Department of **Agriculture, Fisheries and Forestry**
Fisheries Queensland

Fish habitat vulnerability mapping in coastal Queensland

Report 2: Townsville region

Queensland Government

Fish habitat vulnerability mapping in coastal Queensland

Report 2: Townsville Region

Cape Cleveland, Townsville, Queensland.

Fish habitat vulnerability mapping in coastal Queensland Report 2: Townsville Region

John Beumer [1] David Sully [1] and Dawn Couchman [2]
1. Department of National Parks, Recreation, Sport and Racing
2. Department of Agriculture, Fisheries and Forestry

July 2012

Please cite this report as:
Beumer, J P, Sully, DW and Couchman, D, 2012. Fish Habitat Vulnerability Mapping in Coastal Queensland. Report 2: Townsville Region. Queensland Government, 35pp.

For complete project results please also read the following report:
Fish Habitat Vulnerability Mapping in Coastal Queensland Report 1: Moreton Bay Region

Contents

List of tables

List of Figures

List of Images

Executive summary

Healthy fish habitats support important socio-economic activities associated with recreational, commercial and indigenous fisheries along coastal Queensland. Predicted sea level rise (SLR) as a result of accelerated climate variation will have ongoing impacts on the fisheries productivity of these habitats. Fisheries Queensland has undertaken a project which audited and mapped the vulnerability of marine vegetation communities (fish habitats) to the physical impacts of SLR. A key project objective was the incorporation of the audits within local government planning schemes to identify and establish adaptation strategies, i.e. retreat areas, to facilitate agreed landward migration of these important fish habitats.

The project has mapped the vulnerability of fish habitats in two regions in east coast Queensland, Moreton Bay and Townsville, with eight sites in Moreton Bay and four sites in Townsville, mapped under four SLR scenarios. Scenarios are based on current base-line distributions of marine vegetation (0 cm) and low (25 cm), medium (75 cm) and high (100 cm) SLR predictions. The 75 cm scenario is indicative of the 80 cm SLR of the Queensland Coastal Plan 2012. The Moreton Bay audits are the subject of a separate report (Beumer et al 2012) and are based on three models.

The methodology for high resolution mapping of changes in fish habitats due to SLR was developed in Moreton Bay and has been applied to and tested on the Townsville Region sites. It is available for local governments to apply to other regions to accommodate shifts in marine plant communities.

For the Townsville region, Models 1 and 2 have been applied. The models are:

- Model 1 – Constrained. Losses only with SLR. No ability for marine plants to move by landward colonisation due to either natural or human barriers or rate of SLR is too fast for marine plants to adapt to.
- Model 2 – Unconstrained. Losses and gains. Marine plants are able to move by landward colonisation with SLR where contours allow.

In summary, for Model 1, based on the audits from the four sites, 23% of the current marine plant communities' distribution would be lost. For Model 2, the changes range from losses of -7 to -19% to gains of +28 to + 50%. This is based on losses at TV01 and TV02, with gains at TV03 and TV04, in the extent of the marine plant community at the 100 cm SLR scenario. The overall result for Model 2 at the 100 cm SLR scenario is a slight gain of 2%.

However, this predicted gain is based on the increase of some ~1300 ha at TV04, a site that currently has high freshwater and wildlife conservation values and tourism benefits. If these values and benefits were to be protected through the construction of a bund at the current HAT line to prevent tidal intrusion from future SLR, for TV04 this would see a loss of ~ 8% of the current marine plant community distribution, as per Model 1. For the Townsville Region, the total for the four sites would be reduced to 20 264 ha; leading to an overall loss of ~ 5% at the 100 cm SLR.

1. Introduction

Marine fisheries rely heavily on healthy intertidal habitats and projected sea level rise (SLR), increasing ocean acidity, temperatures and alterations to runoff, as a result of climate variation, will have significant impacts on these fish habitats. Tidal range affects the proportion of mangroves impacted by SLR (Lovelock and Ellison, 2007). Mapping predicted changes from these impacts will enable local governments to incorporate the anticipated habitat changes into planning schemes (e.g. vegetated buffers and retreat areas), to maintain optimal fish habitat diversity for local and regional fisheries. The reported SLR of 7 mm/year since 1993 for Papua New Guinea (PCCSP 2011) confirms the urgency of a better understanding of the effects of SLR on marine plant communities.

Queensland, as a leader in the field of marine plant and related tidal habitat management is looking to better understand the impacts of climate variability and change on fish habitats and dependent fisheries resources. There has been a limited focus on marine ecosystem climate variation related research on marine ecosystems compared to research that has been conducted on terrestrial ecosystems. Fish and crab species targeted by commercial and recreational fishing depend on connected tidal wetlands for fisheries production to support catches (Meynecke et al 2008). Without adaptation such as strategic planning to accommodate shifts in habitats, climate change will have significant impacts on fish production, catch composition, coastal fishing, coastal communities and associated socio-economic benefits in Queensland.

The project delivers in part the recommendation in the Climate Change and the Great Barrier Reef: A Vulnerability Assessment (Johnson and Marshall, eds., 2007) Report, for more detailed information on the effects of SLR on mangroves and other tidal fish habitats to enable greater ability to predict future consequences of climate change impacts to coastal communities and the fishing industry. One of the management responses recommended in Chapter 9 of the Report - vulnerability of mangroves and associated tidal habitats to climate change - is specifically addressed:

> “1. Quantitative assessment of lands that will become intertidal by 2080. Digital elevation models of estuaries are needed to augment and improve the OzEstuaries (now OzCoasts) database.”

The need for systematic mapping of mangroves, seagrasses and intertidal flats, including habitat area, plant density and species composition, is also a research priority in the recently released report: Vulnerability of Tropical Pacific Fisheries to Climate Change (Bell, Johnson and Hobday, editors, 2011). This report also noted that there is a need to provide information and mapping at locally relevant scales to better enable managers to identify the fish habitats most at risk so as to focus management efforts.

The project is linked to the Fisheries Queensland Strategy and the Northern Tropical Australia Program for adaptation of fishing and aquaculture sectors to climate change. Information from the project will lead to enhanced strategic planning for coastal development and better informed decisions for climate change adaptation strategies for fish habitat managers and fishers, and build resilience for coastal communities.

Mapping the vulnerability of marine fish habitats to the physical impacts of SLR due to climate change, will generate audits of the potential change in extent of mangrove and saltmarsh communities to be incorporated into development of local government planning schemes and related planning instruments to integrate adaptation strategies for accommodating fish habitat shifts.

1.2 Project outline

The purpose of this project is to increase understanding by state and local governments, fishing industry sectors and the community of the requirement for the landward and southward shifts in marine plant communities and other associated fish habitats as a result of climate change (SLR) through incorporating the audits about predicted shifts into coastal planning. Documenting and understanding these shifts in fish habitats will facilitate identification and planning for adaptation strategies that maximise the extent, diversity and ecosystem services of fish habitats into the future.

The project has developed specific methodology for preparing high resolution vulnerability fish habitat maps for selected coastal regions. The maps are based on marine plant zone (Figure 1), digital elevation and contour data and 2009 aerial photography. A key aim of the project is to enhance coastal management through incorporation of these maps and the audits in local government planning instruments for use during development assessment processes. The methodology is able to be transferred through a data agreement so that local governments can apply it to other coastal regions.

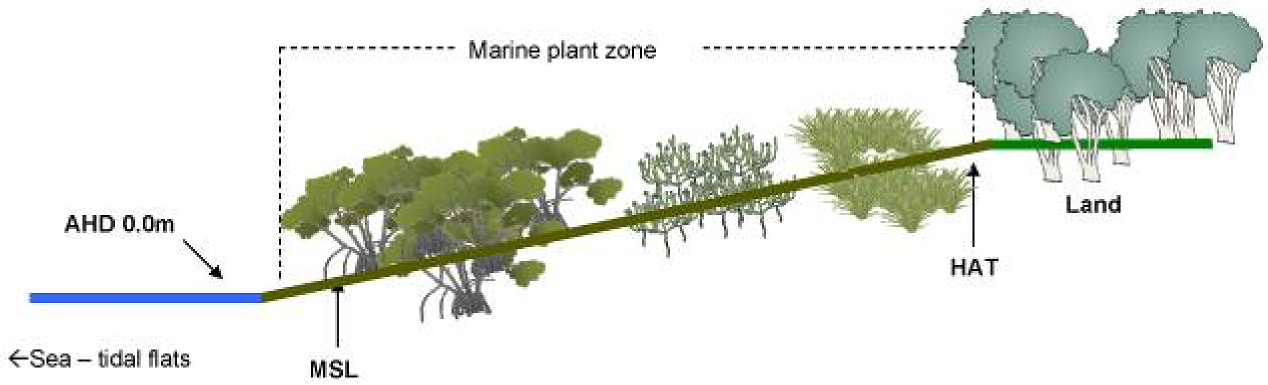


Figure 1 Conceptual diagram showing the distribution within the marine plant zone

The methodology provides:

- spatial mapping and elevation modelling of the current extent of marine fish habitats (using marine plants as indicator and most visible) in the selected regions; and
- audits of the extent of marine plant zone (communities) between mean sea level (MSL) and the level of the highest astronomical tide (HAT) for current day distribution (base-line) and at three sea level rise scenarios of 25 cm, 75 cm and 100 cm for each region.

Audits based on:

- Model 1 – Constrained (losses only);
- Model 2 – Unconstrained (losses and gains assuming marine plants can colonise landward); and
- support to local governments to recognise and achieve planning outcomes to include buffers and retreat areas for marine plant communities to establish in the future.

This report documents the audits for the four sites within the Townsville region.

2. Methods

2.1 Mapping

LiDAR[i] elevation data has been proven to be useful in mapping the micro topography of mangrove intertidal habitats. Knight *et al* (2009) applied the methodology to map the hydro-dynamics of a mangrove system in southeast Queensland to identify the early life-history stages of the saltmarsh mosquito, a known insect pest and human disease carrier.

The Queensland, Commonwealth and a number of local governments undertook a LiDAR acquisition program during 2008-2010 to provide data for the Improved Coastal Mapping project and for emergency services planning for evacuation routes in the event of natural disasters such as cyclone, storm surge and flooding events. This data was quality assured and rectified and forms the primary data set used for this project.

Imagery used for the mapping included 2010 Central Queensland and Townsville aerial photography (captured 2009) to define polygon extent (seaward mangrove edge and HAT) for the baseline distribution. Imagery resolution was 0.5 m resolution for all sites.

The methodology for the habitat mapping component involved four main stages:

- review of currently available datasets for both vegetation and bathymetric data;
- acquisition of processed LiDAR 25 cm contour polygon data and current imagery;
- refinement of site selection through initial use of C-Fish catch grids; and
- geoprocessing, using ESRI ArcGIS software, once LiDAR extents were selected in respect to the current day habitat extent. LiDAR polygons were further simplified to provide up to three polygons for each 25 cm increment.

The extensive LiDAR dataset available required a sampling approach to be taken to set a limit on the size of the sites selected in the Townsville region. This is an important point as the amount of data encapsulated in TV02, for example (over 34 000 tiles), and the necessity to join data sets flown at different times created technical difficulties. A key aim was to also capture as complete a wetland system (usually river mouth and deltas) within the HAT zone for the site as possible. The area for each site was refined through consideration of the calculation of HAT zones and capture of significant marine plant communities. LiDAR polygons were 'clipped' out from the main dataset between 0.00 AHD and 3 m AHD and further simplified to up to three polygons for each contour level.

