MODELLING THE POTENTIAL IMPACTS OF SEA LEVEL RISE ON COASTAL WETLANDS IN NORTH-EASTERN NSW AUSTRALIA

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Abstract

The coastal wetlands of north-eastern NSW Australia are increasingly being affected by anthropogenic factors such as urbanisation, residential development and agricultural development. This is because they are located in the fastest growing non-metropolitan region in the state of NSW. However, little is known about their vulnerability to sea level rise as a result of climate change. The aim of this research is to predict the impact of sea level rise (SLR) on coastal wetland and their vulnerability to erosion. Digital Elevation Model (DEM) and Revised Universal Soil Loss Equation modelling approaches were used to assess the impacts of sea level rise on the coastal wetlands. Geographic Information System (GIS) provided the framework for mapping and analysis. The maps showed coastal wetland areas that are vulnerable to sea level rise and areas of potential soil loss along the coast. This information could be used by local authorities in planning and conservation of coastal wetlands.

Introduction

Climate change is projected to have significant impacts on the earth's coastal systems and low-lying areas globally, regionally and locally. The anthropogenic impacts to coastal wetland communities such as urbanization, residential development and agricultural development would therefore be exacerbated by climate change. Accelerated sea level rise (SLR) caused by climate change would have severe impacts to coastal wetland communities in terms of inundation and erosion. This will generally lead to a higher coastal water level and an increased in salinity (IPCC, 2007a). The coastal wetland communities would be affected depending on the level of change in the coastal ecosystems. The coastal wetland communities include: mangroves and saltmarshes, coastal swamps, forested and dunal wetland communities. Mangroves and saltmarshes are estuarine areas that are susceptible to tidal flooding and support species such as *Avicenia marina* and *Aegiceras corniculatum* (Green, 1997). Coastal swamps include shallow marshes and meadows with species such as *Leptospermum spp. Melaleuca squarrosa, Callistemon citrinus, Epacris spp., Banksia spp. Hakea teretifolia, Bauera spp. Dillwynia floribunda,* and *Symphionema paludosum*. Forested wetlands are dominated by trees and mostly occurred on fertile soils, mostly at low altitude with species such as *Melaleuca quinquenervia* (broad-leaved paperbark). Dunal wetlands occur on coastal sand dunes or plains with vegetation that includes sedges, rushes and heaths (Green, 1997). These wetland communities may adapt to sea level rise provided the change in their ecosystem is within their threshold of adaptation. They may migrate inland provided there is an unblocked and suitable area inland for migration or else they might be extinct. According to the modelling carried out by McFadden et al. (2007) on coastal wetlands (excluding sea grasses), there will be a global loss of 33% and 44% given a 36cm and 72cm sea level rise respectively in the period of 2000 to 2080. Regionally, there would be severe loss of coastal wetlands in the Atlantic and Gulf of Mexico coasts of North and Central America, the Caribbean, the Mediterranean, the Baltic and most small islands due to their low tidal range (Nicholls, 2004).

Assessing coastal vulnerability to sea level has been addressed globally by several recent studies (Kleinosky et al, 2007; Kumar, 2006; Thumerer et al, 2000; van der Meulen, 1991; Wu et al, 2002). Most of the studies found significant threat to coastal environments due to sea level rise. In Australia, several studies have looked at sea level rise on coastal wetland communities (Eliot et al. 1999; Ellison, 1994; Semeniuk, 1994; Woodroffe, 1990). They found that wetlands such as mangroves are very vulnerable to inundation and erosion as they are mainly limited to current tidal zone.

Soil erosion is a significant issue in coastal environments which is often accelerated by clearing. According to Wischmeier and Smith (1978), the main contributing factors to erosion are soil erodibility, slope length, slope steepness, rainfall intensity, land cover and land practices. Several recent soil erosion risk studies have been carried out within Australia (Simms et al. 2003; Yang & Chapman, 2006). They found that catchments and steep lands on coastal escarpment are sensistive to soil erosion. However, there is no known research of the vulnerability of coastal wetland communities to both erosion and sea level rise especially in the north-eastern region of NSW. There are gaps in our understandings such as what wetland types are mostly at risk of erosion and sea level rise along the coast? What extent of the wetlands is likely to be inundated and eroded? This study aims at assessing the impacts of sea level rise on coastal wetland and their vulnerability to erosion.

