seagrass at Patonga was in close proximity to unsewered housing, public parks, a boat ramp and artificial seawalls. At the sub-catchment scale seagrass had medium levels of NCHS in all sites except Patonga and Cowan Creek. These sites had medium-high levels of NCHS which brought the overall level of NCHS for these sites to high. These sites were in sub-catchments with high proportion of marinas, moorings, public wharves and artificial seawalls.

Table 5.28 Summary of NCHS results and levels for seagrass sites in the Hawkesbury.

H – high, MH – medium-high, M – medium, L – low, Prop'n - proportion

	NCHS 10m		**NCHS Catch. scale**		**NCHS 10 & Catch Scales**	
Site Name	Prop'n	Level	Prop'n	Level	Prop'n	Level
Cowan Ck, below Bobbin Hd	0.03	L	0.78	MH	0.81	H
Smiths Ck	0.00	L	0.44	M	0.44	M
Patonga entrance	0.27	ML	0.67	MH	0.93	H
Dangar Is	0.03	L	0.44	M	0.48	M
Mullet	0.00	L	0.44	M	0.44	M

5.3.1.2. Mangroves

Mangroves had low levels of NCHS at the small spatial scale at all sites except Farmland, Seymores Creek and Brooklyn (Table 5.29). Farmland and Seymores had low-medium and Brooklyn medium levels of NCHS. These three sites had the highest concentrations of human activities within 10m of the habitats. At the sub-catchment/reach scale all sites had medium levels of NCHS. The overall level of NCHS was high for Brooklyn, medium-high for One Tree, Farmland, Courangra, Seymores and Crosslands. The remaining sites all had medium levels of NCHS (Table 5.29).

Table 5.29 Summary of NCHS results and levels for mangrove sites in the Hawkesbury.

H – high, MH – medium-high, M – medium, L – low, Prop'n - proportion

	NCHS 10m		**NCHS Catch. scale**		**NCHS 10 & Catch Scales**	
Site Name	Prop'n	Level	Prop'n	Level	Prop'n	Level
One Tree Reach	0.17	L	0.54	M	0.71	MH
Farmland	0.20	ML	0.54	M	0.74	MH
Courangra Point	0.13	L	0.54	M	0.67	MH
Gentleman's Halt	0.00	L	0.54	M	0.54	M
Pumpkin Creek	0.03	L	0.54	M	0.57	M
Seymores Creek	0.20	ML	0.54	M	0.74	MH
Brooklyn Oval	0.40	M	0.54	M	0.94	H
Big Bay	0	L	0.54	M	0.54	M
Coba Bay	0	L	0.54	M	0.54	M
Crosslands	0.13	L	0.54	M	0.67	MH
Calna Creek	0	L	0.54	M	0.54	M
Mangrove, Poporan Ck	0	L	0.50	M	0.50	M

5.3.1.3. Saltmarsh

Saltmarsh had low levels of NCHS at the small spatial scale at all sites except for Seymores Creek and Brooklyn. These had medium-low and medium levels respectively (Table 5.30). At the large spatial all sites had medium levels of NCHS. Overall NCHS levels were high for Brooklyn, medium-high for Courangra, Seymores and Crosslands and medium for the remaining sites.

Table 5.30 Summary of NCHS results and levels for mangrove sites in the Hawkesbury.

H – high, MH – medium-high, M – medium, L – low, Prop'n - proportion

	NCHS 10m		NCHS Catch. scale		NCHS 10 & Catch Scales	
Site Name	Prop'n	Level	Prop'n	Level	Prop'n	Level
Courangra Point	0.17	L	0.52	M	0.68	MH
Gentleman's Halt	0.00	L	0.45	M	0.45	M
Pumpkin Creek	0.03	L	0.55	M	0.59	M
Seymores Creek	0.20	ML	0.45	M	0.65	MH
Brooklyn Oval	0.40	M	0.55	M	0.95	H
Big Bay	0	L	0.59	M	0.59	M
Coba Bay	0	L	0.48	M	0.48	M
Crosslands	0.13	L	0.59	M	0.72	MH
Calna Creek	0	L	0.48	M	0.48	M
Mangrove, Poporan Ck	0	L	0.52	M	0.52	M

Vulnerability levels

Combining the overall NCHS levels with resilience for each species and site, determined the vulnerability levels for each SLR scenario. For both Cowan and Patonga *Z. capricorni* habitat had moderate-high vulnerability under all SLR scenarios (Table 5.31) in summer and winter. The remaining sites had moderate vulnerability under all scenarios in both seasons except Mullet which had low vulnerability under minimum 2030 SLR scenario. *H. ovalis* had moderate vulnerability at Dangar Island in both seasons and all scenarios. Similarly at Patonga this species had moderate-high vulnerability.

Table 5.31 Summary of vulnerability levels for seagrass species in the Hawkesbury.

H – high, MH – moderate-high, M – moderate, L – low, Blank – not present, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
		1	2	3	5	6	9	10	13	14	15
Season	**Species:**	*Zostera*	*Zostera*	*Zostera*	*Zostera*	*Zostera*	*Zostera*	*Zostera*	*Zostera*	*Zostera*	*Zostera*
Summer	Cowan Bobbin Hd	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Smiths Crk	M	M	M	M	M	M	M	M	M	M
	Dangar Is	M	M	M	M	M	M	M	M	M	M
	Mullet upper	M	M	M	M	M	L	L	M	M	M
	Patonga	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
Winter	Cowan Bobbin Hd	MH	MH	MH	M	M	M	M	MH	MH	M
	Smiths Crk	M	M	M	M	M	M	M	M	M	M
	Dangar Is	M	M	M	M	M	M	M	M	M	M
	Mullet upper	M	M	M	M	M	L	L	M	M	L
	Patonga	MH	MH	MH	MH	MH	MH	M	MH	MH	MH
	Species:	*Halophila*	*Halophila*	*Halophila*	*Halophila*	*Halophila*	*Halophila*	*Halophila*	*Halophila*	*Halophila*	*Halophila*
Summer	Cowan Bobbin Hd										
	Smiths Crk										
	Dangar Is	M	M	M	M	M	M	M	M	M	M
	Mullet upper										
	Patonga	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
Winter	Cowan Bobbin Hd										
	Smiths Crk										
	Dangar Is	M	M	M	M	M	M	M	M	M	M
	Mullet upper										
	Patonga	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH

A. marina had moderate-high vulnerability under all scenarios for the four sites with the highest concentration of human activities – One Tree Reach, Farmland, Seymores and Brooklyn, in both summer and winter. At the remaining sites *A. marina* had moderate vulnerability in both seasons. Only at Gentlemans was the vulnerability of *A. marina* low under all scenarios (Table 5.32). The vulnerability of *A. corniculatum* was more variable among sites, seasons and across scenarios. Generally it had moderate-high vulnerability except for Pumpkin Creek and Big Bay where the level dropped to moderate under average and minimum SLR scenarios (Table 5.32) during summer and under all scenarios during winter. *A. corniculatum* at Gentlemans, Coba Bay and Popran sites consistently had moderate vulnerability among scenarios and seasons.

The following pages contain Figures 7.1 – 7.4 which are the maps of vulnerability levels for seagrass habitat. Only sites with vulnerability levels greater than low are presented. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 7.1 Map of Cowan Creek, Bobbin Head site showing vulnerability levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.2 Map of Cowan Creek, Bobbin Head site showing vulnerability levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.3 Map of Patonga site showing vulnerability levels for seagrasses during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.4 Map of Patonga site showing vulnerability levels for seagrasses during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.

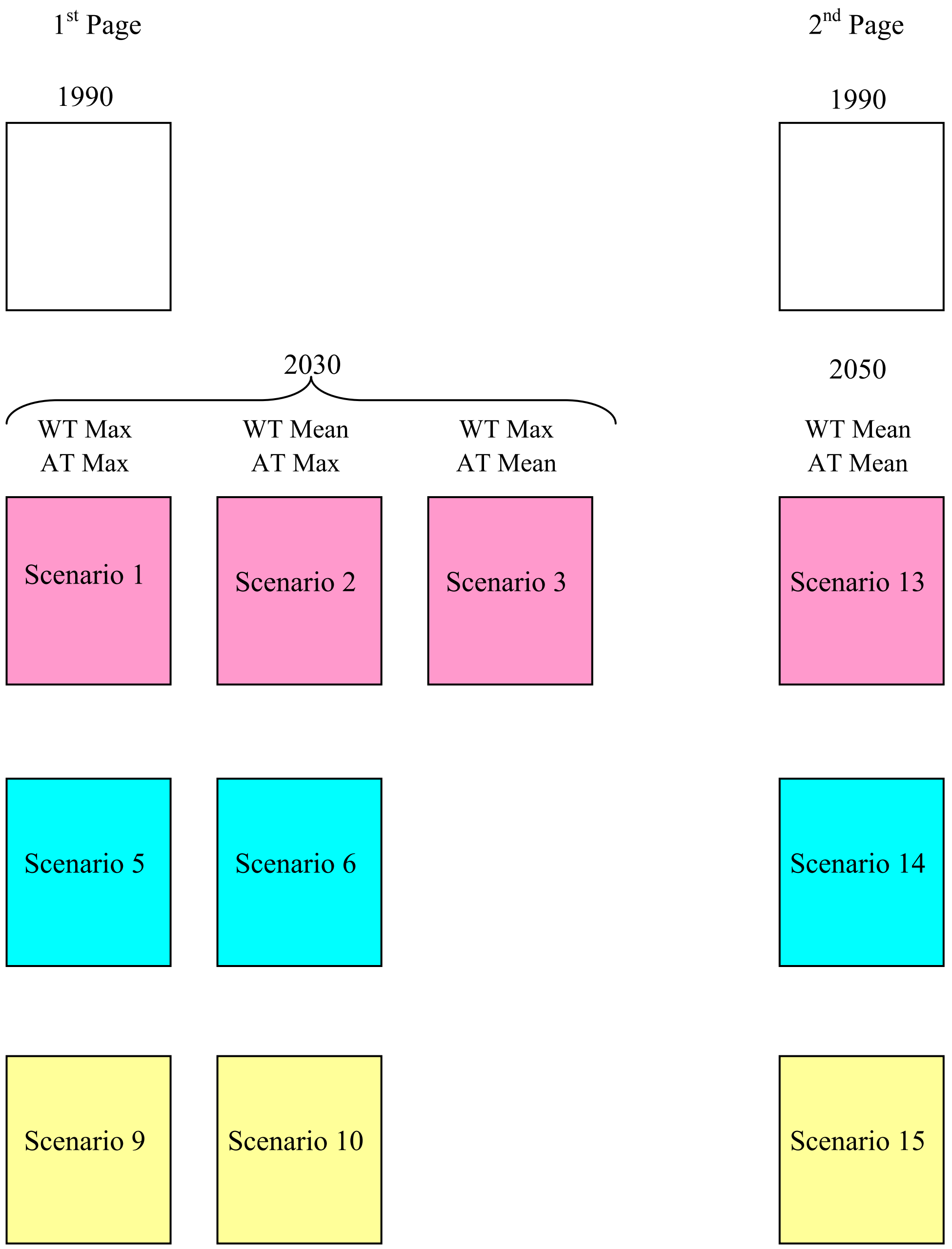


Table 5.32 Summary of vulnerability levels for mangrove species in the Hawkesbury.