Each site in the Townsville region varies in size, mapped scale and extent of marine plants covered in the audits produced for current day and each of the three SLR scenarios:

- current day MSL is set as the baseline at 0 cm
- SLR 25 cm
- SLR 75 cm and;
- SLR 100 cm.

Up to eight polygon levels per SLR scenario were mapped at each site (Figure 2). The landward extent mapped was to 1 m above current day HAT level for each site.

---

[i] LiDAR – Light Detection and Ranging remote sensing technology that uses light to map elevation at high resolution.

The seaward (outer) edge of the mangrove community was adopted as the MSL line and aligned with the nearest 25 cm LiDAR contour. This contour is set as the baseline (C1 in Figure 2) for the initial audit and seaward edge of the current mangrove distribution. The total of the inter-contour areas - between C1 and C2, C2 and C3, C3 and C4, and C4 and C5 - is taken as the current (baseline) audit of the intertidal marine plant distribution.

For the three SLR scenarios; the total of the inter-contour areas is:

- SLR 25 cm audit - between the C2 and C6 contours;
- SLR of 75 cm audit - between the C4 and C8 contours; and
- SLR 100 cm audit - between C5 and C9 contours.

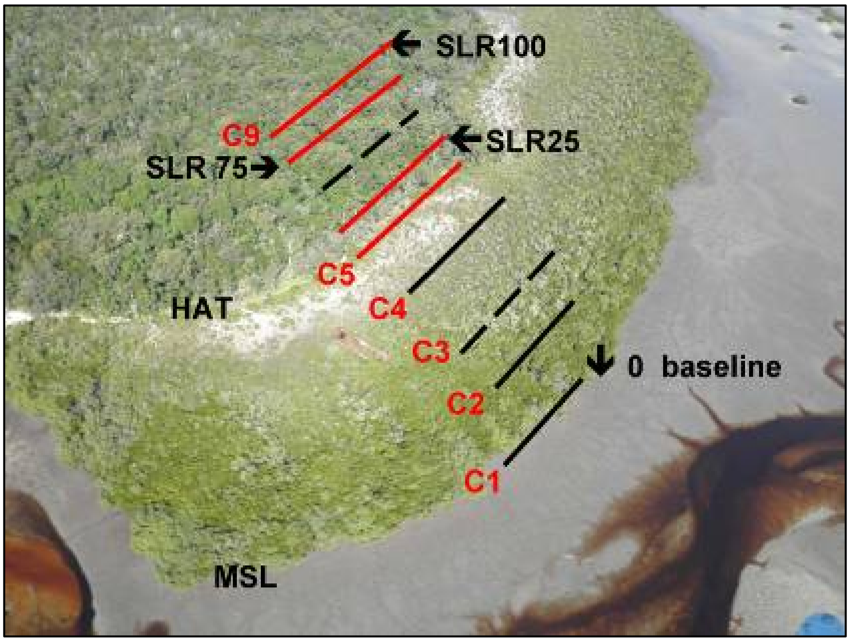


Figure 2 MSL, HAT, LiDAR contours and sea level rise scenarios

Townsville City Council has been selected to develop the first Coastal Hazard Adaptation Strategy (CHAS) under the Queensland Coastal Plan (2012). The Plan requires councils to develop a CHAS for urban localities within high coastal hazard areas, including the impact of future sea level rise. The Townsville City Council will be the first Queensland council to develop an adaptation strategy. The landmark pilot project will provide guidance for other coastal councils (35 in all) to develop strategies for their own local government areas.

Audit results can be used to inform the TCC CHAS and planning and assessment of development adjacent to coastal areas as well as planning for biodiversity protection and enhancement. The 75 cm SLR scenario relates to the Coastal Plan SLR of 80 cm by 2100.

2.2 Modelling

The project provides high resolution fish habitat vulnerability mapping for the selected coastal regions for areas with different levels of development (developed shoreline versus undeveloped shoreline). The project mapped intertidal vegetation between MSL and the HAT and included predominately mangrove forests and to a lesser extent, saltmarsh communities (Figure 2).

Two models were used to determine the impacts of the adopted SLR scenarios in terms of losses and gains of extent of marine plant communities for the four Townsville sites. Each model is explained in detail below.

Model 1 – **Constrained.** This Model assumes no capacity for shift in marine plant communities (Figure 3). Therefore the audit is a calculation of losses only due to permanent inundation of the seaward edge of the marine plant community under the SLR scenarios (Table 4). In Model 1, the claypan and saltmarsh communities provide the only initial retreat capacity (IRC) for mangrove communities to move into (Figure 1). Physical and chemical barriers, armouring of property and infrastructure, and lack of time for marine plants to adjust constrain the marine plant community shift. MSL moves landward but HAT is fixed.

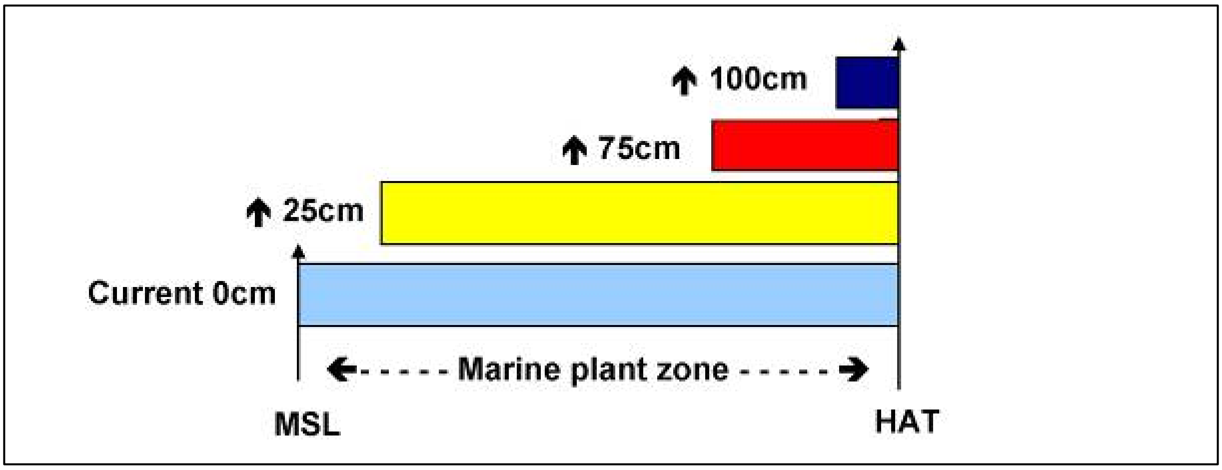


Figure 3 Model 1 – Marine plant zone reduced as sea level rises; losses only.

Model 2 – **Unconstrained**. This Model assumes marine plant communities have capacity to colonise new upland areas and to keep pace with SLR and that there are no physical or chemical barriers (Figure 4). Claypan and saltmarsh communities are the initial retreat areas for mangrove communities, with further shift into lands above HAT. The audit includes losses and gains for each SLR scenario. Both MSL and HAT move landwards.

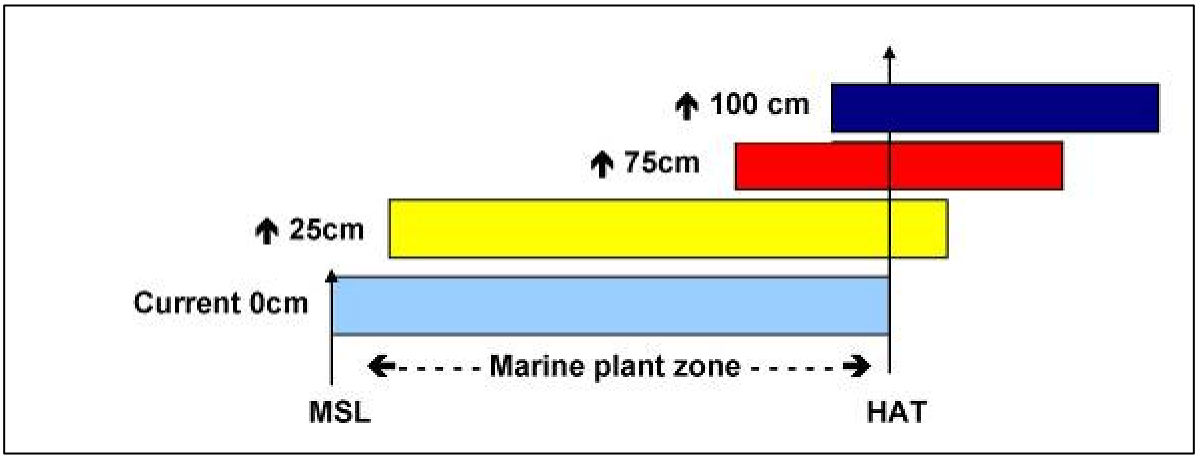


Figure 4 Model 2 – Marine plant zone shifts landward as new areas colonised with SLR.

2.3 Communication

The audit mapping enables the predicted impacts of future SLR on marine plant distribution to be incorporated when making planning decisions, so that the future shifts can be anticipated and accommodate in coastal planning through identification and formal establishment of buffers and retreat areas. To facilitate the uptake of the mapping and future use of the developed methodology for additional mapping by local governments, initial stakeholder meetings with Townsville City Council and NQ Dry Tropics natural resource management group have been held.

The final audits for the Townsville region will be communicated to the relevant local government and the fishing industry. Once data agreements are in place the audit data can be incorporated in local government planning and development assessment processes.

Local, site-specific information on the likely SLR impacts for locally important fish habitats have been highlighted in the work undertaken for this project. The important value of this information was quickly recognised by local government officers, in particular natural resource managers and planners, to provide visual representation of future needs for coastal communities. The audits and maps are powerful tools to assist in strengthening local government planning schemes and regional plan adaptation strategies for how and where the landward migration of marine plants and tidal fish habitats are to be accommodated to ensure that the current diversity of fish habitat remains.

3. Study area

The study area extends over four sites (Figure 8) from the Burdekin delta (TV01) in the south to the Bohle River catchment (TV04) to the north, along approximately 150 km of coastline and within two local government areas (Burdekin Shire and Townsville City). Home Hill and Townsville are the two major population centres and the area includes part of the Bowling Green Bay Ramsar wetland site and several declared Fish Habitat areas including Bohle River, Bowling Green Bay, Burdekin and Cleveland Bay.

The city of Townsville (2011 population ~190,000) is a major service centre and the main centre for government administration outside Brisbane. The region has significant transport infrastructure with Queensland Rail and the Port of Townsville providing a transport hub for mining and agricultural industries, as well as for locally-based Xstrata Copper Refinery, Sun Metals Zinc Refinery, Queensland Nickel and the Queensland Sugar Corporation Distribution Centre. Townsville Port is currently undergoing expansion to accommodate economic growth.

The Townsville local government was one of five included in the planning for climate change by Queensland coastal Councils' analysis (DCCEE 2011), relative to a 1.1 m SLR. The analysis assessed likely impacts on coastal buildings and infrastructure and included adaptive responses to both development and 'nature' (Zeppel, 2011), with 4 of the Councils emphasising 'nature' as the highest adaptive action (37%).