Materials and Methods

Site Description-Location and climate

The study area extends from Evans Head to Tweed Heads within 20 m elevation from the coastline of north eastern New South Wales (Fig. 1). This is because the coastal zone was defined in this research as all areas less than 20 m elevation from the coastline. It is a low land area bounded around latitudes 28^0 09′ S and 29^0 06′ S, and longitude 153^0 00′ E. Major urban centres within the study area are Kingscliff, Murwillumbah, Pottsville, Ballina, Broadwater, Woodburn and Byron Bay. The region is subtropical with a pronounced summer and autumn ‘wet’ season and drier winters and springs. It is one of the wettest areas in the state of NSW with intense rainfall and mildest winters. February-March is generally the wettest period receiving about 30% of the average annual rainfall while June to October usually receives 20% of the average annual rainfall (Morand, 1996).

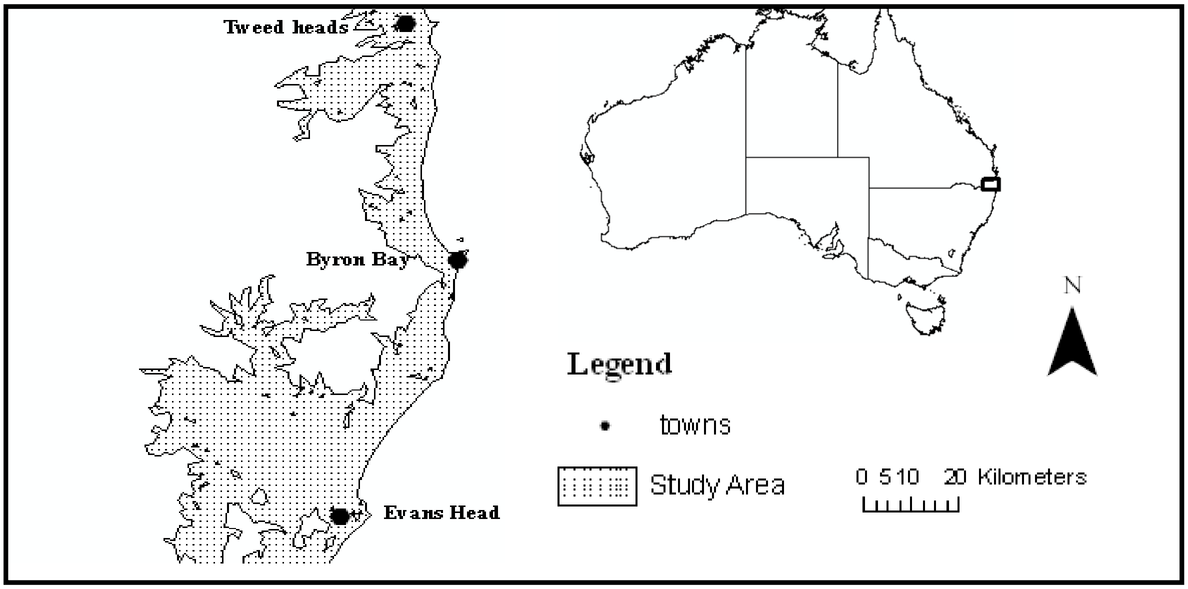

Fig.1 Study area from Tweed Heads to Evans Head, north eastern NSW Australia

Sea level rise Projection

Global average sea level rise for 1990 -2100 is projected to be 9- 88cm according to the IPCC (2001) Third Assessment Report (TAR).Warrick et al. (1996) in the Second Assessment Report (SAR) predicted a similar range of 0.20 – 0.86m by the year 2100 based on the 1990 sea level. According to IPCC (2007b) Fourth Assessment Report (FAR), global sea level rise is projected in the range of 18 – 59cm between 1980 to 1999 and 2090 to 2099. However due to the uncertainty on ice sheet discharge based on recent evidence of acceleration in Greenland and Antarctica, this study assumes a rise of about 1m by the year 2100.