H – high, MH – moderate-high, M – moderate, L – low, Blank – not present, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
		1	2	3	5	6	9	10	13	14	15
Season	**Species:**	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*	*Avicennia*
Summer	One Tree Reach	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Farmland	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Couranga Point	M	M	M	M	M	M	M	M	M	M
	Gentlemans Halt	L	L	L	L	L	L	L	L	L	L
	Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Big Bay	M	M	M	M	M	M	M	M	M	M
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
	Poporan Creek	M	M	M	M	M	M	M	M	M	M
Winter	One Tree Reach	MH	MH	MH	M	M	M	M	MH	M	M
	Farmland	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Couranga Point	M	M	M	M	M	L	L	M	M	M
	Gentlemans Halt	L	L	L	L	L	L	L	L	L	L
	Pumpkin Creek	M	M	M	M	M	M	M	M	M	M
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Big Bay	M	M	M	M	M	M	M	M	M	M
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
	Poporan Creek	M	M	M	L	L	L	L	M	M	L
	Species:	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*	*Aegiceras*
Summer	One Tree Reach	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Farmland	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Couranga Point	MH	MH	MH	MH	MH	M	MH	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	MH	MH	MH	M	M	M	M	MH	M	M
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Big Bay	MH	MH	M	M	M	M	M	MH	M	M
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Poporan Creek	M	M	M	M	M	M	M	M	M	M
Winter	One Tree Reach	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Farmland	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Couranga Point	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	M	M	M	M	M	M	M	MH	M	M
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Big Bay	M	M	M	M	M	M	M	M	M	M
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Poporan Creek	M	M	M	M	M	M	M	M	M	M

J. krausii also had variable vulnerability among sites, seasons and scenarios. Brooklyn was the only site where *J. krausii* had high vulnerability in both seasons but only under maximum SLR scenarios and one average SLR scenario. Gentlemans, Coba Bay, Crosslands/Calna and Popran had moderate vulnerability for *J. krausii* irrespective of scenario or season. *J. krausii* at the remaining sites was consistently at moderate-high vulnerability levels (Table 5.33). *S. virginicus* had a high vulnerability level under all scenarios only at Brooklyn during summer. In winter it remained high except under the minimum 2030 SLR scenario where it dropped to moderate-high. At Gentlemans *S. virginicus* had a moderate vulnerability under all scenarios during winter and under average and minimum SLR scenarios during summer. The remaining sites had primarily moderate-high vulnerability levels for *S. virginicus* (Table 5.33). *S. quinqueflora* had a similar pattern of vulnerability to *J. krausii* with Brooklyn having the highest vulnerability and Gentlemans, Coba Bay and Popran having moderate vulnerability (Table 5.33).

The following pages contain Figures 7.5 – 7.12 which are the maps of vulnerability levels for mangrove habitat. Only sites with vulnerability levels greater than low are presented. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 7.5 Map of One Tree Reach site showing vulnerability levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.6 Map of One Tree Reach site showing vulnerability levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.7 Map of Seymores Creek site showing vulnerability levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.8 Map of Seymores Creek site showing vulnerability levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.9 Map of Brooklyn Oval site showing vulnerability levels for mangroves during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.10 Map of Brooklyn Oval site showing vulnerability levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.11 Map of Farmland site showing vulnerability levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.12 Map of Farmland site showing vulnerability levels for mangroves during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

WT – water temperature, AT – air temperature, Max – maximum.

Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.

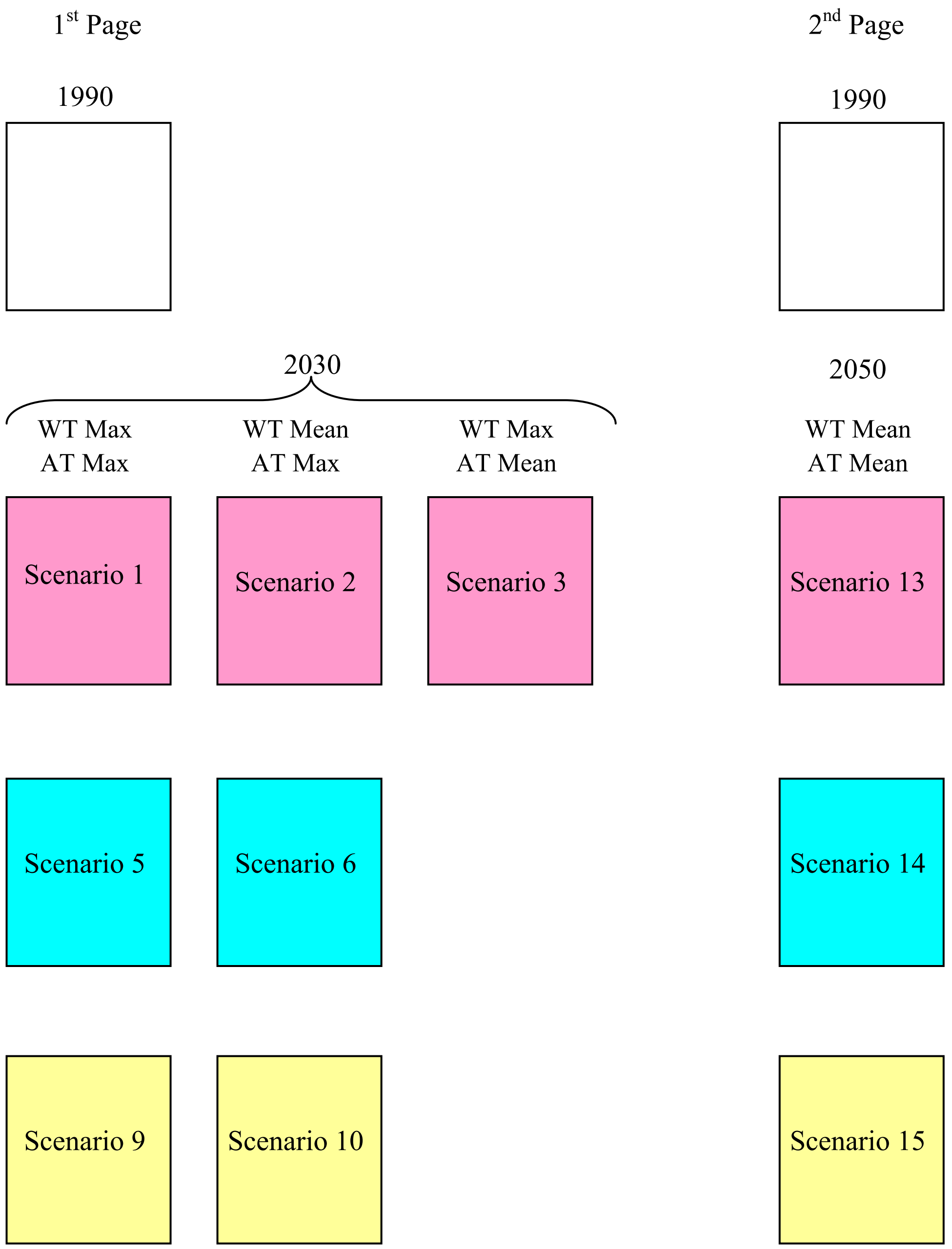


Table 5.33 Summary of vulnerability levels for saltmarsh species in the Hawkesbury.

H – high, MH – moderate-high, M – moderate, L – low, Blank – not present, Sarcoc – *Sarcocornia*, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group. See text for explanation.

		Scenario									
		1	2	3	5	6	9	10	13	14	15
Season	**Species:**	*Juncus*	*Juncus*	*Juncus*	*Juncus*	*Juncus*	*Juncus*	*Juncus*	*Juncus*	*Juncus*	*Juncus*
Summer	Couranga Point	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	H	H	MH	MH	MH	MH	MH	H	H	MH
	Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
	Poporan Creek	M	M	M	M	M	M	M	M	M	M
Winter	Couranga Point	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	H	H	H	MH	MH	MH	MH	H	MH	MH
	Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	M	M	M	M	M	M	M	M	M	M
	Poporan Creek	M	M	M	M	M	M	M	M	M	M
	Species:	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*	*Sporobolus*
Summer	Couranga Point	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Gentlemans Halt	MH	MH	MH	M	M	M	M	MH	M	M
	Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	H	H	H	H	H	H	H	H	H	H
	Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Coba Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Poporan Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
Winter	Couranga Point	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	H	H	H	H	H	MH	MH	H	H	H
	Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Coba Bay	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Poporan Creek	MH	MH	MH	M	M	M	M	MH	M	M
	Species:	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*	*Sarcoc.*
Summer	Couranga Point	MH	MH	MH	MH	MH	M	MH	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	H	H	H	H	H	MH	MH	H	H	H
	Big Bay	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Coba Bay	M	M	M	M	M	M	M	MH	M	M
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Poporan Creek	M	M	M	M	M	M	M	M	M	M
Winter	Couranga Point	MH	MH	MH	MH	MH	M	M	MH	MH	MH
	Gentlemans Halt	M	M	M	M	M	M	M	M	M	M
	Pumpkin Creek	MH	MH	MH	M	M	M	M	MH	M	M
	Seymores Creek	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Brooklyn Oval	H	H	H	MH	MH	MH	MH	H	MH	MH
	Big Bay	MH	MH	MH	M	M	M	M	MH	M	M
	Coba Bay	M	M	M	M	M	M	M	M	M	M
	Crosslands & Calna	MH	MH	MH	MH	MH	MH	MH	MH	MH	MH
	Crosslands & Calna	M	M	M	M	M	M	M	MH	M	M
	Poporan Creek	M	M	M	M	M	M	M	M	M	M

The following pages contain Figures 7.13 – 7.30 which are the maps of vulnerability levels for *J. krausii* saltmarsh habitat. Only sites with vulnerability levels greater than low are presented. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 7.13 Map of One Tree Reach site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.14 Map of One Tree Reach site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.15 Map of Courangra Point site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.16 Map of Courangra Point site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.17 Map of Gentlemans Halt site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.18 Map of Gentlemans Halt site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.19 Map of Pumpkin Creek site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.20 Map of Pumpkin Creek site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.21 Map of Seymores Creek site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.22 Map of Seymores Creek site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.23 Map of Brooklyn site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.24 Map of Brooklyn site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.25 Map of Crosslands site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.26 Map of Crosslands site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.27 Map of Farmland site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.28 Map of Farmland site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.29 Map of Calna Creek site showing vulnerability levels for *Juncus kraussi* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.30 Map of Calna Creek site showing vulnerability levels for *Juncus kraussi* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

All figures are 2 pages.

Key to layout:

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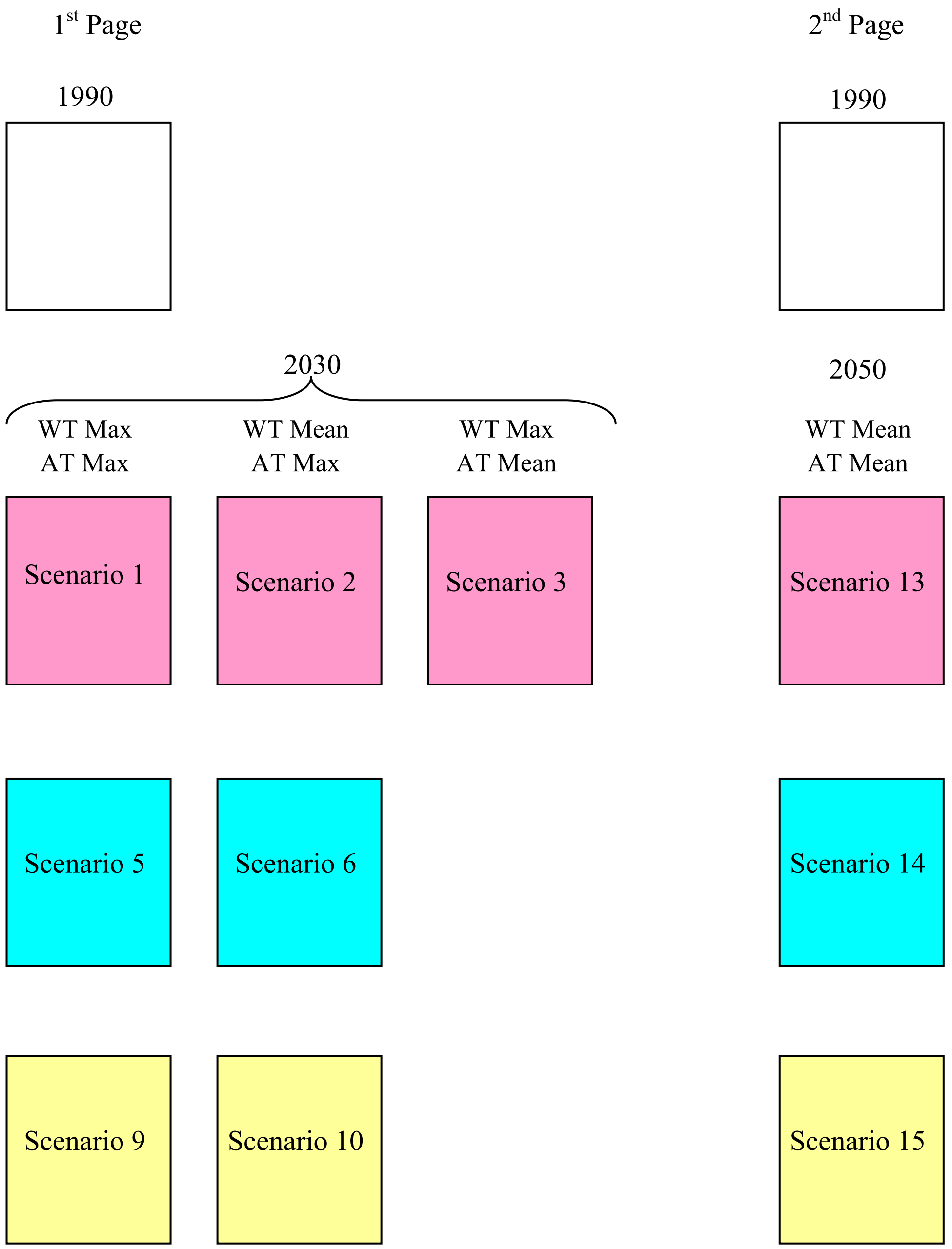
Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11 and 12 not shown as their results did not differ from the other scenarios within their sea level group. See text for explanation.