The region is tropical and supports extensive mangrove and reduced saltmarsh communities, a percentage of which are within protected areas: declared Fish Habitat Areas and marine and conservation parks. The estuarine wetlands (mangrove and saltmarsh / saltpan) of the Townsville Region study area cover approximately 533 000 hectares (Source: Wetlandinfo summary information for LGAs). Within the Burdekin Dry Tropics catchments, the area of mangroves and saltmarsh modified (pre-clear to recent post-clear extent) is 2100 ha (GBRMPA 2012).

Mangrove species are adapted to different levels of tidal inundation, soil type and freshwater inflow which results in particular species occupying sometimes quite distinct zones in the intertidal wetlands (Duke, 2006). In North Queensland, mangrove communities have a greater diversity (39 species recorded), with the Townsville Region having 23 species compared with seven species for Moreton Bay. North Queensland also has a higher representation of smaller mangrove species such as *Acanthus ilicifolius* (Spiny Holly mangrove), *Pemphis acidula* (Reef Barrier mangrove) and *Scyphiphora hydrophylacea* (Yamstick mangrove). Alligator Creek which flows into Bowling Green Bay (TV02) has 15 mangrove species (Duke, 1995).

Image 1: Mangrove zonation in the Barratas, TV02

Typical zones of the pioneer species *Avicennia marina* occur along the seaward edge or a mix of *Avicennia* and the red or tall-stilted mangroves (*Rhizophora spp*.), especially along estuarine river banks. Landward of this zone will be *Xylocarpus*, *Sonneratia*, *Osbornia* and *Bruguiera* species in wetter areas or the *Ceriops* and *Cynometra spp* and Blind-your-eye (*Excoecaria agallocha*) mangroves often growing at the top of the bank. In contrast, the diversity of saltmarsh species in North Queensland is lower than that in south-east Queensland.

3.1 Fish habitat diversity

The Townsville region is high in biodiversity as it spans both the wet and dry tropics and is adjacent to the Great Barrier Reef lagoon and World Heritage Area. The tide-dominated deltas of the Burdekin and to a lesser extent the Bohle Rivers influence the coastal landscape. The wet season brings large flows to the deltas which are characterised by expanses of sand banks and a maze of tidal channels. Intertidal fish habitats are dominated by the mangrove species mentioned above, sometimes forming distinct bands or zones of one species. Importantly, the connectivity between estuarine and freshwater habitats supports key species such as barramundi and mangrove jack.

A public research forum in November 2011 as part of the National Estuaries Network Symposium presented results of recent fish habitat research documenting habitat and fisheries interrelationships.

3.2 Wild-harvest fisheries

The Townsville region study area lies adjacent to commercial trawl, net and crab (pot) fisheries that take prawns (tiger, red-spot king, endeavour and banana), scallops, bugs, grey mackerel, barramundi, threadfin and mud crabs (Williams, 2002). These fisheries provide local employment directly in the industry and in associated businesses and services for the processing and sale of seafood as well as the purchase, repair and maintenance of fishing vessels and equipment. The fishing industry is also integral to visitors to the region who come to enjoy local fresh seafood.

In addition, recreational fisheries for many inshore and reef finfish species and for offshore gamefish rely on and benefit from coastal marine plant communities.

Between 2001-2010, the commercial fisheries of the coastal and estuarine areas immediately adjacent to the study area contributed approx $67 million to the overall Gross Value of Production (GVP) for seafood harvest in Queensland (GVP $185 million)[ii].

Table 1 Summary of wild-harvest fisheries operating adjacent to the Townsville and Burdekin LGAs (2001-2010)

Fishery	Main species	Weight (t)	Value $GVP X 1000	Key habitats
Line	Various coral reef species (NB GBRMPA 2004 rezoning brought in quota operations).	225	2759	Juveniles of many species migrate from estuaries and in-shore areas to reef habitats
Net	Various fin-fish including barramundi, mackerel and threadfins	3462	15 795	Mangrove lined estuaries, mud and sand banks, channels
Crab (pot)	Mud crabs	776	12 313	Adults live in mangrove forests and estuaries,

[ii] South East Queensland State of the Region Technical Report 2008 – Part 4, page 173. DLGP

Fishery	Main species	Weight (t)	Value $GVP X 1000	Key habitats
				mud banks, offshore spawning
Trawl	Prawns, scallops, bugs	2791	35 911	Mangrove and seagrass communities, mud and sand banks / substrate
Total		**7254**	**66 778**	

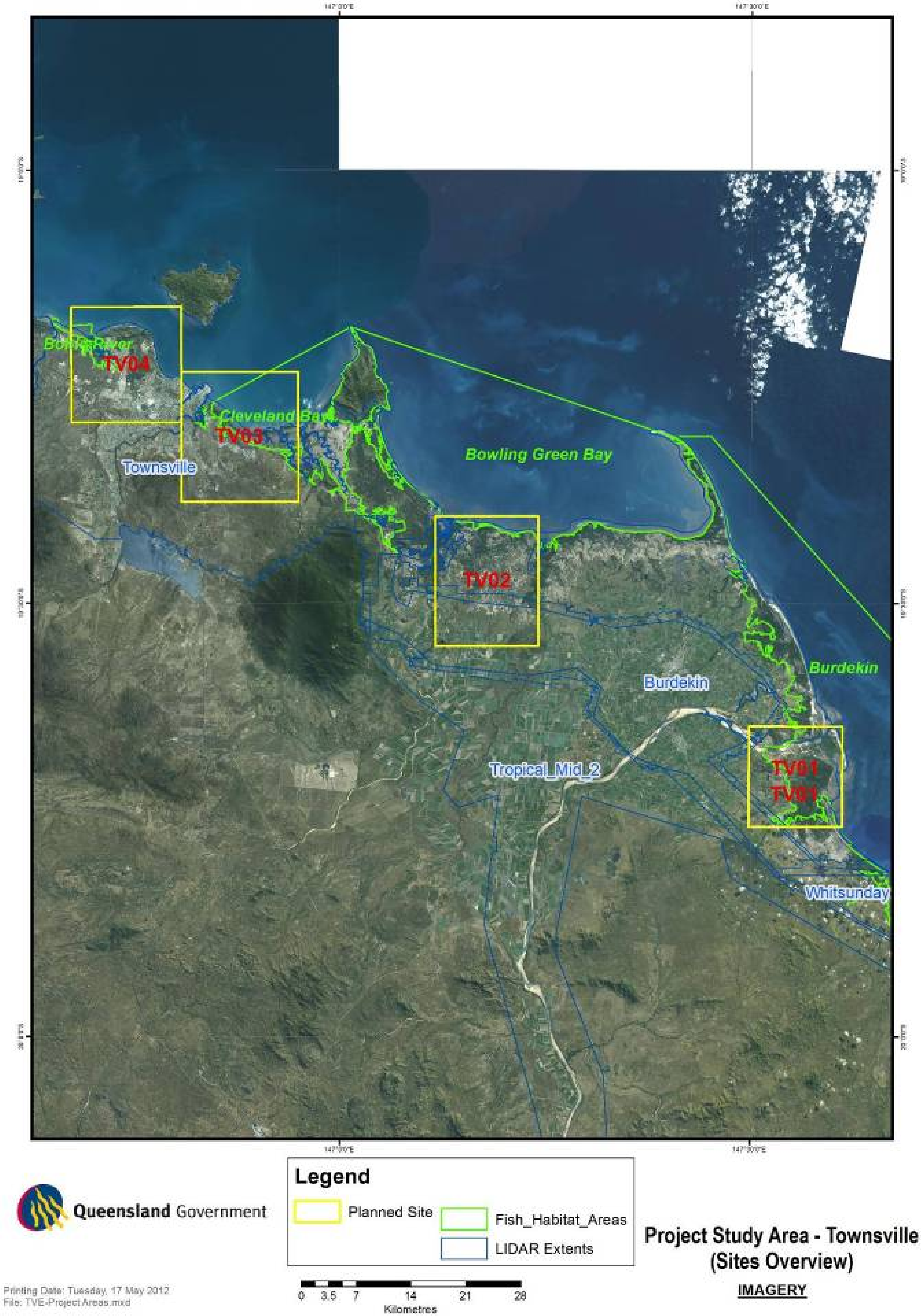


Figure 5 Location of the 4 Townsville Region study sites.

3.4 Site description

Table 2 provides a summary of each site and lists its name, location, current marine plant area and a brief description. Composite SLR scenario maps of Model 2 for each site are in Appendix 1.

Table 2 summary information for all Townsville Region sites

Site	Location	Protected area	Area (ha) marine plants	Scale	Description
TV01 Wunjunga Burdekin delta	**19°18'29.88"S** **146°52'44.4"E**	**Burdekin FHA**	3834	1:48 000	Large riverine delta, with numerous sand and mangrove islands, next to highly developed cane areas
TV02 Bowling Green Bay Barratas	**19°13'30.00"S** **146°44'31.2"E**	**Bowling Green Bay FHA; Ramsar site**	12242	1:55 000	Large embayment, with 4 small creek systems, with mangrove lined banks; adjacent to intensive cane farming
TV03 Ross River / Alligator Creek Cleveland Bay	**19°28'30.00"S** **147°10'44.4"E**	**Cleveland Bay FHA**	2655	1:60 000	Large embayment, with Ross River and several minor creeks, with mangrove lined banks; large areas of clay and salt pans
TV04 Bohle / Town Common Bohle Catchment	**19°43'15.24"S** **147°33'14.4"E**	**Bohle FHA**	2556	1: 60 000	Semi-urban mangrove lined estuary, with Town Common upstream

3.3 Historic marine plant mapping for Townsville region

In 1998, the Queensland Herbarium mapped the coastal wetlands of South East Queensland from the Tweed River to the Sunshine coast. This study included coastal vegetation to the 2.5 m contour above AHD and extended across the entire Moreton Bay region. The area of each marine plant group (GVP) within each local government area was calculated and is presented in Table 2. Under Model 1, the IRC for marine plants will only be the claypan and samphire habitats, GVT2 and GVT3. Mangroves (GVT1) will expand into these areas at the expense of the existing communities.

4. Results

For each of the four sites in the Townsville region, the extent of marine plant distribution was calculated as an audit, commencing with current day (baseline at 0 cm) and followed by each of the three SLR scenarios: SLR 25 cm; SLR 75 cm and SLR 100 cm. Models 1 and 2 were applied. From the audits generated, the impacts of the adopted SLR scenarios was determined in terms of losses and gains within the extent of marine plant communities for each of the four Townsville region sites.

The Models 1 and 2 audit cover 21 827 ha or about 0.25% of the total marine plant community area in the Townsville region of about 533 000[iii] ha of which approximately 13 500 ha is mangrove community. The estuarine wetlands (mangrove and saltmarsh / saltpan) of the Townsville region study area cover approximately 533 000 hectares (Source: Department of Environment and Heritage Protection Wetlandinfo summary information for the Burdekin and Townsville local government areas).

The following sections provide summaries of the audits and impacts of the SLR scenarios on the extent of marine plants for each of the four Townsville region sites for each of the two Models (as per Section 2 - Methods).