Sea Level Rise Model

High resolution Digital Elevation Model (DEM) with a 5 m pixel size was used to identify areas vulnerable to a sea level rise of 1m along the coast. This was carried out using raster reclassification in ArcGIS 9.3 and the wetlands likely to be inundated identified (Fig.2).

Erosion Model

The Revised Universal Loss Equation (RUSLE) was derived from Universal Soil Loss Equation (USLE) and is written as

$A = R \times K \times LS \times C \times P$ ------------------- (1)

Where

- A is the computed soil loss per unit area, usually in tons per hectare per year (t/ha/yr);
- R is the rainfall–runoff erosivity factor (usually in MJmm/ha h yr);
- K is the soil erodibility factor (t h/MJ mm), a measure of the susceptibility of soil to erosion;
- LS is the slope and slope steepness factor;

- C is the cover and management factor; and
- P is the conservation support-practices factor.

RUSLE factors and their derivation are properly documented (Renard et al.1997; Wischmeier & Smith, 1978).This model has been a leading tool for soil erosion prediction and conservation planning in America and other parts of the world (Mitasova & Mitas, 1999).

The methodology for this study (Fig.2) involved two components i.e. sea level rise modelling and Erosion modelling. The sea level rise risk map developed was used to intersect a wetland map for the study area. The output map was overlaid with the potential soil loss map in order to identify wetland vulnerable to sea level rise and erosion.