The following pages contain Figures 7.31 – 7.54 which are the maps of vulnerability levels for *S. virginicus* saltmarsh habitat. Only sites with vulnerability levels greater than low are presented. Due to the layout and size of these figures, captions for each figure are given below. All figures are two pages and the layout for each page is presented in the diagram on the following page. The layout is the same for each site.

Figure 7.31 Map of One Tree Reach site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.32 Map of One Tree Reach site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.33 Map of Courangra Point site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.34 Map of Courangra Point site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.35 Map of Gentlemans Halt site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.36 Map of Gentlemans Halt site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.37 Map of Pumpkin Creek site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.38 Map of Pumpkin Creek site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.39 Map of Seymores Creek site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.40 Map of Seymores Creek site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.41 Map of Brooklyn site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.42 Map of Brooklyn site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.43 Map of Big Bay site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.44 Map of Big Bay site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.45 Map of Coba Bay site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.46 Map of Coba Bay site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.47 Map of Crosslands site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.48 Map of Crosslands site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.49 Map of Popran Creek site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.50 Map of Popran Creek site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.51 Map of Farmland site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.52 Map of Farmland site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.53 Map of Calna Creek site showing vulnerability levels for *Sporobolus* saltmarsh during summer for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

Figure 7.54 Map of Calna Creek site showing vulnerability levels for *Sporobolus* saltmarsh during winter for scenarios 1, 2, 3, 5, 6, 9, 10, 13-15 compared to 1990.

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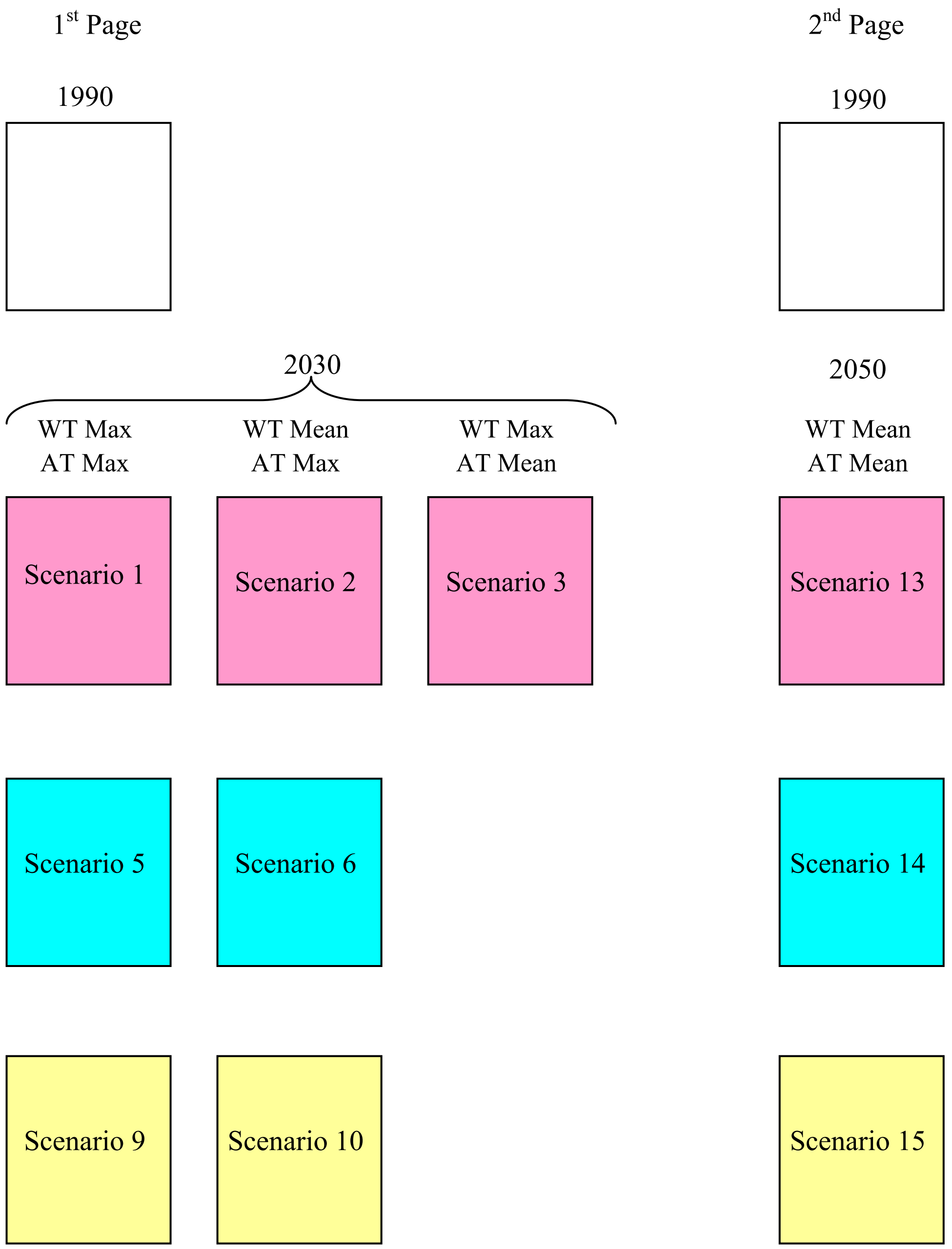

5.4. Stage 4 – Priority Action Assessment

Prioritisation of where the most effective responses to managing estuarine habitats in the face of the potential effects of climate change was determined using the results for the maximum SLR scenarios for both years. These presented the worst case scenarios for sea level rise, water temperature and air temperature. For each habitat the sites with the highest vulnerability and highest resilience levels were selected first, then sites with second highest resilience levels and so on. Thus management action could then be directed to sites that have the potential for the greatest opportunity for successful adaptation to the effects of climate change. There was insufficient information at a site level to prioritise which NCHS would be efficacious to address. However, the purpose of the focus action tables presented below is to list the potential effects of each NCHS and therefore give management both a guide and a means of justifying which actions (or no actions) they choose to take.

For each site identified, the NCHS measures calculated in Section 5.3.1 at the small and large spatial scale that were contributing to its level of vulnerability were extracted. The potential effects each type of NCHS could have on the capacity of a habitat at that site to respond to climate change were identified. The following descriptions focus only on sites within the HSC boundary, and hence do not address sites on the northern side of the estuary.

5.4.1. Seagrass

Cowan Creek, below Bobbin Head had the highest level of vulnerability for seagrass under both scenarios of moderate-high (Table 5.34). However, seagrass (represented by *Z. capricorni* only) was the most resilient here due to the potential for it to expand or shift further upstream and its moderate vegetative growth form. This patch also makes up a substantial proportion of the seagrass within the Cowan sub-catchment, indicating it may have an important role as a source of genetic diversity for other patches within Cowan. At the small spatial scale the Bobbin Head marina is in close proximity. This could be a source of increased turbidity from boat traffic potentially impacting growth and density of the seagrass bed at this site. At the larger spatial of the Cowan sub-catchment, there were five different human activities with a collective of nine stressors. The potential effects of these stressors on seagrass habitats within the sub-catchment include decreased growth and density, reduced reproductive output and contraction of spatial area.

Table 5.34 Focus action table for seagrass at Cowan Creek site.

H – high, MH – moderate-high, M – moderate, L – low

Site:	Cowan, Bobbin Head
Habitat:	Seagrass
Area (Ha):	2.81
Prop'n of Sub-catch:	0.20
Historic % Change: (1940-2000)	-100.00

	Summer	Winter
Resilience - 2030:	MH	MH
Resilience - 2050:	M	MH
Vulnerability:	MH	MH

NCHS Scale	Stressor		Measure	Potential effects on adaptive capacity
10m	Prop'n marinas over all sites		0.10	Reduced growth & density by - increased turbidity decreasing light availability; damage from propeller scaring
	Marina # per Ha of habitat		0.36	
Sub-catchment	Prop'n NCHS		0.71	
	Prop'n Susceptible		0.20	
	Recreational fishing	Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompeting for space
	Aquatic recreation	Proportion of public access points within 10m of habitat	0.571	Reduced growth & density by - increased turbidity decreasing light availability; damage from propeller scaring/trampling
		Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space
	Stormwater & catchment runoff	Proportion of urban, industrial & commercial landuse to water surface area of bay	0.375	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Foreshore development	Proportion of artifical rockwall within 10m of habitat	0.643	Reduced growth & density by - increased localised water turbulence
		Proportion of housing blocks (unsewered) within 10m of habitat	0.310	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms
		Proportion of wharves & jetties within 10m of habitat	0.163	Reduced growth & density by - increased turbidity decreasing light availability; damage from propeller scaring/trampling
		Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space
	Commercial vessels	Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space

Seagrass at Dangar Island had a moderate level of vulnerability and moderate resilience in summer and moderate-high resilience in winter. This patch is a substantial proportion of the total seagrass habitat found in the fluvial reach of the estuary (Table 5.35). Given its position in the middle of the estuary with large tidal currents running across and around the bed, it may be an important source of genetic diversity for other seagrass patches in the sub-catchments and upstream reaches. At the small spatial scale its potential stressors consist of the high concentration of marinas and unsewered housing blocks. At the larger spatial scale recreational fishing, aquatic recreation, sewage treatment and ferry services could affect its growth and density.