4.1 Model 1 results

The audits, based on Model 1 (Table 4) - the constrained approach where the intertidal areas are inundated progressively (and marine plants are lost) as the sea level rises - do not accommodate landward migration. This is a 'worst case' scenario as it does not take into account any ability for landward migration of marine plants which could be prevented from moving due to human or natural barriers, or an inability to keep pace with the rate of SLR.

For each of the four sites in the Townsville region, relatively little loss occurs between the baseline and SLR 25 cm. Between SLR 25 cm to SLR 75 cm, the greatest losses are for TV01 (Wunjunga) and TV02 (Bowling Green – Barratas). Further substantial losses follow with the final 25 cm SLR to 100 cm for both these sites with relatively minor changes for TV03 (Ross River - Alligator Creek) and TV04 (Bohle – Town Common). At the 100 cm SLR, TV01 (Wunjunga) has lost >50% of its marine plant community, while of the other three sites, changes to the communities range from 8 – 18% from the of the baseline (current) communities of the Townsville region. Overall for the Townsville region, based on the audits from the four sites, 23% of the current marine plant communities' distribution would be lost.

[iii] Department of Environment and Heritage Protection, Townsville Coastal Hazard Adaptation Strategy Pilot Project 2012.

Table 3 Model 1 audit summary for theTownsville Region

Site Area (ha)/SLR	TV01 Wunjunga	TV02 Bowling Green - Barratas	TV03 Ross River – Alligator Creek	TV04 Bohle - Town Common	Total TV Region
Current	3834	12 242	2655	2556	21 287
SLR 25	3649	12 118	2593	2521	20 881
SLR 75	3100	11 791	2467	2453	19 811
SLR 100	1785	10 005	2368	2338	16 496
Change per site @ 100 cm	**- 53%**	**-18%**	**-11%**	**-8%**	**-23%**

4.2 Model 2 result

The audits based on Model 2 (Table 5) - unconstrained – accommodate migration of marine plants landward into areas with suitable elevation. Soil type, accretion, erosion and impacts of extreme events are not components of the Model. With this Model, the losses are marginally smaller than those from Model 1 for the 2 of the Townsville region sites. However for the other 2 sites, there are considerable gains at each site at SLR 100 cm, building on earlier gains at SLR 25cm and SLR 75 cm.

Table 4 Model 2 audit summary: Townsville Region

Site Area (ha)/SLR	TV01 Wunjunga	TV02 Bowling Green - Barratas	TV03 Ross River – Alligator Creek	TV04 Bohle – Town Common	Total TV Region
Current	3834	12 242	2655	2556	21 287
SLR 25	4080	12 694	2896	2934	22 604
SLR 75	4108	12 912	3318	3625	23 963
SLR 100	3116	11 407	3403	3824	21 750
Change per site @ 100 cm	**- 19%**	**- 7%**	**+28%**	**+50%**	**+2%**

Changes in extent of the marine plant community vary at each site depending on the tidal regime and topography, natural contours and presence / absence of hard structures such as revetment walls or roads and the extent of adjacent land use.

For the Townsville region, the changes range from losses of -7 to -19% to gains of +28 to + 50%. This is based on losses at TV01 and TV02, with gains at TV03 and TV04, in the extent of the marine plant community at the 100 cm SLR scenario. The overall result for the Townsville Region study area (TV01-TV04) at the 100 cm SLR scenario is a slight gain of 2%.

However, this predicted gain is based on the increase of some ~1300 ha at TV04, a site that currently has high freshwater and wildlife conservation values and tourism benefits. If these values and benefits were to be protected through the construction of a bund at the current HAT line to prevent tidal intrusion from future SLR, for TV04 this would see a loss of ~ 8% of the current marine plant community distribution, as per Model 1. For the Townsville region, the total for the four sites would be reduced to 20 264 ha; leading to an overall loss of ~ 5%. at the 100 cm SLR.

4.3 Project status

The intertidal marine plant community at each site in the Townsville region has been assessed within the four sites. Audits of the changes to the marine plant zone at each site have been completed for each SLR scenario. As described above, the audits indicate there are variable opportunities to accommodate buffers and retreat areas for the landward migration of marine plants.

Overall, for the Townsville region at the 100 cm SLR scenario, Model 1 shows a 23% loss, while Model 2 shows an increase landward of 2%. Any landward increase would occur at the expense of adjacent sensitive coastal freshwater swamps through colonisation by the mangrove community in an unconstrained system where no defence measures are taken to protect coastal assets, both built and natural.

4.4 Implications of audits

Distribution of marine plant species along the tidal profile will change as sea level rise, and tidal profile change. Saltmarsh and mangrove species occupy distinct niches and zones which are determined by elevation, soil type, frequency of tidal inundation, influence of freshwater runoff and groundwater, latitude and nutrients among other things (Duke 2006; Johns 2006; 2010; Saintilan 2009).

Given the greater diversity of mangrove species and their different aerial root types, the capacity of northern mangrove communities to assist in settling suspended sediments will alter as communities shift. Variation in root densities of tropical mangrove species has been identified as impacting on turbulence-induced erosion and shallow subsidence (Krauss et al 2003) in tidal habitats.

What seems likely and which has been recorded in other estuaries along the east coast of Australia (Saintilan and Williams 1999) is that mangrove communities will invade saltmarsh areas. This will mean that the gains in marine plant communities for Moreton Bay will largely be at the expense of saltmarsh and adjacent sensitive freshwater communities (e.g. paperbark (*Melaleuca)* forests and swamps).

Saltmarshes are critical habitats for local and migratory bird species as well as fish species and provide important nutrient exchanges through the connectivity between the terrestrial and marine environments. The adjacent freshwater communities are of high fisheries and ecological values and often remnant, following coastal development. Freshwater habitats are critical to fish species that are anadromous (move onto freshwaters to spawn) or are catadromous (move to estuaries and inshore waters to spawn). The importance of freshwater wetlands for fish has been documented for the Townsville region (Veitch and Sawynok, 2005).

There is recent evidence of changes to the distribution and extent of mangroves recorded in other Pacific Island countries and territories. Waycott et al (2011) note a gradual retreat of the mangrove zone due to SLR rate of 0.7 mm per year in southern PNG (PCCSP 2011). There the dominant *Bruguiera* mangrove species has been replaced by *Rhizophora* species. Mangroves are sensitive to even minor changes in coastal conditions, such as altered drainage patterns, tidal heights, saltwater intrusion, accretion or erosion in response to changes in sea level. The response of mangroves to these changes can be seen through variations in the community composition (zonation) and relative abundance of plant species within the mangrove habitat (Waycott et al 2011; Duke 2006).

Given the dependence of fish, prawns and crabs on marine plant communities (Ley 2005) as a source of primary production, any changes within these communities will impact on the composition, distribution and abundance of the fish and invertebrate communities on which commercial, recreational and indigenous fisheries rely. The recent Australian Society for Fish Biology Conference (2010) allowed presentation and technical debate (MAFR 2011) on the impacts of climate change and Australian aquatic environments, confirming the key impacts, currently being documented and/or predicted to occur, on fish stocks and fish species.

Lovelock and Ellison (2007) identified projected changes in mangrove and saltmarsh areas for both the Burdekin (TV01) and Bohle (TV04) systems. With the same or increased rate of sediment trapping and sea level rise exceeding vertical accretion, losses of saltmarsh flora and fauna are predicted with an increase in mangrove species diversity.

5. Adaptation to SLR risk

A consequence of SLR for each of the models is the likely changes that will occur in both the diversity and extent of intertidal marine plant communities. Where there are limited or no retreat opportunities available due to steep banks or existing hard engineering structures such as revetments, bunds and walls, intertidal marine plant communities will be lost completely or substantially reduced to a narrow band (Model 1). Similarly for Model 2, even though marine plants may be able to migrate landwards if the substrate and slope are suitable, the suite of marine plant species will reduce and mangroves will out-compete and dominate saltmarsh species; the latter becoming less diverse, if not lost.

Adaptations to the changes in intertidal vegetation extent and diversity and fisheries productivity due to the impacts of SLR will involve consideration of various options. Some key adaptation options for consideration by the fishing industry and for local government are discussed below. Early in the project, a risk management matrix (Appendix 2, Moreton Bay report) was developed to help summarise the various climate adaptation pathways that exist for fish habitats and fisheries production. A risk statement and a way forward were developed as part of the scoping process for the project and are reproduced below:

Vulnerability of Fish Habitats (Marine Plant Communities) - RISK STATEMENT

- the risk to the fishing sectors of losing marine plant habitats will result in changes in fisheries production, catch composition and seafood availability;
- this level of risk requires an urgent response from senior levels of industry and from local, state and federal governments for policy and management; and
- the risk can be mitigated through provision of retreat areas for marine plant habitats through strategic planning instruments at local and state government levels and through fishing sectors adapting catch and marketing strategies for changes in catch composition.

Vulnerability of Fish Habitats (Marine Plant Communities) - WAY FORWARD

- select key sites that are audited in terms of current marine plant distributions and their diversity;
- selected sites to reflect different coastal areas where low, medium and high levels of development (i.e. potential barriers);
- develop several scenarios of SLR and map and audit likely changes in marine plant distributions and diversity; and
- liaise with key stakeholders, e.g. local governments and fishing industry, to ensure that planning instruments consider future marine plant communities and by definition, future fish communities and catching of these.

5.1 Issue identification for stakeholders

The risk management matrix identified the various risks that accelerated SLR, rising temperatures and greenhouse gas levels (primarily CO2) will have on the extent and distribution of marine plants and probable outcomes for local and regional fisheries production. Fishers and fisheries managers will need to develop alternative ways to access and protect fisheries resources. The Declared Fish Habitat Area (FHA) network will also need to be amended to reflect changes in critical fish habitat extent and distribution, including boundary definition. Meynecke (2009), states that maintenance of fisheries sustainability will be dependent on maintaining and placing new declared FHAs in areas with high structural connectivity within the fish habitat mosaic.

A major risk to fish habitats is the loss of habitats due to ‘coastal squeeze’ (Figure 6) where barriers such as man-made structures or natural land features prevent the SLR imposed landward shift of marine plants. Appropriate regional and local planning along coastal foreshores may limit the extent of the ‘coastal squeeze’, especially in areas deemed to be high fish habitat and fisheries values.

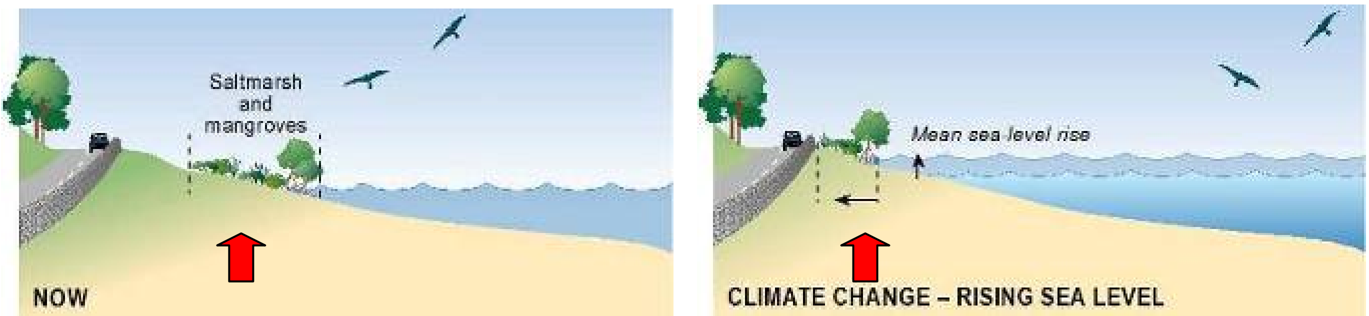


Figure 6 Loss of fish habitats due to ‘coastal squeeze’ adapted from DCC 2009 report.