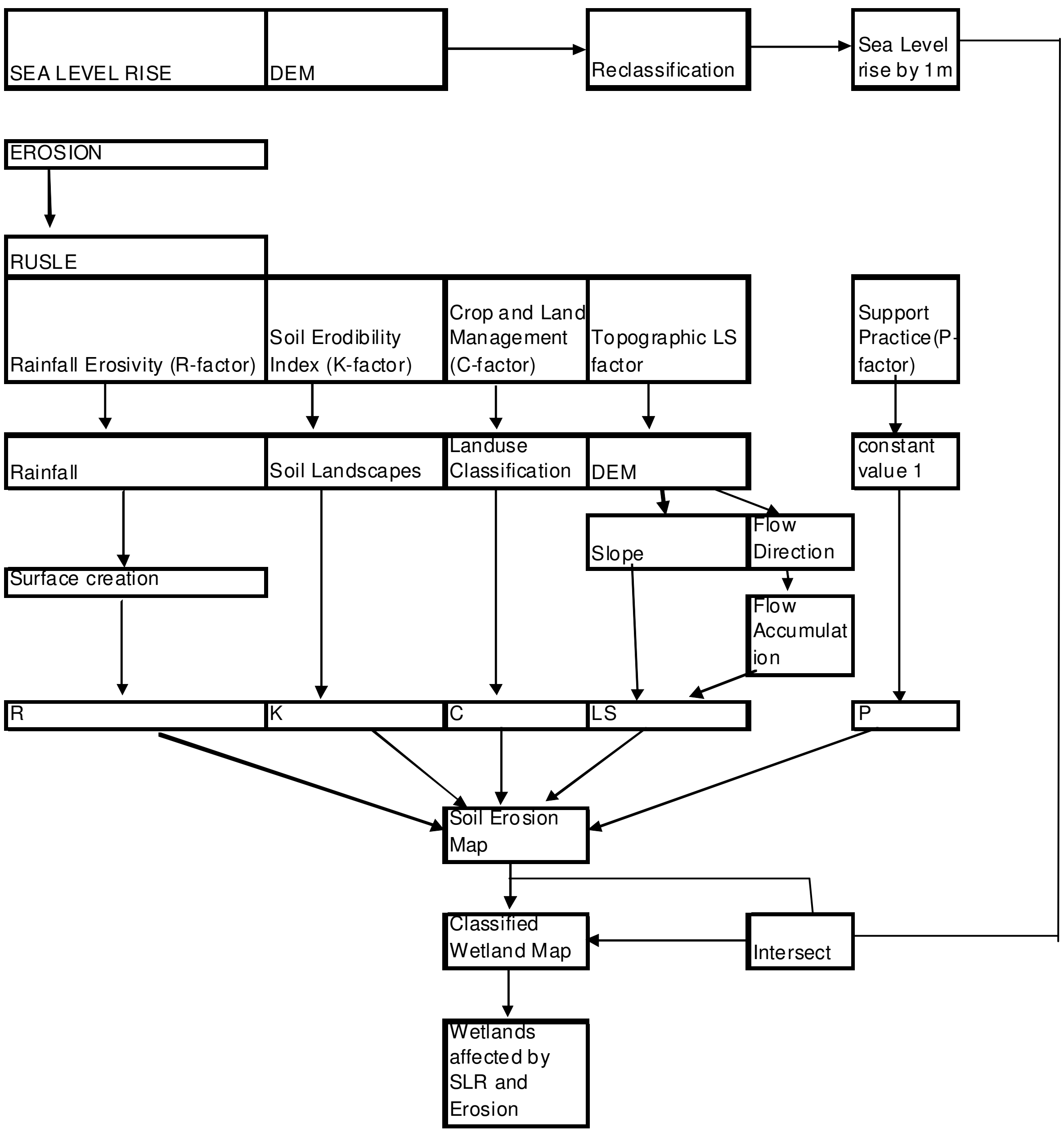

Fig.2 A flow diagram of the methodology used in the study

Rainfall-runoff Erosivity factor (R): It is a measure of the ability of rainfall to cause erosion. It is a product of kinetic energy and maximum 30-minute intensity (EI_{30}) for each storm. In the state of NSW, there is a rainfall erosivity contour (isoerodent) map (Landcom, 2004; Rosewell, 1993) which was generated from point measurements across the state of NSW for more than 29 meteorological stations with more than 20 years of records (CaLM, 1995). This was interpolated in ArcGIS 9.3 to create a rainfall grid layer with a cell size of 25m using the topogrid programme which is based on the ANUDEM programme developed by Michael Hutchinson (1989).

Soil Erodibility Index (K factor): This is the measure of the susceptibility of individual soil particles to detachment and transport by rainfall or runoff. The SI unit is t h/ MJ mm. The contributing factors of soil erodibility are soil texture, structure, organic matter and permeability. Soils with high proportion of clay would usually have low K values because of their high resistance to detachment. Soils with coarse texture such as coarse sand would also have low K values because they generate little runoff even though they are easily detachable. Medium textured soils, such as the silt loam soils have moderate K values whereas high silt content soils have high K values. This is because, high silt content soils are easily detached, tend to crust and produce high rates of runoff (Yang & Chapman, 2006). The K values for the various soil landscapes in the study area (Morand1994; 1996; 2001) were added to a theme of a soil landscape map for the region to generate a grid layer of soil erodibility in ArcGIS.

The Topographic LS factor: The slope length and steepness (LS) factor represent the effect of slope length and steepness on erosion. The effect of steepness on erosion is greater than slope length. However both are usually considered together as LS factor because they affect the magnitude of erosion. Slope length is defined as the distance from the source of runoff to the point where deposition begins or runoff becomes focused into a defined channel (Simms, et al., 2003).

The formula for calculating the computed LS factor is:

$T = (A/ 22.13)^{0.6} (\sin B/0.0896)^{1.3}$ -------------------- (2)

Where

A is the upslope contributing factor,

B is the slope angle (Simms, et al., 2003)

However, because upslope area better reflects the impact of concentrated flow on increased erosion rather than slope length (Mitasova & Mitas, 1999), slope length was replaced by upslope area in the LS factor. The process for computation in ArcGIS 9.3 was as follows:

- Using Spatial Analyst Extension, slope was derived from 25 m DEM
- Using the Hydrological Extension, sinks in the DEM were identified and filled
- Flow Direction was generated using the filled DEM as input grid
- Flow Accumulation was derived using Flow Direction as input grid
- Using Raster Calculator, LS was computed using the expression

POW ([flow accumulation] * 25/22.13, 0.6) * POW ((Sin ([slope of DEM] * 0.01745/0.0896), 1.3))

The Crop and Land Management (C factor): This represents the effect of land use on soil erosion (Renard, et al., 1997). It is the ratio of soil loss from land cropped under specific conditions to the corresponding loss from continuous tilled bare fallow (Wischmeier & Smith, 1978). In this study, a Land use/Land cover map was generated using Landsat ETM+ and their various C factors allocated for each Land use/Land cover class. A grid layer of C factor was later generated as an input in the model using ArcGIS 9.3. Cover types ranged from 0.003 -1 and were adapted values from (Gonzalez, 2008; Printemps, et al., 2007; Simms, et al., 2003).