Table 5.34 Focus action table for seagrass at Dangar Island site.
H – high, MH – moderate-high, M – moderate, L – low

Site:	Dangar Is	
Habitat:	Seagrass	
Area (Ha):	12.23	
Prop'n of Sub-catch:	0.42	
Historic % Change: (1940-2000)	390.39	
	Summer	Winter
Resilience - 2030:	M	MH
Resilience - 2050:	M	MH
Vulnerability:	M	M

NCHS Scale	Stressor		Measure	Potential effects on adaptive capacity
10m	Propn marinas over all sites		0.50	Reduced growth & density by - increased turbidity decreasing light availability; damage from propeller scaring
	Marina # per Ha of habitat		0.409	
	Propn unsewered housing blocks over all sites		0.24	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Unsewered housing # per Ha of habitat		1.31	
Sub-catchment	Propn NCHP		0.86	
	Proportion Suscpt		0.23	
	Recreational fishing	Annual ('08/'09) shore fishing hours per length of foreshore of bay	717.17	Reduced growth & density by - damage from trampling
		Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space
	Aquatic recreation	Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space
	Foreshore development	Proportion of habitat area within 10m of oyster lease	0.20	Impaired propagule dispersal by - changed tidal flow & obstruction from instream structures
		Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space
	Sewage outfalls/ treatment	Number of STP in bay and/or upstream	>4	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Commercial vessels	Frequency of ferry services per day (car or passenger)	17	Reduced growth & density by - increased turbidity decreasing light availability; damage from propeller scaring/trampling
		Vector for non-native invasive species	Yes	Decreased area, reproductive output by - plant invasives outcompete for space

5.4.2. Mangroves

The mangroves at One Tree Reach and Farmland sites (represented by *A. marina*) had moderate-high levels of vulnerability but a moderate-high level of resilience. At the small spatial scale they have a high proportion of farm land surrounding the mangrove habitat and a road both of which would affect the mangroves capacity to shift further inland (Table 5.35, 3.36). However, the farmland also presented the largest potential area of all sites available for mangroves to shift into if conditions were suitable. At the larger spatial scale there were seven human activities with a collective 14 stressors. Of particular relevance to these two sites were the potential effects from the groundwater pressure in the riverine reach. This may affect, either positively or negatively, the wetland hydrological processes that control surface elevation levels at these sites, which play and important role in capacity of mangroves to respond to the effects of climate change.

Table 5.35 Focus action table for mangroves at One Tree Reach site.

H – high, MH – moderate-high, M – moderate, L – low, VH – very high

Site:	One Tree Reach
Habitat:	Mangrove
Area (Ha):	3.48
Prop'n of Sub-catch:	0.014
Historic % Change: (1940-2000)	NC

	Summer	Winter
Resilience - 2030:	MH	MH
Resilience - 2050:	MH	MH
Vulnerability:	MH	MH

NCHS Scale	Stressor		Measure	Potential effects on adaptive capacity
10m	Propn wharves over all sites		0.14	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
	Wharf # per Ha of habitat		0.57	
	Farm area Ha		12.10	Prevents expansion or upslope shift by - clearing & blockages of channels
	Prop'n farm area		0.78	
Sub-catchment	Propn NCHS		0.71	
	Proportion Susceptible		0.23	
	Recreational fishing	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal
	Aquatic recreation	Proportion of public access points within 10m of habitat	0.429	Reduced establishment & growth of seedlings by - damage from trampling
		Proportion of habitat within a no wash zones	0	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Foreshore development	Proportion of artifical rockwall within 10m of habitat	0.654	Reduced growth & density by - increased localised water turbulence
		Proportion of housing blocks (unsewered) within 10m of habitat	0.357	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
		Proportion of wharves & jetties within 10m of habitat	0.689	
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Commercial vessels	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Sewage outfalls/treatment	Number of STP in bay and/or upstream	>3	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Commercial vessels	Frequency of ferry services per day (car or passenger)	Cont.	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
	Groundwater pressures	Landuse	H	Increased exposure to inundation by - reduced surface elevation from increased groundwater extraction
		Localised impact	M	
		Aquifer structure	VH	

Table 5.36 Focus action table for mangroves at Farmland site.

H – high, MH – moderate-high, M – moderate, L – low, VH – very high

Site:	Farmland
Habitat:	Mangrove
Area (Ha):	2.02
Prop'n of Sub-catch:	0.008
Historic % Change: (1940-2000)	NC

	Summer	Winter
Resilience - 2030:	MH	MH
Resilience - 2050:	MH	MH
Vulnerability:	MH	MH

NCHS Scale	Stressor		Measure	Potential effects on adaptive capacity
10m	Propn unsewered housing blocks over all site		0.03	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms;
	Unsewered housing # per Ha		0.99	
	Propn wharves over all sites		0.07	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
	Wharf # per Ha of habitat		0.49	
	Propn farmland boundary closest to site (m)		0.11	Prevents expansion or upslope shift by - clearing & blockages of channels
	Farm area Ha		12.74	
	Prop'n farm area		0.86	
Sub-catchment	Propn NCHS		0.71	
	Proportion Susceptible		0.23	
	Recreational fishing	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Aquatic recreation	Proportion of public access points within 10m of habitat	0.429	Reduced establishment & growth of seedlings by - damage from trampling
		Proportion of habitat within a no wash zones	0	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Foreshore development	Proportion of artifical rockwall within 10m of habitat	0.654	Reduced growth & density by - increased localised water turbulence
		Proportion of housing blocks (unsewered) within 10m of habitat	0.357	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
		Proportion of wharves & jetties within 10m of	0.689	
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Commercial vessels	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Sewage outfalls/treatment	Number of STP in bay and/or upstream	>3	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Commercial vessels	Frequency of ferry services per day (car or passenger)	Cont.	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
	Groundwater	Landuse	H	Increased exposure to inundation by - reduced surface elevation from increased groundwater extraction
		Localised impact	M	
		Aquifer structure	VH	

Mangroves at Seymores Creek also had moderate-high levels of vulnerability with moderate resilience in summer and moderate-high resilience in winter (Table 5.37). At the small spatial scale the site has one of the highest concentrations of NCHS which could affect mangrove stability by erosion, growth and establishment of seedlings and cause tree damage. At the larger spatial scale the site is situation in the estuary with the highest number of different human activities including stormwater outlets, marinas and unsewered housing blocks. There is some scope for expansion inland but it is very limited.

Table 5.37 Focus action table for mangroves at Seymores Creek site.

H – high, MH – moderate-high, M – moderate, L – low, VH – very high

Site:	Seymores Creek	
Habitat:	Mangrove	
Area (Ha):	4.83	
Prop'n of Sub-catch:	0.024	
Historic % Change: (1940-2000)	NC	
	Summer	Winter
Resilience - 2030:	M	MH
Resilience - 2050:	M	MH
Vulnerability:	MH	MH

NCHS Scale	Stressor		Measure	Potential effects on adaptive capacity
10m	Propn marinas over all sites		0.20	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
	Marina # per Ha		0.41	
	Propn boat ramps over all sites		0.33	Reduced establishment & growth of seedlings by - damage from trampling
	Boat ramps # per Ha		0.21	
	Propn artifical rockwall over all sites		0.38	Erosion of sediment by - increased localised water turbulence
	Propn unsewered housing blocks over all site		0.18	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Unsewered housing # per Ha		2.48	
Sub-catchment	Propn NCHS		0.86	
	Proportion Susceptible		0.30	
	Recreational fishing	Annual ('08/'09) shore fishing hours per length of foreshore of bay	717.17	Reduced establishment & growth of seedlings by - damage from trampling
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Aquatic recreation	Proportion of public access points within 10m of habitat	0.455	Reduced establishment & growth of seedlings by - damage from trampling
		Number of marinas within 10m of a habitat	1	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Foreshore development	Proportion of artifical rockwall within 10m of habitat	0.321	Erosion of sediment by - increased localised water turbulence
		Proportion of housing blocks (unsewered) within 10m of habitat	0.188	Decreased growth by - elevated nutrients increasing epiphytic growth & algal blooms; Decreased reproductive output by - increased freshwater flows changing salinity regimes
		Proportion of wharves & jetties within 10m of a habitat	0.192	Tree damage & impaired propagule dispersal by - localised turbulence from boat wash
		Porportion of oyster leases within 10m of a habitat	0.192	Impaired propagule dispersal by - changed tidal flow & obstruction from instream structures
		Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Commercial vessel	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Groundwater pressures	Landuse	H	Increased exposure to inundation by - reduced surface elevation from increased groundwater extraction
		Localised impact	M	
		Aquifer structure	VH	

5.4.3. Saltmarsh

Saltmarsh at Courangra Point had a moderate-high level of vulnerability and a moderate level of resilience (represented by *J. krausii*) (Table 5.38). The saltmarsh at this site is approximately a third of the total saltmarsh habitat occurring in the riverine reach of the estuary. Therefore, it could have a substantial role as a source of genetic diversity to other saltmarsh habitat in the reach and may contribute significantly to the overall reproductive output of this habitat type in the area. At the small spatial scale it only has one NCHS, that of farmland. The proportion of potential expandable area was just under half the area of saltmarsh, suggesting farmland maybe an opportunity to allow the habitat to shift and/or expand into in response to the effects of climate change. At the large spatial scale this reach had a relatively low concentration of NCHS. However, groundwater pressures were relatively high and this may have a significant effect on surface elevation dynamics which affects the ability of saltmarsh to take advantage of any opportunities to shift further landward.

Table 5.38 Focus action table for saltmarsh at Courangra Point site.

H – high, MH – moderate-high, M – moderate, L – low, VH – very high

Site:	Couranga Point
Habitat:	Saltmarsh
Area (Ha):	39.60
Prop'n of Sub-catch:	0.369
Historic % Change: (1940-2000)	-37.26

	Summer	Winter
Resilience - 2030:		
Juncus	M	M
Sporobulus	L	L
Resilience - 2050:		
Juncus	M	M
Sporobulus	L	L
Vulnerability:		
Juncus	MH	MH
Sporobulus	MH	MH

NCHS Scale	**Stressor**		**Measure**	**Potential effects on adaptive capacity**
10m	Propn farmland boundary closest to site (m)		0.68	Prevents expansion or upslope shift by - clearing, barriers & soil modification;
	Farm area Ha		19.67	
	Prop'n farm area		0.33	Impaired seedling establishment by - facitating terrestial invasion of plant species downslope
Sub-catchment	Propn NCHS		0.43	
	Proportion Susceptible		0.07	
	Foreshore development	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Sewage outfalls/ treatment	Number of STP in bay and/or upstream	>3	Decreased growth by - elevated nutrients Impaired reproductive output by - increased freshwater flows changing salinity regimes
	Groundwater pressures	Landuse	H	Increased exposure to inundation by - reduced surface elevation from increased groundwater extraction
		Localised impact	M	
		Aquifer structure	VH	Impaired establishment of seedlings by - lowered water levels or poor water quality

Saltmarsh at Pumpkin Creek similarly had a moderate-high level of vulnerability and moderate resilience (Table 5.39). This habitat patch represented over 40% of the saltmarsh in the fluvial reach. However, its position in a relatively narrow valley and small creek, may limit its contribution to genetic diversity to other saltmarsh habitats. At the small the small spatial scale it has a very low concentration of NCHS, with only a small farmland boundary close to the site. There is a small area for potential expansion or shifting. At the large spatial scale there is not a large number of NCHS but groundwater pressures are high and could affect its capacity to respond to the effects of climate change.

Table 5.39 Focus action table for saltmarsh at Pumpkin Creek site.

H – high, MH – moderate-high, M – moderate, L – low, VH – very high

Site:	Pumpkin Creek
Habitat:	Saltmarsh
Area (Ha):	8.10
Prop'n of Sub-catch:	0.424
Historic % Change: (1940-2000)	-85.18

	Summer	Winter
Resilience - 2030:		
Juncus	M	M
Sporobulus	L	L
Resilience - 2050:		
Juncus	M	M
Sporobulus	L	L
Vulnerability:		
Juncus	MH	MH
Sporobulus	MH	MH

NCHS Scale	**Stressor**		**Measure**	**Potential effects on adaptive capacity**
10m	Propn over all sites farmland boundary closest to site		0.03	Impaired seedling establishment by - facitating terrestial invasion of plant species downslope
Sub-catchment	Propn NCHS		0.57	
	Proportion Susceptible		0.09	
	Foreshore development	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Sewage outfalls/ treatment	Number of STP in bay and/or upstream	>3	Decreased growth by - elevated nutrients Impaired reproductive output by - increased freshwater flows changing salinity regimes
	Groundwater pressures	Landuse	H	Increased exposure to inundation by - reduced surface elevation from increased groundwater extraction
		Localised impact	M	
		Aquifer structure	VH	Impaired establishment of seedlings by - lowered water levels or poor water quality

Big Bay has saltmarsh habitat at either end of its two most inland points and are therefore similar in nature to the saltmarsh habitat in Pumpkin Creek (Table 5.40). The vulnerability of saltmarsh at Big Bay was moderate-high and its resilience moderate. It is a smaller proportion of the total saltmarsh habitat in the Berowra sub-catchment than Pumpkin Creek and has a only a limited area for expansion, despite having no small scale NCHS. At the larger spatial scale there were six NCHS half of these being groundwater pressures.