5.1.1 Local government

A key outcome of the project was to provide audits at a local level on the impacts of projected SLR on coastal fish habitats to alert local governments and to encourage and to support planning and assessment decisions in the coastal zone. The audits provide a visual and spatial tool to enable use of the data in local government GIS, planning schemes and assessment systems.

Options that the state and local governments can consider include:

Do nothing – no consideration of fish habitats or fisheries

- continue with business as usual, making no concession or investment for protection of future fish habitats;
- no strategic approach to planning and protection of key conservation values;
- decline of local fishing industry and fresh seafood to the community as fisheries production is lost; and
- recreational fishing opportunities and local supporting industries decline.

Reactive – 'as needed' consideration of fish habitats or fisheries

- ad hoc protection of threatened adjacent freshwater biodiversity values and foreshore habitats;
- multiple competing conservation values are not holistically dealt with;
- private and public property defence with armouring is unmanaged;
- no planned retreat; and
- decline of local fishing industry and fresh seafood as fisheries production is lost.

Proactive – strategic consideration of fish habitats or fisheries

- strategic protection of mapped key fish habitats and retreat / buffer areas;
- coordinated conservation management objectives for biodiversity values;
- integrated insect pest management;
- strategic approach to coastal planning with 'soft' retreat and resilience building approach; and
- assessment of coastal developments that includes a risk management approach to SLR and increased exposure to coastal hazards.

The Queensland Coastal Plan 2012 now requires local governments to prepare coastal hazard adaptation plans for those areas that have been developed that may be at risk of an 80 cm SLR at 2100. Zeppel (2011) reported on a review of the different climate change adaptation action approaches used by four coastal Councils (Cairns, Gold Coast, Redland and Sunshine Coast) in Queensland, in response to the Coastal Plan.

The adaptation responses reviewed were grouped into several categories including:

- *Emphasising Nature* – focus is on protecting the environment to buffer the impacts of climate change;
- *Emphasising development* – focus is on protecting the built environment;
- *Managing nature* – actions include beach nourishment, artificial reefs;
- *Emphasising communities* – focus is on public access, health risks, safety and engagement;
- *Council governance* – relates to internal council processes for dealing with climate change impacts.

Significant coastal public and private buildings and infrastructure are at risk in coastal Queensland (94 000 buildings, Qld Coastal Plan 2011) from predicted storm tides and SLR. This has led to the focus of local governments in primarily protecting the built environment from erosion. Out of 35 coastal Councils, only four have developed climate change strategies or action plans with the emphasis being on council governance to implement climate actions, along with actions emphasising nature to protect the environment, assets and public areas (Zeppel 2011).

Fish habitats are now recognised as a "State Interest" under the planning legislation and local government planning schemes are required to include retreat areas to accommodate landward migration of marine plants.

In discussion with the Townsville City Council and NQ Dry Tropics, planning for retreat and buffer areas was recognised as a priority, as well as the future trade-offs that may need to be made in terms of protecting increasingly threatened freshwater ecosystems at the expense of landward migration of marine plants..

As illustrated in Table 5 Model 2 audit results, the predicted gain for tidal fish habitats is based on the increase of some ~1300 ha at TV04 (Bohle – Town Common), a site that currently has high freshwater and wildlife conservation values and tourism benefits. If these values and benefits were to be protected through the construction of a bund at the current HAT line to prevent tidal intrusion from future SLR, for TV04 this would see a loss of ~ 8% of the current marine plant community distribution, as per Model 1. For the Townsville region, the total for the four sites would be reduced to 20 264 ha; leading to an overall loss of ~ 5% at the 100 cm SLR.

Long-term protection to these communities within an LG conservation and management strategy is appropriate and a regional approach may also be required. For example, adjacent land uses for TV01 and TV02 may restrict migration. For TV03 and TV04 where there are predicted increases, particularly for areas surrounding the Ross River and Bohle Town Common, continuing coastal development is likely to influence the extent of increases.

5.1.2 Fishing industry

Key considerations for the fishing industry include the changes predicted for the highly productive intertidal habitats are that support fish, prawn and crab nurseries; the reliance of inshore fisheries including recreational, indigenous and commercial fisheries and of offshore fisheries such as the charter, prawns and gamefish; all dependent on these intertidal habitats.

Nationally, 2009-10 GVP for fisheries was $2.2 billion, with fisheries exports totalling $1.2 billion and imports $1.5 billion (ABARE, 2011). Australia currently imports 70% of its seafood and this imbalance is likely to increase if coastal fish habitats are not given protection through strategic planning and management.

For the fishing industry sectors in Queensland, the GVP for 2011-12 is $448 million, of which the components are: $284 million commercial, $91 million aquaculture and approx $73 million recreational. Most coastal communities and related industries are reliant on local fishing industry sectors for the socio-economic benefits generated.

The East Coast Otter Trawl Fishery (ECOTF) is a fishery partly reliant on the marine plant communities of the four Townsville sites. This fishery has been the subject of a vulnerability assessment to climate change impacts (GBRMPA 2011) where changes to species availability and other factors were investigated and discussed and the adaptive capacity of the industry was highlighted.

In general, the adaptation options identified in the ECOTF workshops for the fishing industry include:

- Possible restructure of fishing industry
  - fishers opt out of industry;
  - fishers move into other fisheries;
  - government buyback schemes; and
  - consideration of impacts to coastal communities if the fishing fleet relocates.
- Target species change
  - different fish species become economical to target; and
  - ensure market acceptability (e.g. bream species are replaced by mullet).
- Gear changes required to be able to target different species
  - ability to innovate and trial; and
  - rapid uptake.
- Fishery management
  - area fished changes;
  - fished species abundant in new areas; and
  - flexible management arrangements.

5.2 Regional context

The boxed table in Figure 10 below provides an estimate, based on the Model 2 approach, of the percentage loss of mangroves and seagrass habitats in 2035 and 2100 for Pacific Island countries and territories (PICTs). The effects of SLR are expected to result in losses of around 10% of mangrove habitat by 2035. By 2100, ‘likely’ losses are predicted to be around 50% to 60% in most of these PICTs, with losses of up to 80% predicted as ‘somewhat likely’ (e.g. Tonga), Waycott et al (2011, page 345).

Table 6.5 Projected percentage loss in areas of mangrove and seagrass habitats for the B1 and A2 emissions scenarios in 2035 and 2100 in Pacific Island countries and territories (PICTs) that have total areas of mangroves and seagrasses > 5 km^2. These estimates are based on the expert opinion of the authors because data on the land area to be inundated for the B1 and A2 scenarios are not yet available to inform a quantitative assessment. The estimates include the perceived scope for the major areas of the existing mangroves and seagrasses in each PICT to migrate, or not migrate, landwards as the case may be.

PICT	Mangroves B1/A2 2035	Mangroves B1 2100	Mangroves A2 2100	Seagrasses B1/A2 2035	Seagrasses B1 2100	Seagrasses A2 2100
Melanesia						
Fiji	10	50	60	< 5	5–10	10–20
New Caledonia	10	50	60	5–10	5–20	10–25
PNG	10	50	60	5–20	5–30	10–35
Solomon Islands	10	50	60	5–20	5–30	10–35
Vanuatu	10	50	60	5–20	5–30	10–35
Micronesia						
FSM	10	50	60	< 5–10	5–25	10–30
Guam	10	60	70	5–20	5–35	10–50
CNMI	30	70	80	< 5–10	5–25	10–35
Palau	10	50	60	< 5–10	5–25	10–35
Polynesia						
French Polynesia	10	50	60	< 5	5–10	10–20
Samoa	10	50	60	5–20	5–35	10–50
Tonga	30	70	80	5–10	5–20	10–20

Likelihood: Unlikely (0%–29%), Somewhat likely (29%–66%), Likely (66%–90%), Very likely (90%–100%)

Confidence: Very low (0%–5%), Low (5%–33%), Medium (33%–66%), High (66%–95%), Very high (95%–100%)

Figure 7 Projected loss of mangrove and seagrass habitats in Pacific Island countries and territories

The above figure provides a snapshot of what current SLR predictions for the Tropical Pacific will mean for intertidal and subtidal marine fish habitats in the region. For Moreton Bay, the impacts of sea level rise will vary from north to south (Table 3) at the different scenarios. In the Melanesian group of countries, larger losses of mangroves and seagrass fish habitats have been predicted: most of these countries are at similar or lower latitudes than Townsville.

6. Stakeholder consultation

An integral component of conducting and delivering the project has been early and continued communication with key stakeholders. The Townsville region has two local governments, with the four study sites located within these: Burdekin Regional Council (TV01) and Townsville City Council (TV02, TV03 and TV04).

An initial meeting has been held with Townsville City Council staff to create awareness of the project and to provide information on the project objectives. Local governments are key stakeholders as the principal land managers on the coastal zone. The future management and protection of identified retreat and buffer areas within this zone is primarily their responsibility.

Other major stakeholders consulted for the Townsville Region have been North Queensland Dry Tropics and local DAFF Fisheries Queensland and GBRMPA staff. The public National Estuaries Science Forum held in November 2011 in Townsville included a presentation on the project, its findings and its implications.

Further consultation is required to integrate the audits into each Council's GIS, planning and development assessment processes. Additionally, liaison with the local fishing industry sectors and indigenous peoples to create awareness and understanding is appropriate. The Tables below provide a summary of stakeholder consultation for the project.

Table 5 Local government consultation

Stakeholder	***Presentation / briefing***	***Comments***
Townsville City Council	• August 2011 – Presentation to Townsville City Council	• Reviewed results for Moreton Bay and agreed on sites for Townsville Region • Positive response and interest in how other LGs are adopting the audit results

Table 6 Consultation activities with industry, research organisations and national bodies

Organisation	***Presentation / briefing***	***Comments***
Australian Society for Fish Biology National Conference, September 2010, Melbourne	• Participation in workshops and technical discussion	• Greater awareness of climate vulnerability and its implications; formal presentation of changes to fish, fisheries and habitats to date (MAFR 2011)
National Seachange Taskforce	• March 2011 – Presentation to the inaugural Australian Coastal Research Forum, Torquay, Victoria	• Positive response to presentation – coastal local governments nationally seeking local information for adaptation to climate change SLR • Input provided to the National Seachange Taskforce Coastal Policy (Sept 2009) • Invitation to provide an update on project outcomes to 2012 conference. Not taken up
34th International Symposium on Remote Sensing of the Environment	• April 2011 – Presentation on methodology to international audience	• Opportunity to discuss methodology with peers • Use of audits as visualisation tool for end users well received • Innovative application of spatial analysis
QCCCE / DAFF Steering Committee	• July 2011 – Presentation to CQAI Steering Committee • April 2012 – Presentation to CQAI Steering Committee	• Committee was impressed with project progress and outcomes, methodology, stakeholder engagement • Acknowledged that the project has provided very practical information and tools
NSW Fisheries	• August 2011 – Briefing to NSW	• Strong interest in results and

Organisation	Presentation / briefing	Comments
	Fisheries Fish Habitat Managers	methodology used. • Scope for use in NSW estuaries, building on baseline marine plant mapping
NQ Dry Tropics	• August 2011 – Presentation to NQ Dry Tropics in Townsville	• Agreed on sites to audit in Townsville region • Positive response to methodology and outcomes from Moreton Bay audits
GBRMPA	• August 2011 – Met with Rachel Pears and ECOTF workshop	• Links with GBRMPA climate change adaptation project for trawl industry
Fishing Industry	• November 2011 – Met with Eric Perez (QSIA) • December 2011 – Met with John Page and David Sterling (MBSIA)	• Positive response to briefing and visualisation of impacts of SLR on fish habitats • Provided insight to adaptation issues for certain fishing methods (tunnel netting)

References

Bell JD, Johnson, JE and Hobday, AJ (eds), 2011. Vulnerability of Tropical Pacific Fisheries to Climate Change, published by the Secretariat of the Pacific Community, Noumea, New Caledonia, 925pp.

Beumer, J P, Sully, DW and Couchman, D, 2012. Fish Habitat Vulnerability Mapping in Coastal Queensland. Report 1: Moreton Bay Region. Queensland Government, 61pp.

De Vries C, Danaher, K and Couchman, D, 2002. Summary of Coastal Wetland Communities in Queensland by Local Government Area. Information Series QI02118. Department of Primary Industries, Brisbane, 62 pp.

Department of Climate Change, 2009. Climate change risks to Australia's coasts. A first pass National assessment. Australian Government, Canberra, 168 pp.

Department of Environment and Heritage Protection, Townsville Coastal Hazard Adaptation Strategy Pilot Project, web page 2012. www.ehp.qld.gov.au/climatechange/townsville-strategy-pilot-program.html

Department of Environment and Resource Management, 2011. Queensland Coastal Plan, Queensland Government, 106pp. www.derm.qld.gov.au/coastalplan/#document_sections

Department of Climate Change and Energy Efficiency, 2011. Analysis by local government area – Queensland. In: Climate risks to coastal buildings and infrastructure: a Supplement to the First Pass National Assessment, pp.20.

Duke, NC, 1995. Mangroves in the Great Barrier Reef World Heritage Area: current status, long-term trends, management implications and research. In: Wadenfeld, D, Oliver, J, and Davis, K (eds). State of the Great Barrier Reef World Heritage Area Workshop, Townsville, Workshop Series No 23, Proceedings, pp.288-299.

Duke, NC, 2006. Australia's mangroves: the authoritative guide to Australia's mangrove plants, The University of Queensland, Brisbane, 200pp.

Great Barrier Reef Marine Park Authority, 2012. Informing the outlook for Great barrier Reef Coastal Systems. i-v, 1-114pp.

IAN image library, Dianne Kleine, website: www.ian.umces.edu/imagelibrary/

Johns, L, 2006; 2010 (2nd edition). Field guide to common saltmarsh plants of Queensland, Department of Employment, Economic Development and Innovation, Queensland Government, 70pp.

Johnson, JE and Marshall, PA, (editors) 2007. Climate Change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Australia, 818pp.

Knight, JM, Dale, PER, Spencer, J and Griffin, L, 2009. Exploring LiDAR data for mapping the micro-topography and tidal hydrodynamics of mangrove ecosystems: An example from southeast Queensland, Australia. *Estuarine, Coastal and Shelf Science*, 85(4):593-600.

Krausse, KW, Allen, JA and Cahoon, DR, 2003. Differential rates of vertical accretion and elevation change among aerial root types in Micronesian mangrove forests. *Estuarine Coastal and Shelf Science,* 56:251-259.

Ley, JA, 2005. Linking fish assemblages and attributes of mangrove estuaries in tropical Australia: criteria for regional reserves. *Marine Ecology Progress Series*, 305:41-57.

Lovelock, CE and Ellison, J, 2007. *Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change*. In: Climate change and the Great Barrier Reef: a vulnerability assessment. Part II: Species and species groups, Chapter 9, pp.238-269. Great Barrier Reef Marine Park Authority, Townsville, QLD.

Lovelock, CE, Bennion, V, Grinham, A and Cahoon, DR, 2011.The Role of Surface and Subsurface Processes in Keeping Pace with Sea Level Rise in Intertidal Wetlands of Moreton Bay, Queensland, Australia. *Ecosystems*, 14:745–757.

MAFR 2011. Climate Change and Australian Aquatic Environments, Fish and Fisheries. Special Issue *Marine and Freshwater Research* 62 (9): 981 - 1164.

Meynecke, J.-O, Lee, SY and Duke, NC, 2008. Linking spatial metrics and fish catch reveal the importance of coastal wetland connectivity to inshore fisheries in Queensland, Australia. *Biological Conservation*, 141:981 – 996.

Meynecke, J-O, 2009. Coastal habitat connectivity - implications for declared fish habitat networks in Queensland, Australia. *Pacific Conservation Biology*, 15(2) :96-101.

Morison, A and Pears, R, 2011. Climate change vulnerability assessment for the East Coast Otter Trawl Fishery: A brief synthesis of information. Prepared for the Great Barrier Reef Marine Park Authority, Townsville, Australia, 82pp.

National Estuaries Network 21st Meeting November 2011. Public Science Symposium ‘Research and Management of North Queensland Marine Ecosystems’, abstracts booklet, 23pp.

Pacific Climate Change Science Program (PCCSP), 2011. Current and future climate of Papua New Guinea. International Climate Change Adaptation Initiative, 8pp.

Rogers, K (prepared by), 2011, Coastal Wetland Vulnerability to Sea Level Rise. Final Report for the Rivers and Wetlands Unit, NSW Department of Climate Change and Water, 132pp.

Saintilan, S, 2009. Australian Saltmarsh Ecology, CSIRO Publishing, Collingwood, Victoria, 236pp.

Veitch, V and Sawynok, B, 2005. Freshwater wetlands and fish: importance of freshwater wetlands to marine fisheries resources in the Great Barrier Reef. Sunfish Queensland Report No:SQ200401:1-136.

Waycott M, McKenzie LJ, Mellors JE, Ellison JC, Sheaves MT, Collier C, Schwarz A, Webb A, Johnson JE and Payri CE, 2011. Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change. In: Bell JD, Johnson JE and Hobday AJ (eds) (2011) Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community, Noumea, New Caledonia, pp.297 – 368.

Zeppel, H. 2011. Planning for climate change by Queensland Local Councils. Paper presented to the 20th NSW Coastal Conference, Tweed Heads, November 2011, 8pp. www.coastalconference.com/2011/default.asp

Appendix 1: Model 2 - Maps depicting the current and future extent of marine plants (mangroves and saltmarsh) for each site

Maps showing SLR scenarios highlighting the loss (LHS) and gain (RHS) of fish habitats