Table 5.40 Focus action table for saltmarsh at Big Bay site.

H – high, MH – moderate-high, M – moderate, L – low, VH – very high

Site:	Big Bay
Habitat:	Saltmarsh
Area (Ha):	3.634
Prop'n of Sub-catch:	0.268
Historic % Change: (1940-2000)	-80.98

	Summer	Winter
Resilience - 2030:		
Juncus	M	M
Sporobulus	L	L
Resilience - 2050:		
Juncus	M	M
Sporobulus	L	L
Vulnerability:		
Juncus	MH	MH
Sporobulus	MH	MH

NCHS Scale	Stressor		Measure	Potential effects on adaptive capacity
10m	Nil			
Sub-catchment	Propn NCHS		0.71	
	Proportion Susceptible		0.16	
	Foreshore development	Vector for non-native invasive species	Yes	Impaired reproductive output by - seed predation from animal invasives
	Stormwater & catchment runoff	Proportion of urban, industrial & commercial landuse to water	2.410	Decreased reproductive output by - increased freshwater flows changing salinity regimes
	Sewage outfalls/ treatment	Number of STP in bay	2	Decreased growth by - elevated nutrients Impaired reproductive output by - increased freshwater flows changing salinity regimes
	Groundwater pressures	Landuse	H	Increased exposure to inundation by - reduced surface elevation from increased groundwater extraction
		Localised impact	M	
		Aquifer structure	VH	Impaired establishment of seedlings by - lowered water levels or poor water quality

6. DISCUSSION AND RECOMMENDATIONS

6.1. Overall Assessment

Table 6.1 summarises all the habitat types assessed in this study as the percentage of sites with the different levels at each stage for each scenario. From this table we gain the following overall picture of the assessments.

Based on climate change variables only, under the worst case scenarios of 1, 2, 3, and 13 for summer, only seagrass and floodplain habitats had 100% of sites with the highest risk (moderate-high and high, respectively) of loss of habitat. This was based on their exposure and sensitivity to climate change variables only. Mangroves (represented by *A. marina*) and saltmarsh (represented by *J. krausii*) had moderate to low levels of risk of loss in both seasons. When the capacity of habitats to respond to the potential effects of climate change was added, mangroves had the highest levels of resilience of all habitats. This occurred for all scenarios and seasons. Seagrass had the next highest resilience followed by saltmarsh. Incorporation of small and large scale NCHS resulted in saltmarsh having the largest percentage of sites with the highest vulnerability under all scenarios and seasons. No habitat type had a large percentage of sites with the lowest vulnerability level. Mangroves had the largest percentage of sites with moderate vulnerability.

These results suggest that when NCHS are incorporated with the potential impacts of the effects of climate change the outcomes for a habitat can be substantially altered. If the assessment was solely based on the exposure and sensitivity of habitats to climate change variables then it could have been concluded that management of seagrass beds would be of little value in the longer term. However, when the capacity to respond to changed conditions due to climate variables were added seagrass habitats showed consistently high levels of resilience. Saltmarsh, which had lower levels of risk of loss than seagrass, had lower resilience than seagrass at most sites, giving saltmarsh a higher priority for management. Finally, when NCHS were incorporated all habitats had increased vulnerability to being negatively affected by climate change disturbances to varying extents. The four staged assessment also revealed windows of opportunity where management action might be effective in enabling habitats to improve their level of resilience. For example, rehabilitating potential areas for habitats to expand or move into or increasing the protection of seagrass beds at some sites. However, all these results need to be treated with caution and take the following limitations of this study into account

Table 6.1. Summary of all stages in the vulnerability assessment for all habitats. Percentages are the number of sites with a level. H – high, MH – moderate-high, M – moderate, L – low, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level.

Habitat: Seagrass
Species: Zostera

Season	Stage	Level	Scenario 1	2	3	5	6	9	10	13	14	15
Summer	Risk	% MH	100.0	100.0	100.0	20.0	20.0	0.0	0.0	100.0	60.0	20.0
		% M	0.0	0.0	0.0	80.0	80.0	80.0	80.0	0.0	40.0	80.0
		% L	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0	0.0
	Resilience	% MH	20.0	20.0	20.0	80.0	80.0	100.0	100.0	0.0	40.0	80.0
		% M	80.0	80.0	80.0	20.0	20.0	0.0	0.0	100.0	60.0	20.0
		% L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Vulnerability	% MH	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
		% M	60.0	60.0	60.0	60.0	60.0	40.0	40.0	60.0	60.0	60.0
		% L	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0	0.0
Winter	Risk	% MH	40.0	40.0	40.0	0.0	0.0	0.0	0.0	60.0	20.0	0.0
		% M	60.0	60.0	60.0	80.0	60.0	60.0	40.0	40.0	80.0	60.0
		% L	0.0	0.0	0.0	20.0	40.0	40.0	60.0	0.0	0.0	40.0
	Resilience	% H	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0	0.0
		% MH	60.0	60.0	60.0	100.0	100.0	80.0	80.0	60.0	100.0	100.0
		% M	40.0	40.0	40.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0
	Vulnerability	% MH	40.0	40.0	40.0	20.0	20.0	20.0	0.0	40.0	40.0	20.0
		% M	60.0	60.0	60.0	80.0	80.0	60.0	80.0	60.0	60.0	60.0
		% L	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0	20.0

Habitat: Mangroves
Species: Avicennia

SEASON	Stage	Level	Scenario 1	2	3	5	6	9	10	13	14	15
Summer	Risk	% MH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		% M	55.6	55.6	55.6	11.1	11.1	0.0	0.0	55.6	22.2	11.1
		% L	44.4	44.4	44.4	88.9	88.9	100.0	100.0	44.4	77.8	88.9
	Resilience	% MH	81.8	81.8	90.9	90.9	90.9	100.0	100.0	81.8	90.9	90.9
		% M	18.2	18.2	9.1	9.1	9.1	0.0	0.0	18.2	9.1	9.1
		% L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Vulnerability	% MH	36.4	36.4	36.4	36.4	36.4	27.3	27.3	36.4	36.4	36.4
		% M	54.5	54.5	54.5	54.5	54.5	63.6	63.6	54.5	54.5	54.5
		% L	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Winter	Risk	% MH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		% M	20.0	20.0	20.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0
		% L	80.0	80.0	80.0	100.0	100.0	100.0	100.0	80.0	100.0	100.0
	Resilience	% H	0.0	0.0	0.0	9.1	9.1	9.1	9.1	0.0	9.1	9.1
		% MH	90.9	90.9	90.9	90.9	90.9	90.9	90.9	90.9	81.8	90.9
		% M	9.1	9.1	9.1	0.0	0.0	0.0	0.0	9.1	9.1	0.0
	Vulnerability	% MH	36.4	36.4	36.4	27.3	27.3	18.2	18.2	36.4	27.3	27.3
		% M	54.5	54.5	54.5	54.5	54.5	54.5	54.5	54.5	63.6	54.5
		% L	9.1	9.1	9.1	18.2	18.2	27.3	27.3	9.1	9.1	18.2

Habitat: Saltmarsh
Species: Juncus

SEASON	Stage	Level	Scenario 1	2	3	5	6	9	10	13	14	15
Summer	Risk	% MH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		% M	50.0	50.0	50.0	12.5	12.5	0.0	0.0	50.0	25.0	12.5
		% L	50.0	50.0	50.0	87.5	87.5	100.0	100.0	50.0	75.0	87.5
	Resilience	% MH	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
		% M	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9	88.9
		% L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Vulnerability	% MH	50.0	50.0	60.0	60.0	60.0	60.0	60.0	50.0	50.0	60.0
		% M	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
		% L	10.0	10.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	0.0
Winter	Risk	% MH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		% M	22.2	22.2	22.2	0.0	0.0	0.0	0.0	22.2	0.0	0.0
		% L	77.8	77.8	77.8	100.0	100.0	100.0	100.0	77.8	100.0	100.0
	Resilience	% MH	11.1	11.1	11.1	11.1	11.1	22.2	22.2	11.1	11.1	11.1
		% M	88.9	88.9	88.9	88.9	88.9	77.8	77.8	88.9	88.9	88.9
		% L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Vulnerability	% H	10.0	10.0	10.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0
		% MH	50.0	50.0	50.0	60.0	60.0	60.0	60.0	50.0	60.0	60.0
		% M	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Habitat: Floodplain forest

SEASON	Stage	Level	Scenario 1	2	3	5	6	9	10	13	14	15
Summer	Risk	% H	100.0	100.0	100.0	66.7	66.7	0.0	0.0	100.0	66.7	66.7
		% MH	0.0	0.0	0.0	33.3	33.3	100.0	100.0	0.0	33.3	33.3
Winter	Risk	% H	66.7	66.7	66.7	0.0	0.0	0.0	0.0	66.7	33.3	0.0
		% MH	33.3	33.3	33.3	66.7	66.7	0.0	0.0	33.3	33.3	66.7
		% M	0.0	0.0	0.0	33.3	33.3	33.3	33.3	0.0	33.3	33.3
		% L	0.0	0.0	0.0	0.0	0.0	66.7	66.7	0.0	0.0	0.0

6.2. Limitations of the study

6.2.1. Hydrological modelling

Whilst the estuarine physical processes and dynamics for all scenarios were modelled well by the hydrodynamic model it was limited to using fixed catchment inputs and the average rainfall for 1990, due to run-times and resources. Therefore, the same temporal pattern of catchment inputs was reproduced in all the climate change scenarios. Climate change is predicted to affect rainfall patterns and volumes, although there are large variations in both positive and negative directions. As noted in Chapter 4 the Hawkesbury Estuary Elcom model is capable of dynamically interfacing with catchment models that capture temporal and spatial variability in rainfall and their manifestation as freshwater flows into the estuary. Although the Hawkesbury catchment is large and complex, development of a catchment model or even sub-catchment models would enable the hydrodynamic model to run a greater range of climate change scenarios incorporating the effects on rainfall and storm patterns (given appropriate timeframes and resources to do so). This would allow outputs on a larger range of variables such as turbidity and flow velocities. These variables would assist in determining how estuarine habitats might be affected by sediment deposition and erosion, light availability and small and large scale temporal variability is salinity.

The grid size of the cells used in the hydrodynamic model did not always match the size of the habitat patches examined. Sometimes the grid cells were larger and some were smaller than the habitat patch. This meant that the outputs from the grid cell located at each site, may not be representative of what each habitat at a site could be exposed to. Using smaller grid cells and obtaining outputs for more than one grid cell at each site would require much more intensive modelling and longer run-times than current resources allow. However, it might be useful to determine whether this would be feasible for a few sites that HSC are particularly interested in.

6.2.2. Exposure estimates

The thresholds used to determine the duration and magnitude of exposure to each variable were mainly averages taken from a few scientific studies; not enough to perform a meta-analysis of the data to get estimates of variability. Using a single value for a variable to define a hard edge to a threshold does not adequately reflect the natural variability in space and time of the environments species live in. Therefore, the exposure levels calculated in this study should not be taken as definitive but as an indication of the types of exposures species might have to deal with. Clearly, exposure levels would change if different threshold levels were used.

Another limitation was the lack of scientific studies on the biophysical and ecological effects of changes to different variables on individual species, particularly Australian species. There were few experimental studies that specifically examined the responses of species to variables that are affected by climate change, such as salinity, water temperature and inundation. Those that did were usually for non-Australian species (Charles and Dukes 2009). These types of studies on Australian species would greatly enhance our ability to predict how habitats might be affected by climate change and their level of resilience to these effects.