TV01 Wunjunga

TV02 Bowling Green Bay - Barratas

TV03 Ross River – Alligator Creek

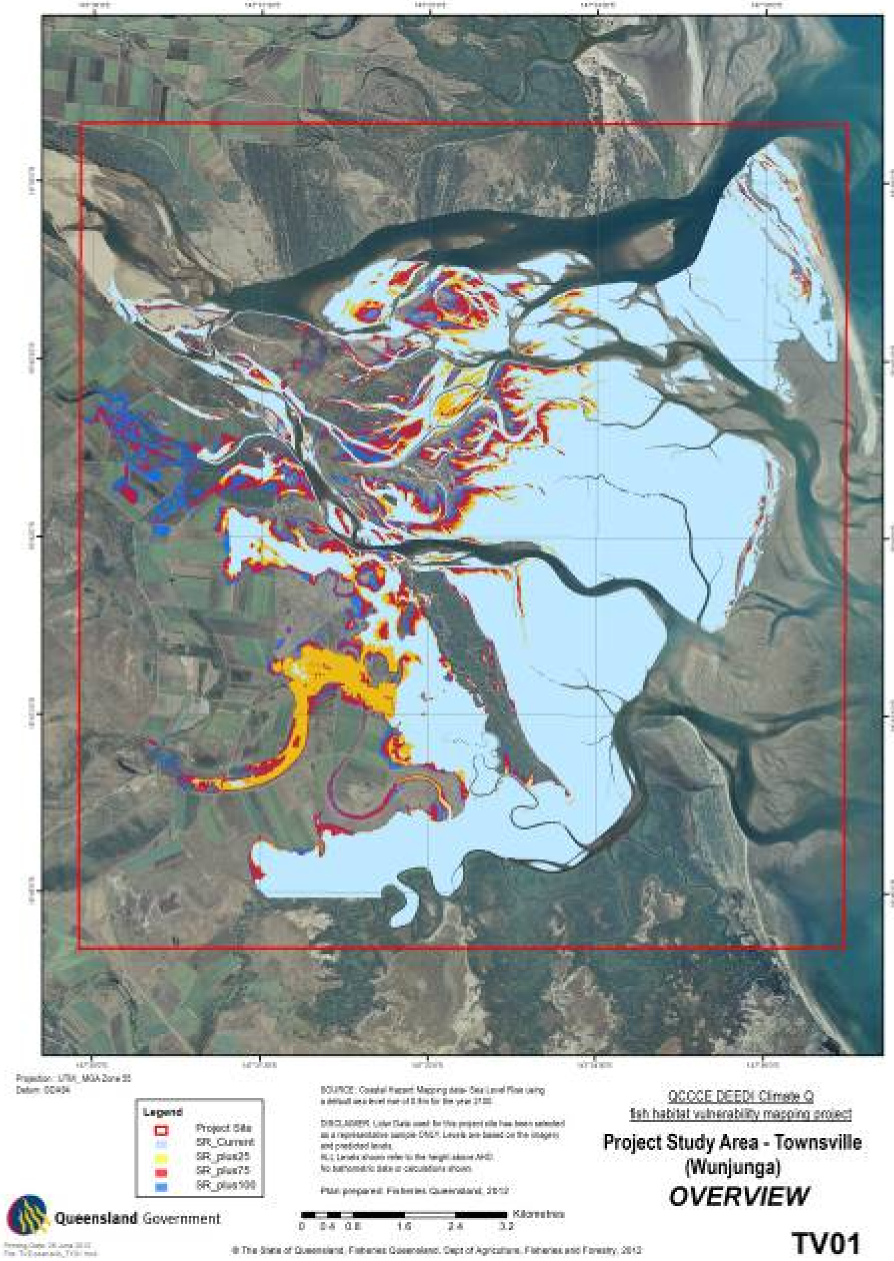
TV04 Bohle River – Town Common

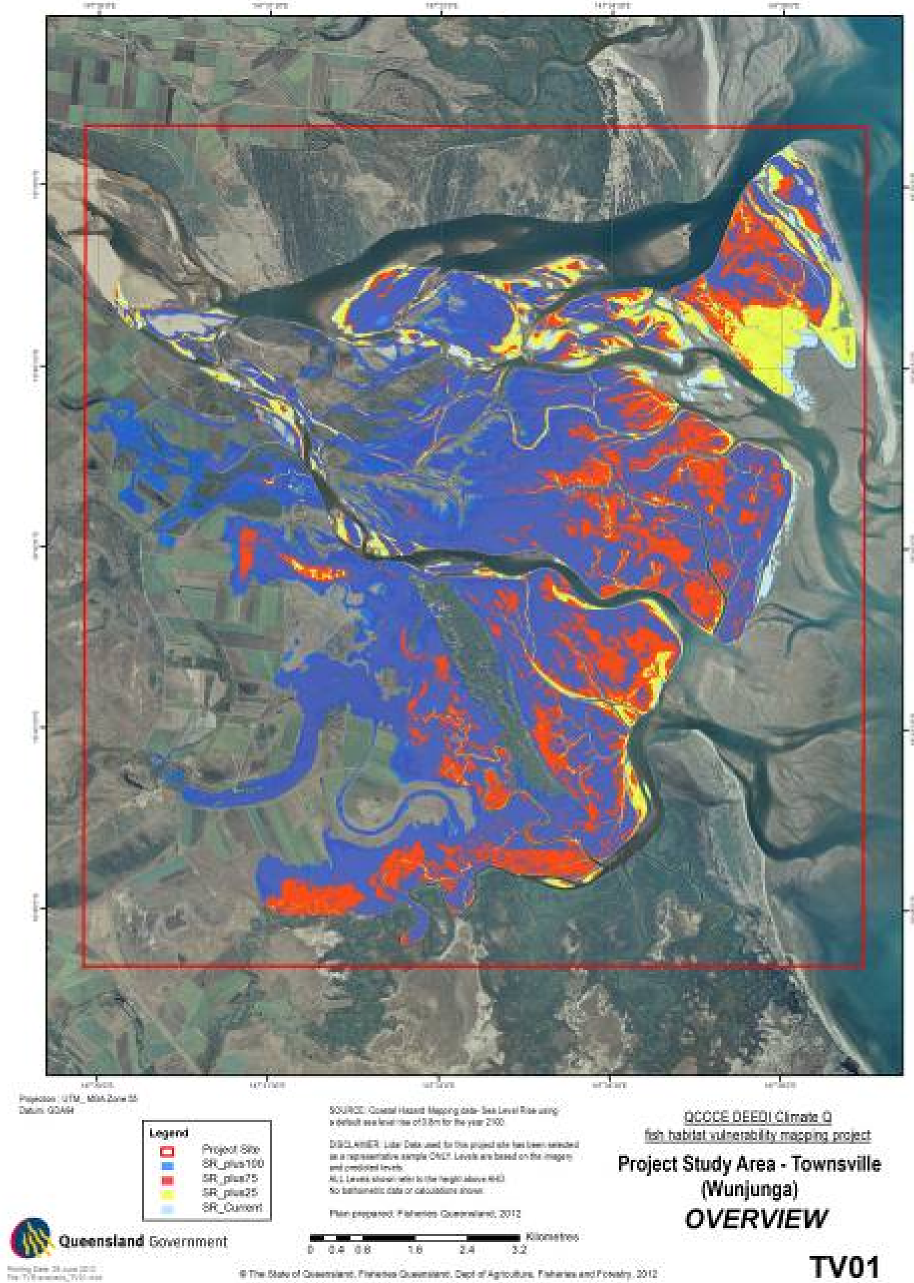
Legend for sea level rise scenarios:

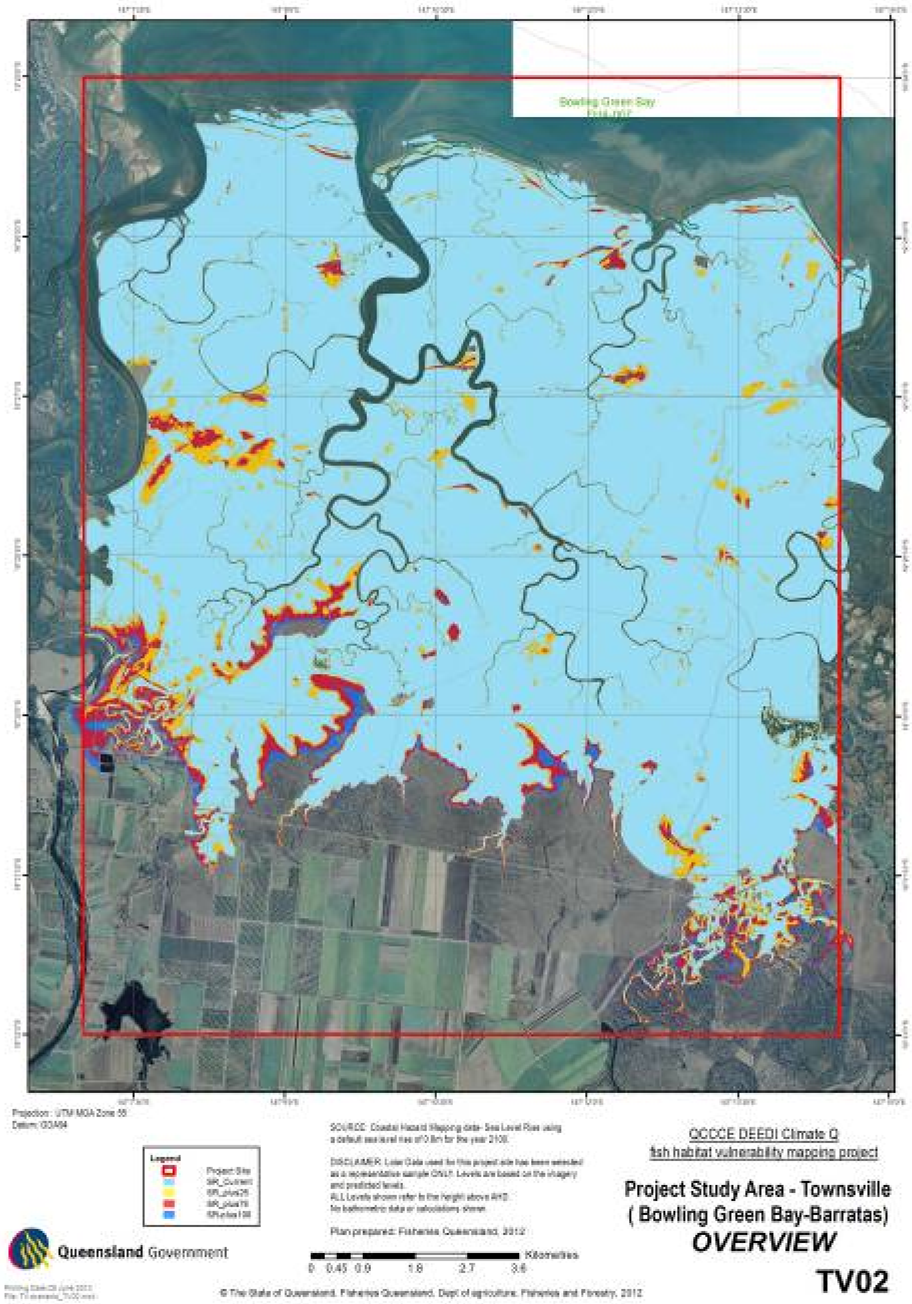
Pale blue –	SLR Current day
Yellow –	SLR plus 25 cm
Red –	SLR plus 75 cm
Dark blue –	SLR plus 100 cm

The SLR plus 75 cm equates to the 80 cm at 2100 SLR scenario for the Queensland Coastal Plan.

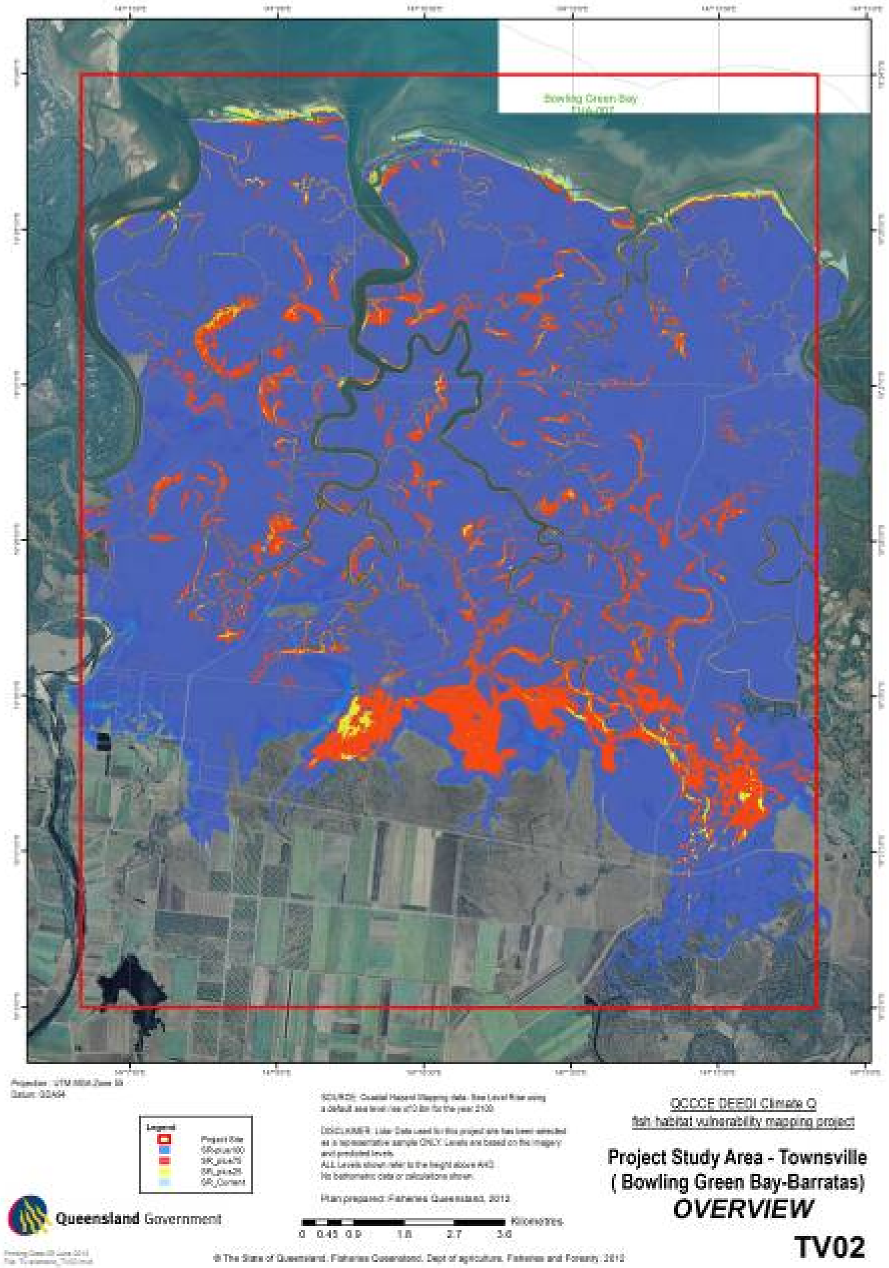
Note – All mapping (including GIS files) for each site and each SLR scenario are available through a data agreement with Fisheries Queensland.