Exposure levels were determined under the assumption that the climate change variables used were additive in their effect. However, in real environments variables interact dynamically. For example, increased air temperature will increase evaporation, changing salinity regimes at localised scales. Changes in salinity can produce changes to density and thermoclines of the water column. These types of interactions make predictions about their effects on estuarine habitats difficult. The assumption of additive effects was the simplest way of incorporating the combined effects in the absence of detailed knowledge about how more complex interactions manifest themselves in the Hawkesbury estuary.

6.2.3. *Sensitivity estimates*

As with the estimates for exposure, there were few studies on Australian species to draw on to determine the sensitivity of species to climate change variables. Sensitivity levels would change if a different set of criteria were used to estimate them. However, in the absence of more complete information the sensitivities represent the best integration of the knowledge on species available.

6.2.4. *Resilience estimates*

For mangrove and saltmarsh habitats the major limitation in determining their resilience was the lack of information about surface elevation dynamics. Surface elevation is governed by complex and interacting above- and below-ground hydrodynamic processes (Cahoon et al., 2011). The rate of surface elevation increase or decrease is an important aspect of the capacity of saltmarsh and mangrove habitats to respond to one of the aspects of climate change – sea level rise. There have been a few studies that have collected surface elevation data at some sites in the Hawkesbury (ACU, 2005). They show that there were substantial differences among sites and between habitat types in the rate of surface elevation change, This suggests that the above- and below-ground hydrodynamic processes do not operate uniformly within an estuary and therefore site specific information is needed to adequately estimate the capacity of saltmarsh and mangrove habitats to respond to climate change variables. Unfortunately, this type of information takes a long time to collect and was outside the scope of this present study. However, a better estimate the resilience of saltmarsh and mangrove habitats on a site specific basis would need this type of information.

The biological and ecological characteristics of species used to determine their capacity to respond to the effects of climate change assumed that the characteristics will remain unchanged over the next 20 to 40 years. However, there is evidence in other studies that these characteristics may slowly adapt to a gradually changing environment (Waycott, 2000). Consequently, a species' level of resilience to the effects of climate change may improve over a long time period and be different to what has been estimated in this study. Furthermore, as our understanding of how habitats respond to the effects of a changing environment other biological and ecological characteristics of species maybe included and others removed, which would also change their level of resilience.

There were few studies that provided quantitative information about the biological and ecological characteristics of Australian species relevant in determining a species' resilience. Information about the proportion of flowering plants in a population, seed dispersal distances, germination conditions and rates of success, seedling survival and growth rates and recruitment requirements was sparse. One of the exceptions was for the two species of mangrove. Ecological studies done in the early 1990's by Clarke (Clarke and Allaway 1993; Clarke 1994) collected exactly this type of information, long before climate change was high on the agenda. Equivalent studies are needed for other estuarine habitat species (e.g. Inglis, 2000; Inglis and Lincoln Smith, 1998) to provide a better understanding of the capacity of habitats to respond to the effects of climate change.

6.2.5. *Vulnerability estimates*

The limitations of the NCHS identified in this study are the same as those in the ecological risk assessment study for the Hawkesbury (Astles et al., 2010). The stressors used were mostly surrogates for more direct disturbances. For example, the number of parks within 10m of a habitat was a surrogate for trampling and gross pollution disturbances. These surrogates had to be used in the absence of more direct measures, such as the number of people using a park and the proportion of those people walking through mangrove habitats adjacent to parks over a specified time. Therefore, it should be noted in this study that the connection of a stressor with a site does not automatically mean that it has a negative impact on the habitats at that site. It only indicates that there is a potential for that stressor to be exerting a pressure on those habitats. As for the ecological risk assessment, a quantitative assessment is required about the condition of those habitats where stressors have been identified that are potentially contributing to its vulnerability to the effects of climate change.

The link between NCHS and their effects on the capacity of a species to respond to a changed environment is also assumed. The effects of NCHS have on habitats and how these effects then flow-on to influence a habitat's level of resilience requires targeted experimental studies. However, the assumption of the link is not without grounds, as studies done elsewhere on other habitat types suggest that this is occurring (Walther, 2010). It more precautionary to assume that NCHS do affect a habitat's resilience to the effects of climate change and provide management agencies with much clearer guidance about what they can do to manage their natural resources in the face of a changing climate.

6.2.6. Habitat connectivity

The assessment was done on habitats as separate patches. However, the connectivity among estuarine habitat patches and different habitat types is important in the overall functioning of estuaries. Our understanding of how these connectivities occur at different spatial and temporal scales is still developing. Therefore, assessing the effects of climate change on these connectivities would be highly uncertain. However, it would be important to examine the condition of habitats within the Hawkesbury estuary where natural connectivities have been fragmented, such as at One Tree Reach, compared to those that are still relatively intact, such as Big Bay. Potentially, the effects of climate change may be exacerbated at sites where connectivity, at least at the adjacent spatial scale, has become fragmented. Therefore, one possible management response that might contribute to enhancing the resilience of habitats is to restore some level of connectivity between adjacent habitat types.

6.3. Recommendations

The following recommendations are listed in order of priority. These recommendations are in addition to those contained in Chapter 4 from the hydrodynamic modelling.

1. Surface elevation studies should be done for mangrove and saltmarsh habitats at One Tree Reach, Courangra, Gentlemans Halt and Pumkin Creek sites.

2. A scientific and economic feasibility study should be undertaken on the rehabilitation of available land for habitat expansion for mangrove and saltmarsh habitats at One Tree Reach, Farmland and Courangra sites.

3. A detailed study be done on the effects of current human stressors on the condition and ecological function of the seagrass bed at Dangar Island and determine practical and cost-effective ways of minimising their effects.

4. The magnitude, frequency and duration of human stressors at sites with habitats that have moderate-high resilience and the quantification of the condition of those habitats should be done. Sites could include, but not be limited to, Cowan Creek, Crosslands/Calna Creek and Brooklyn.

5. Undertake field surveys to obtain height and slope data for mangroves and saltmarsh habitats at One Tree Reach, Courangra, Gentlemans Halt, Big Bay, Coba Bay and Pumpkin Creek. This data should then be used to predict changes in the distribution of these habitats under different sea level rise scenarios.

6. Source or commission the development of a suitable catchment model of the Hawkesbury that would provide catchment inputs into the estuary and be dynamically linked to the current Hawkesbury hydrological model developed for this study.

7. Ecological studies on floodplain forest, saltmarsh and seagrass species in the Hawkesbury estuary should be done to determine their reproductive output, dispersal, colonising and recruitment patterns and vegetative

growth rates and nutrient requirements. This information would provide a better understanding of their capacity to translocate to new habitats.

8. Experimental studies should be done on seagrass, saltmarsh, mangroves and floodplain forests to determine their physiological and ecological responses to different combinations of climate change variables.

9. Quantification of the condition of habitat patches that have become fragmented by NCHS should be done and compared with relatively unfragmented patches to further assess whether their level of resilience to the effects climate change may differ and identify any avenues for appropriate management action to occur.

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8. APPENDICES

8.1. Appendix 1 - Process for calculating relative sea level rise for Hawkesbury Climate Change Project

Table A1.1 List of data components and sources used in the calculation of relative sea level rise

RSL – relative sea level, TAR – third assessment report, AR4 – fourth assessment report

Data component	Source
Global Average	IPCC TAR. Section II, Table II.5.1 Models Average
Global minimum	Hunter (2010). Adjusted projections between TAR and AR4 for 21stC decades, Appendix A Table 1
Global maximum	Hunter (2010). Adjusted projections between TAR and AR4 for 21stC decades, Appendix A Table 2
Regional SL Aust Coast, departures from global	www.oceanclimatechange.org.au – Section: Seal Level www.cmar.csiro.au/sealevel/sl_proj_regional.html - Projections for Australian Region, csv files for 2030, 2070.
Local vertical land motion	Hunter (2010). p. 336, based on Lambeck (2002)

Procedure as per CSIRO Sea Level Website: http://www.cmar.csiro.au/sealevel/sl_proj_regional.html

The following data were added together to obtain relative sea level rise:

1. Global average SL projection
2. Regional departure from global average
3. Local vertical land motion

Notes:

1. The above figures are all based on the A1B climate change scenario as this was the scenario which had the most detailed data available. The A1B scenario is one of the worst case scenarios of global warming but not the most pessimistic. A1F1 is the worst case scenario but detailed data (e.g. regional departures from global average for Australia) is not available for the purposes of this project.

2. For 2050 maximum RSL rise was set at 400 mm as per NSW Government's SLR policy Technical note. Based on procedure above the maximum was actually 384 mm. The difference is due three things – i) NSW Government figure is based on the IPCC TAR (for 2030) rather than updated with the AR4 projections, ii) NSW Government figure is based on the worst case CC scenario of A1F1, iii) a rounding adjustment.

3. SLR figures are consistent with the South East Australian Programme examining the potential impacts of climate change for the marine environment. The values cover the northern end of the study area of this programme and therefore are slightly lower to those for the southern end of the study area.

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8.2. Appendix 2 – Summary of field sampling

Table A2.1 Mean percentage cover of most abundant groups for each habitat type in $2m^2$ quadrats

			Bare		Grass		*Juncus*		Leaf litter		Mud		*Sporobolus*		*Suaeda*	
Site	Habitat	Transect	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
One Tree Reach	Mangrove	1									98	2				
		2									100	0				
	Grass land	1	68.33	13.64												
Couranga Point	Mangrove	1	35.80	21.92			11.2	9.74			50	22.36	3	2		
		2									100	0				
	Saltmarsh	1	6.67	1.67	0.17	0.17	70.67	9.46	4.17	4.17			17.50	9.55	0.83	0.83
		2	2.50	2.50			15.00	5.00	44.50	44.50			25.50	24.50		
		3					93.20	5.82								
	Saltmarsh/Casurina	1			47.50	47.50	50.00	50.00								
	Casurina Forest	1					15.25	9.45	74.75	12.94					10.00	3.54
	Grass land	1	1.11	0.73	91.67	6.51			5.56	5.56						
		2			80.44	11.60	0.11	0.11								
Pumpkin Creek	Mangrove	1					8.33	8.33			91.67	8.33				
		2									100	0				
	Saltmarsh/Casurina	1					60.00	30.55	6.67	6.67						
Poporan Creek	Mangrove	1									100	0				
		2									100	0				
	Saltmarsh	1					100	0								
		2					100	0								
		3					100	0								
		4					99.55	0.45								
	Saltmarsh/Casurina	1					83.33	16.67	16.67	16.67						
		2					83.57	7.30								
		3					97.50	2.50								

Table A2.2 Mean number of most abundant groups for each habitat type in $2m^2$ quadrats

		Acacia plants		*Avicennia* seedlings		*Avicennia* tree		Bracken fern		*Casuarina* tree		Dead casuarina sapling		Log		*Melaleuca*		*Phragmites*	
Site	Habitat	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
One Tree Reach	Mangrove			5.00	3.44	4.00	1.14							3.20	1.53				
	Grass land																		
Couranga Point	Mangrove			15.29	7.91	0.29	0.18			0.14	0.14	0.14	0.14	3.14	1.71			0.14	0.14
	Saltmarsh									0.23	0.17	0.31	0.31					0.31	0.31
	Saltmarsh/Casurina									1.00	1.00			0.50	0.50				
	Casurina Forest									2.75	0.75								
	Grass land	1.11	0.69					0.72	0.41	1.00				0.11	0.08				
Poporan Creek	Mangrove			10.75	5.59									2.50	0.29				
	Saltmarsh									0.04	0.04			0.04	0.04			0.31	0.15
	Saltmarsh/Casurina									0.50	0.25			0.21	0.15			1.79	0.58
Pumpkin Creek	Mangrove			1.67	0.92	2.17	1.17							1.17	0.40				
	Saltmarsh/Casurina									1.33	0.88			0.33	0.33	0.33	0.33	3.00	1.73

Table A2.3 Mean number of most abundant groups for each habitat type in $0.5m^2$ quadrats

			Avicennia seedlings		Crab holes		Log		Pneumatophores	
Site	Transect	Habitat	Mean	SE	Mean	SE	Mean	SE	Mean	SE
One Tree Reach	1	Mangrove	0.00	0.00	1.80	1.56	0.00	0.00	41.40	9.13
	2	Grass land	0.00	0.00	0.00		0.00	0.00	0.00	
Couranga Point	1	Mangrove	1.00	0.77	1.20	0.80	0.20	0.20	35.60	11.20
	1	Mangrove/Saltmarsh	0.50	0.50	5.00	2.00	0.00	0.00	28.00	9.00
	2	Saltmarsh	0.00	0.00	0.62	0.31	0.00	0.00	0.69	0.47
	2	Saltmarsh/Casurina	0.00	0.00	0.00		0.00	0.00	0.00	
	3	Casurina Forest	0.00	0.00	3.50	0.87	0.00	0.00	1.25	1.25
	3	Grass land	0.00	0.00	0.00		0.06	0.06	0.00	
Poporan Creek	1	Mangrove	0.25	0.25	0.00		0.00	0.00	86.75	12.36
	2	Saltmarsh	0.00	0.00	0.00		0.00	0.00	0.00	
	2	Saltmarsh/Casurina	0.00	0.00	0.29	0.29	0.07	0.07	1.79	1.14
Pumpkin Creek	1	Mangrove	0.00	0.00	0.20	0.20	0.20	0.20	55.80	2.87
	2	Saltmarsh/Casurina	0.00	0.00	0.00		0.00	0.00	0.00	

Table A2.4 Mean percentage cover of most abundant groups for each habitat types in 0.5m^2 quadrats

			Bare		**Bracken fern**		**Grass**		***Juncus***		**Leaf Litter**		**Log**		**Mud**		**Pneumatophores**		***Sporobolous***		***Suaeda***	
Site	**Transect**	**Habitat**	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
One Tree Reach	1	Mangrove							0	0	15.60	3.74	7.60	1.94	72.00	3.39	4.80	2.78	0	0	0	0
	2	Grass land					95.67	3.38	0	0	3.33	2.40	0	0	0	0	0	0	0	0	0	0
Couranga Point	1	Mangrove							0	0	6.20	1.66	0.6	0.6	88.00	1.38	5.2	1.2	0	0	0	0
	1	Mangrove/Saltmarsh							6	6	29.00	29.00	0	0	64.00	24.00	1	1	0	0	0	0
	2	Saltmarsh	0.77	0.62					77.38	8.94	13.54	6.56	0	0	0.92	0.50	0	0	7.38	6.19	0	0
	2	Saltmarsh/Casurina					40.50	40.50	43.50	43.50	16.00	3.00	0	0	0	0	0	0	0	0	0	0
	3	Casurina Forest	6.25	5.60					0	0	53.00	15.53	0	0	0	0	0	0	0	0	40.75	10.63
	3	Grass land	7.61	5.68	5.00	5.00	65.72	9.69	0	0	19.72	7.16	0.11	0.11	0	0	0	0	0	0	0	0
Poporan Creek	1	Mangrove							0	0	2.50	2.18	2.75	2.75	83.00	5.07	11.75	3.64	0	0	0	0
	2	Saltmarsh							90.92	3.42	8.96	3.42	0	0	0.08	0.08	0	0	0	0	0	0
	3	Saltmarsh/Casurina							86.93	3.21	11.71	3.30	0	0	0.14	0.14	0	0	1.21	0.84	0	0
Pumpkin Creek	1	Mangrove							0	0	11.40	4.78	0.4	0.4	79.40	5.71	8.80	1.93	0	0	0	0
	2	Saltmarsh/Casurina							98.33	1.67	1.67	1.67	0	0	0	0	0	0	0	0	0	0

8.3. Appendix 3 – Potential biological outcomes for different exposure types

Table A3.1 Definition of exposure types used in determining levels of exposure

Exposure Type	Duration	Magnitude	Changed from 1990
A	No	No	No change
B	Yes	No	Bad conditions occur more often but are not worse, i.e. not greater than the natural variability of 1990
C	No	Yes	Bad conditions do not occur more often but when they do they are worse, i.e. greater than the natural variability of 1990
D	Yes	Yes	Bad conditions occur more often and they are worse

Table A3.2 Description of potential outcomes of each exposure type for each habitat and climate change variable.

SG – seagrass, Mn – mangroves, SM – saltmarsh, FPF – floodplain forest, AT – air temperature, WT – water temperature, WD – water depth

Habitat	Variable	Exposure Type	Potential Outcomes
SG	AT	B	*Intertidal*: exposed to desiccating conditions more often and longer periods; depending on water depth it may result in leaves being burnt at very low tides or whole plants becoming desiccated leading to a decrease in above-ground biomass *Subtidal*: water in shallow areas may heat up more quickly and stay elevated for longer which may affect metabolic processes
		C	*Intertidal:* desiccating conditions are more severe; damage to leaves and shoots could occur more rapidly; could result in more patchiness or decreased density of shoots as individual plants succumb at different rates; whole beds may be affected more quickly *Subtidal*: more rapid increase in water temperature at low tide; increased rate rise may affect metabolism; may affect individual plants more than whole beds because variability in individual plant physiology and position in the bed; shallower areas more susceptible; increased patchiness
		D	*Intertidal*: desiccating conditions occur more often and are more severe; could lead to dieback of whole beds within a few tidal cycles *Subtidal*: water temperatures in shallow water will increase more rapidly and stay elevated for longer
	WT	B	*Intertidal & subtidal*: exceeds optimal growing range more often; slower growth of shoots and leaves; some dieback
		C	*Intertidal & subtidal*: exceedance of optimal temperature larger and may take longer to cool; slower vegetative growth leading to slower expansion; decrease in leaf length and shoots; seedlings may not germinate leading to slower colonization
		D	*Intertidal & subtidal*: Growth and germination disrupted more consistently; may result in reduction of bed area or density; reduced reproductive success; vegetative growth reduced

Table A3.2 cont'd

Habitat	Variable	Exposure Type	Potential Outcomes
SG	Salinity	B	Lower salinities more often; leaf death, decreased density of leaves
		C	Larger decreases in salinity; leaf death, decreased density of leaves
		D	Leaf and shoots growth affected; larger area of beds reduced density
	WD	B	Increased water depth not exposing intertidal beds to desiccating conditions as often
		C	Increased depth of subtidal beds decrease light penetration affecting photosynthesis; exacerbated in turbid conditions, decreasing growth rates
Mn	AT	B	Increased respiration more often; increased rate of tissue damage in leaves or new shoots; limits physiological processes; aerial roots may be damaged; altered flowering and germination patterns; increase growing period
		C	Growing tips and seedling growth damage or inhibited; increased tissue death in leaves reducing canopy cover; less dense, shorter aerial roots
		D	Flowering and seedling germination patterns altered, growth of new shoots reduced, dieback of trees, reduction in canopy cover; reduced capacity to expand or migrate
	WT	B	Increased respiration with increased air temperature may lead to decreased net carbon gain in root structure; less stable root structure more vulnerable to erosion or damage from trampling; less uptake of nutrients from soil; longer periods of respiration rate
		C	As for (B) but leading to more severe and wider spread effects
		D	As for (B) & (C)
	Salinity	B	Increased periods of low salinity may increase growth of seedlings; favour germination in *A. corniculatum*
		C	Lower salinity may decrease germination of *A. marina* seeds; less responsive to increases in CO_2 leading to slower growth
		D	Changes in species composition of mangrove stands
	WD	B	Inundated more frequently and for longer periods; reduce aerial root transpiration, decreasing root metabolism
		C	Inundated to a greater depth, may lead to death or decreased growth of seaward edge, especially affecting *A. corniculatucm*; *A. marina* send roots to landward edge
		D	Change in species composition of stands if *A. corniculatucm* unable to move upslope; overall landward migration of mangrove stands

Table A3.2 cont'd

Habitat	Variable	Exposure Type	Potential Outcomes
SM/FPF	AT	B	Increased length of growing season; change in flowering and reproductive cycles
		C	Increased transpiration may decrease root structure, less stable plant stands/patches; less able to take advantage of increased CO2; tissue damage in leaves, growing shoots and seedlings; FPF decrease in canopy density, more light penetration to ground cover which may favour some SM species
		D	Increased growing season maybe countered by increase in extremes in temperature leading to more dieback; less seed germination, ability to expand or colonise new areas limited
	WT	B	When inundated, longer periods when root metabolism inhibited or changed
		C	Higher temperature may cause tissue damage to stems, new shoots and seedlings
		D	More widespread damage to stems and trunks, loss of plants, root structures damaged, less stable
	Salinity	B	Increased soil salinity remains for longer, increased salt stress on root structure or less salt tolerant species
		C	Increased soil salinity may decreased seed germination and growth; increased salt stress on FPF root structure; decreased salinity may favour invasive species
		D	Changed species composition depending on whether salinity increases or decreases; more widespread dieback of plant stands
	WD	B	Extended periods inundated; increased soil saturation and salinity; salt stress more frequent
		C	Inundation deeper causing death in low growth form species; seed germination and seedling growth inhibited
		D	Change in density of plants and leaf cover; distribution either decreased because cannot move upslope or translocated to move away from deeper inundation, if other conditions favourable

8.4. Appendix 4 – Summary of exposure analyses

Table A4.1 Summary of exposure analyses of seagrass habitat for summer.

AT – air temperature, WT – water temperature, WD – water depth, Pa – *Posidonia*, Zc – *Zostera*, Ho – *Halophila*, PS – photosynthesis, gr – growth, Rg – range, Dur – duration, Mag –magnitude, Yes – exceed, NO – not exceeded, Pink – maximum sea level; Blue – mean sea level; Yellow – minimum sea level. Scenarios 4, 7, 8, 11, 12 not shown as they did not differ from the other scenarios within their sea level group.

			SCENARIO:	1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Threshold**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Summer	Cowan Bobbin Head	AT	>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WT	Pa Zc PS > 23°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			Zc gr >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WDH	Change > 10%		NO		NO		NO		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Smiths Creek, Cowan	AT	>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WT	Pa Zc PS > 23°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			Zc gr >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		NO		NO		YES		YES		YES	
		WDH	Change > 10%		NO		NO		NO		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Dangar Island	AT	>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WT	Pa Zc PS > 23°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			Zc gr >15°C	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	NO
			Ho gr >15°C																				
		WDH	Change > 10%		NO		NO		NO		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Mullet Creek upper	AT	>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WT	Pa Zc PS > 23°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Zc gr >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Ho gr >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Patonga	AT	>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WT	Pa Zc PS > 23°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			Zc gr >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Ho gr >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.2 Summary of exposure analyses of seagrass habitat for winter.

Legend same as for previous table.

				SCENARIO: 1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Threshold**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Winter	Cowan Bobbin Head	AT	>35^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	Pa Zc PS > 23^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Zc gr >15^{o}C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WDH	Change > 10%		NO		NO		NO		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Smiths Creek, Cowan	AT	>35^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	Pa Zc PS > 23^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Zc gr >15^{o}C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		NO		NO		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		YES
		WD Rg	Change > 10%		YES		YES		YES		YES		YES		YES		YES		YES		YES		YES
	Dangar Island	AT	>35^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	Pa Zc PS > 23^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Zc gr >15^{o}C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			Ho gr >15^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WDH	Change > 10%		NO		NO		NO		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Mullet Creek upper	AT	>35^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	Pa Zc PS > 23^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Zc gr >15^{o}C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Ho gr >15^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
	Patonga	AT	>35^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	Pa Zc PS > 23^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Zc gr >15^{o}C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Ho gr >15^{o}C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.3 Summary of exposure analyses of mangrove habitat for summer.

Legend same as for Table A4.1.