Projection: UTM_MGA Zone 55
Legend
Project Site
SR_Current
SR_plus25
SR_plus75
SR_plus100
Queensland Government
Kilometres
0 0.4 0.8 1.6 2.4 3.2
QCCCE DEEDI Climate Q
fish habitat vulnerability mapping project
Project Study Area - Townsville
(Wunjunga)
OVERVIEW
TV01

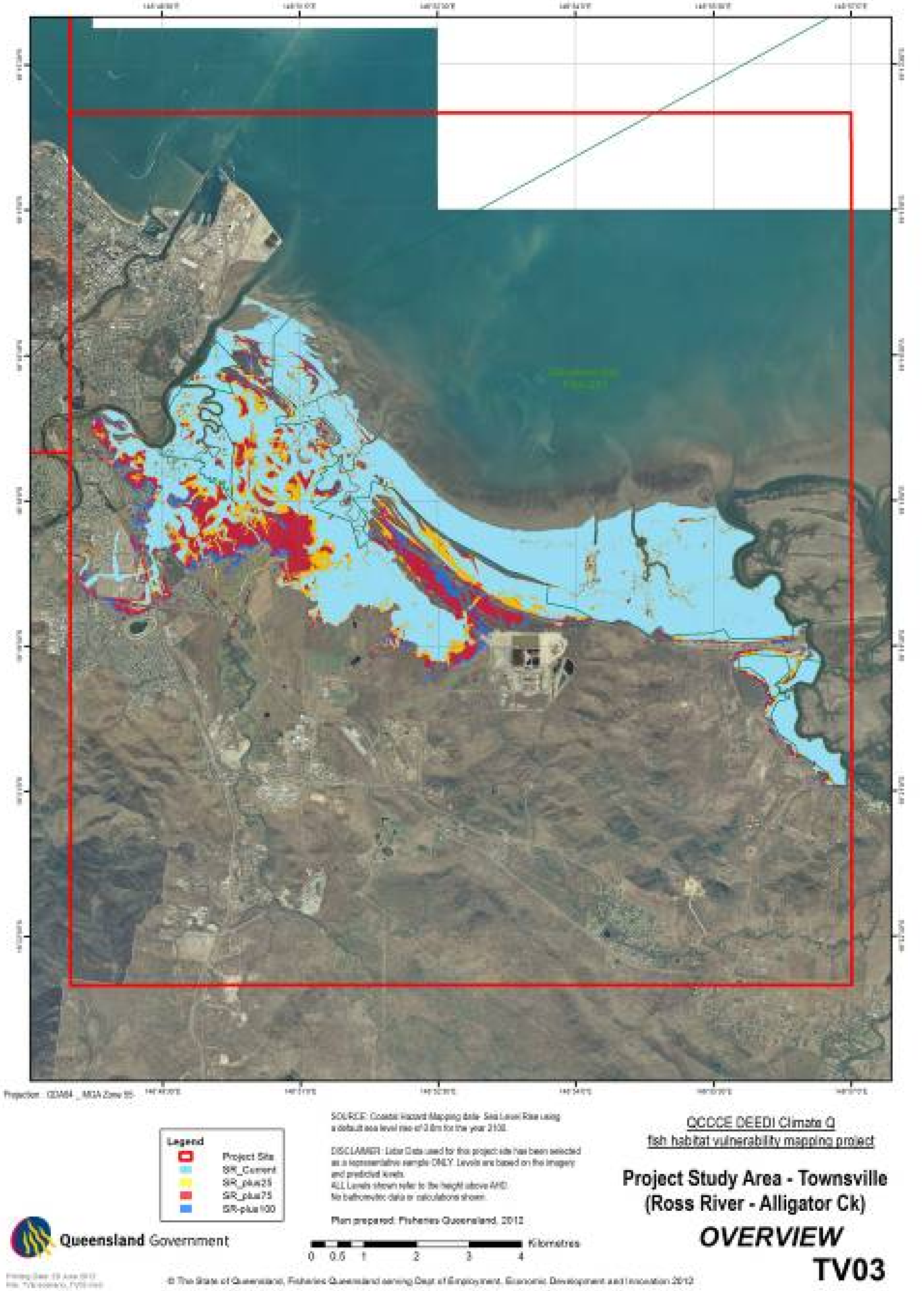

Projection: UTM_MGA Zone 55
Legend
Project Site
SR_plus100
SR_plus75
SR_plus25
SR_Current
Queensland Government
Kilometres
0 0.4 0.8 1.6 2.4 3.2
QCCCE DEEDI Climate Q
fish habitat vulnerability mapping project
Project Study Area - Townsville
(Wunjunga)
OVERVIEW
TV01



Projection : UTM MGA Zone 55
Datum: GDA94
Legend
Project Site
SR_Current
SR_plus25
SR_plus75
SOURCE: Coastal Hazard Mapping data- Sea Level Rise using
a default sea level rise of 0.8m for the year 2100.
DISCLAIMER: Lidar Data used for this project site has been selected
as a representative sample ONLY. Levels are based on the imagery
and predicted levels.
ALL Levels shown refer to the height above AHD.
Plan prepared: Fisheries Queensland, 2012
QCCCE DEEDI Climate Q
fish habitat vulnerability mapping project
Project Study Area - Townsville
(Bowling Green Bay-Barratas)
OVERVIEW
TV02
0 0.45 0.9 1.8 2.7 3.6 Kilometres
Queensland Government
© The State of Queensland, Fisheries Queensland, Dept of agriculture, Fisheries and Forestry, 2012

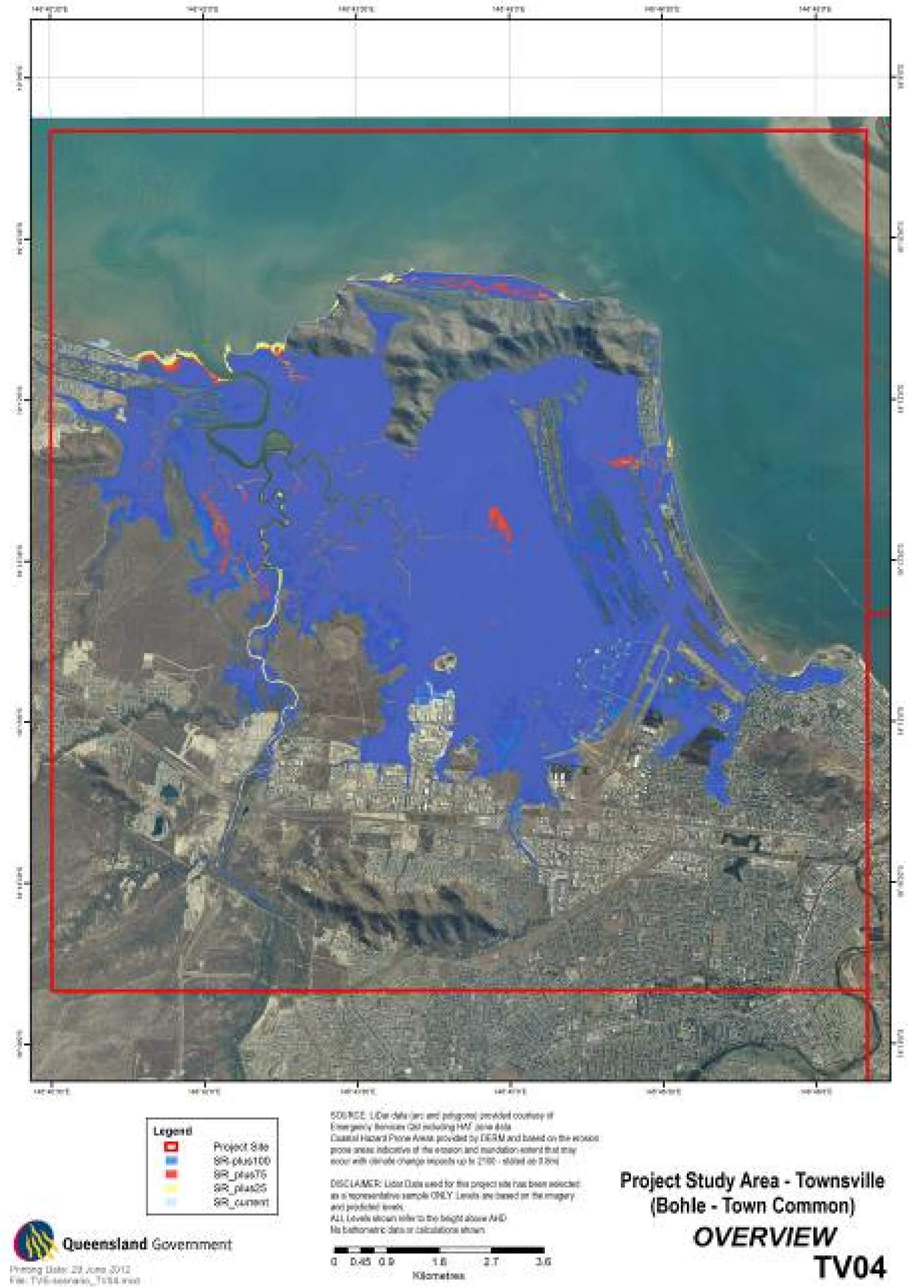


Projection : UTM MGA Zone 55
Datum: GDA94
Legend
Project Site
SR_plus75
SR_plus25
SR_Current
SOURCE: Coastal Hazard Mapping data- Sea Level Rise using
a default sea level rise of 0.8m for the year 2100.
DISCLAIMER: Lidar Data used for this project site has been selected
as a representative sample ONLY. Levels are based on the imagery
and predicted levels.
ALL Levels shown refer to the height above AHD.
No bathometric data or calculations shown.
Plan prepared: Fisheries Queensland, 2012
QCCCE DEEDI Climate Q
fish habitat vulnerability mapping project
Project Study Area - Townsville
(Bowling Green Bay-Barratas)
OVERVIEW
TV02
0 0.45 0.9 1.8 2.7 3.6 Kilometres
Queensland Government
© The State of Queensland, Fisheries Queensland, Dept of agriculture, Fisheries and Forestry, 2012


Legend
Project Site
SR_Current
SR_plus25
SR_plus75
SR-plus100
Plan prepared: Fisheries Queensland, 2012
0 0.5 1 2 3 4 Kilometres
Queensland Government
QCCCE DEEDI Climate Q
fish habitat vulnerability mapping project
Project Study Area - Townsville
(Ross River - Alligator Ck)
OVERVIEW
TV03


Legend
Project Site
SR-plus100
SR_plus75
SR_plus25
SR_Current
Plan prepared: Fisheries Queensland, 2012
0 0.5 1 2 3 4 Kilometres
Queensland Government
QCCCE DEEDI Climate Q
fish habitat vulnerability mapping project
Project Study Area - Townsville
(Ross River - Alligator Ck)
OVERVIEW
TV03


Legend
Project Site
SR_current
SR_plus25
SR_plus75
SR-plus100
Queensland Government
0 0.45 0.9 1.8 2.7 3.6
Kilometres
Project Study Area - Townsville
(Bohle - Town Common)
OVERVIEW
TV04


Legend
Project Site
SR-plus100
SR_plus75
SR_plus25
SR_current
Queensland Government
0 0.45 0.9 1.8 2.7 3.6
Kilometres
Project Study Area - Townsville
(Bohle - Town Common)
OVERVIEW
TV04