				Scenario																			
				1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Threshold**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Summer	One Tree Reach	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Courangra	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
	Gentlemans	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Pumpkin	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

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Table A4.3. cont'd

				Scenario																			
				1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Threshold**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Summer	Seymores	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Brooklyn	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Max	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Min	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Rg	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
	Coba Bay	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Crosslands & Calna	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Poporan	AT	*A. marina* > 33°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		AT	All > 40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	Seeding growth > 5ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
		WT	>24°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.4 Summary of exposure analyses of mangrove habitat for winter.

Legend same as for Table A4.1.

				Scenario 1		2		3		5		6		9		10		13		14		15	
Season	Site	Variable	Threshold	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag
Winter	One Tree Reach	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
	Courangra	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
	Gentlemans	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Pumpkin	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Seymores	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

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Table A4.4 cont'd.

				Scenario 1		Scenario 2		Scenario 3		Scenario 5		Scenario 6		Scenario 9		Scenario 10		Scenario 13		Scenario 14		Scenario 15	
Season	**Site**	**Variable**	**Threshold**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Winter	Brooklyn	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
	Big Bay	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		NO		NO		NO		NO		YES		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Coba Bay	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Crosslands & Calna	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Poporan	AT	*A. marina* > 33°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		AT	All > 40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	Seeding growth > 5ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		WT	>24°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.5 Summary of exposure analyses of saltmarsh habitat for summer.

Legend same as for Table A4.1; germ – germination

				Scenario																			
				1		2		3		5		6		9		10		13		14		15	
Season	Site	Variable	Thresh	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag	Dur	Mag
Summer	Courangra	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
	Gentlemans	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Pumpkin	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Seymores	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Continued next page

Table A4.5cont'd

				Scenario																			
				1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Thresh**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Summer	Brooklyn	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
			Sporobolus >7ppt	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Max	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Min	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Rg	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
	Coba Bay	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Inund	>5 cm	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Crosslands & Calna	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Inund	>5 cm	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Poporan	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*J. krausii* germ >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.6 Summary of exposure analyses of saltmarsh habitat for winter.

Legend same as for Table A4.1, germ – germination

				Scenario 1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Thresh**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Winter	Courangra	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
	Gentlemans	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Pumpkin	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
	Seymores	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
			Sporobolus >7ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Continued next page

Table A4.6 Cont'd

				Scenario																			
				1		2		3		5		6		9		10		13		14		15	
Season	**Site**	**Variable**	**Thresh**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Winter	Brooklyn	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
	Big Bay	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO
			J. krausii seedling gr >20°C	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO
			Sporobolus >7ppt	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		NO		NO		NO		NO		YES		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Coba Bay	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Crosslands & Calna	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Inund	>5 cm	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change > 10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Poporan	AT	*Casurina* seedlings > 25°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
			>35°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*J. krausii* germ >15°C	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
			J. krausii seedling gr >20°C	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Sporobolus >7ppt	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
		Inund	>5 cm	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO
		Wet/Dry	Change > 10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change > 10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change > 10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.7 Summary of exposure analyses of floodplain forest habitat for summer.

Legend same as for Table A4.1, seedl – seedling.

				Scenarios																	
				1	1	2	2	3	3	5	5	6	6	9	9	10	10	13	13	14	14	15	15
SEASON	**Site**	**Var**	**Thresh**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Summer	One Tree Reach	AT	>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*Meleluca* >30ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Meleluca seedl gr >8ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change >10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Min	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
	Brooklyn	AT	>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*Meleluca* >30ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Meleluca seedl gr >8ppt	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change >10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Max	Change >10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Min	Change >10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
		WD Rg	Change >10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
	Seymores	AT	>40°C	YES	NO	YES	NO	NO	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
		Salinity	*Meleluca* >30ppt	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
			Meleluca seedl gr >8ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change >10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change >10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

Table A4.8 Summary of exposure analyses of floodplain forest habitat for winter.

Legend same as for Table A4.1, seedl – seedling.

				Scenarios																			
				1	1	2	2	3	3	5	5	6	6	9	9	10	10	13	13	14	14	15	15
SEASON	**Site**	**Var**	**Thresh**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**	**Dur**	**Mag**
Winter	One Tree Reach	AT	>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*Meleluca* >30ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
			Meleluca seedl gr >8ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
		Wet/Dry	Change >10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change >10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		NO
		WD Min	Change >10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO
		WD Rg	Change >10%		YES		YES		YES		YES		YES		NO		NO		YES		YES		YES
	Brooklyn Oval	AT	>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*Meleluca* >30ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Meleluca seedl gr >8ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	NO	YES	NO
		Wet/Dry	Change >10%	NO		NO		NO		NO		NO		YES		YES		NO		NO		NO	
		WDH	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Rg	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
	Seymores	AT	>40°C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Salinity	*Meleluca* >30ppt	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	YES	NO
			Meleluca seedl gr >8ppt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
		Wet/Dry	Change >10%	YES		YES		YES		YES		YES		YES		YES		YES		YES		YES	
		WDH	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		NO		NO
		WD Max	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Min	Change >10%		YES		YES		YES		NO		NO		NO		NO		YES		YES		NO
		WD Rg	Change >10%		NO		NO		NO		NO		NO		NO		NO		NO		NO		NO

8.5. Appendix 5 – Matrix designs

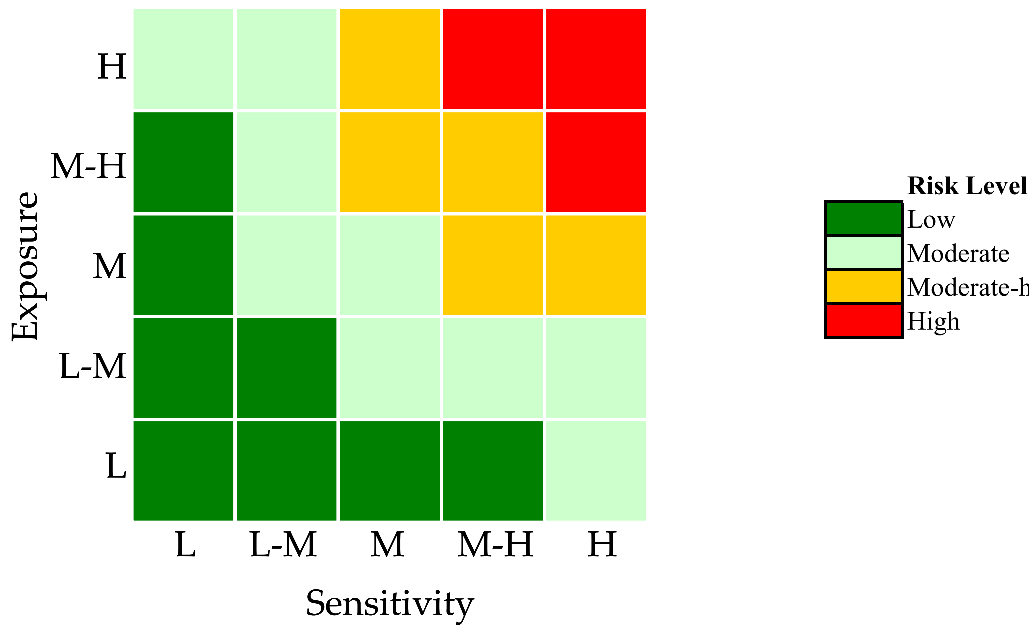

Figure A5.1 Risk matrix for stage 1.

L – low, L-M – low-medium, M – medium, M-H – medium-high, H - high

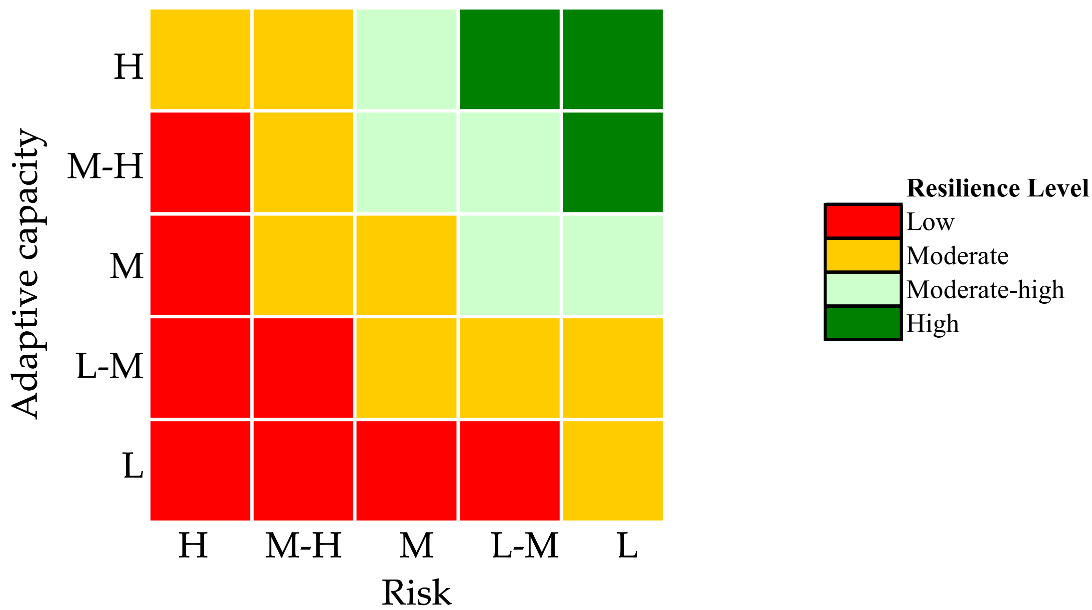

Figure A5.2 Resilience matrix for stage 2.

L – low, L-M – low-medium, M – medium, M-H – medium-high, H - high

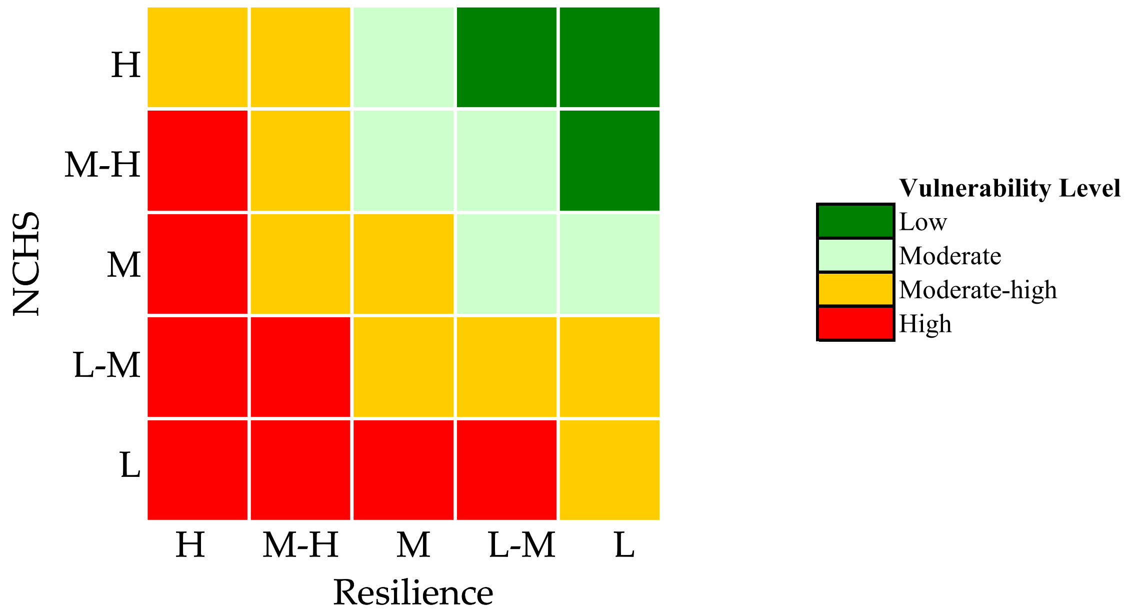

Figure A5.3 Vulnerability matrix for stage 3.

L – low, L-M – low-medium, M – medium, M-H – medium-high, H – high, NCHS – non-climatic human stressors

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