Table 1: Land cover types and their C factors

Natural vegetation	0.003
Agricultural land	0.45
Urban	0.85
Water	0
Bare land	1
Cleared Land	0.45

The support Practice (P factor): This corresponds to the soil conservation measures or other operations that control erosion, such as terraces, strip cropping and contour farming. However, because there was no available information for the study area, P was set to 1
Finally, the map of potential soil loss was produced using Raster Calculator to build the expression: R x K x LS x C x P. Ground truthing was carried out in order to validate some of the high erosion risk areas.

Vulnerable wetlands to both SLR and Erosion

The 1m sea level rise risk map was used to intersect the wetland map produced for the study area using Landsat ETM+. The output file was later intersected with the potential soil loss map of more than 1t $ha^{-1}yr^{-1}$ in order to identify wetlands vulnerable to both SLR and Erosion.

Results and Discussion

The map below showed the impact of sea level rise on inundation along the coast. A subset of the study area i.e. part of the Tweed Heads region was selected (Fig.3).
The study found that about 634 hectares of mangroves and salt marshes would decrease by inundation due to sea level rise of about 1m. This is probably due to the fact that mangrove species such as *Avicennia* and *Rhizophora* are characterized with an elevation of 0.01 to 0.79m while the species in the group of *Aegiceras* and *Bruguiera* occupy areas of 0.33 to 0.89m in elevation (Youssef, 1995). About 83 hectares of forested wetlands, 64 hectares of coastal swamps and 87 hectares of dunal wetlands are also likely to decrease by flooding due to sea level rise of about 1m (Fig.4). This inundation of brackish and fresh water wetlands would alter the hydrological regimes such as the nature and variability of hydro periods and the number and severity of extreme events (Baldwin et al., 2001; Burkett & Kusler, 2000; Sun, et al., 2002).

Fig.3 Coastal areas vulnerable to inundation by a 1m rise in sea level

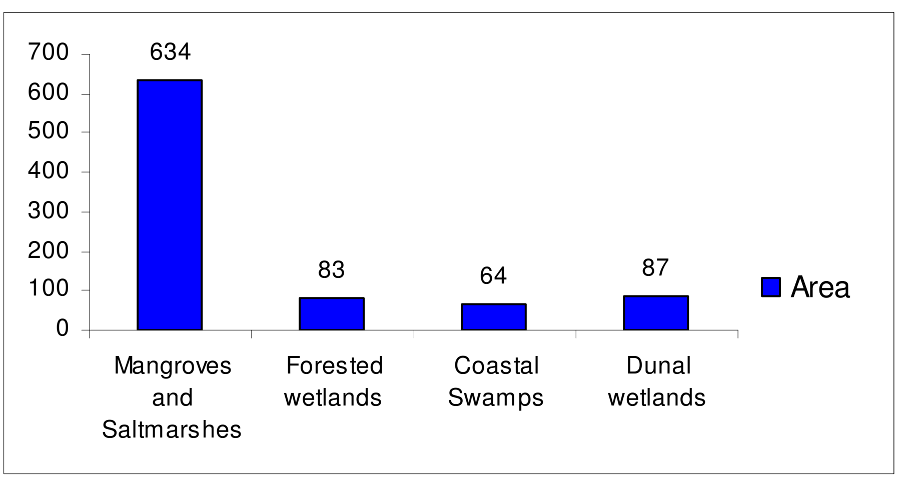

Fig.4 Area of wetlands (ha) likely to be inundated by sea level rise of 1m in north eastern coastal region of NSW

Furthermore, it was found that estuarine water bodies would increase in size by about 688 hectares while the extent of coastal upland water bodies such as rivers, lakes and lagoons would increase by about 2,306 hectares. This would be due to the influx of saline waters from the sea to surrounding coastal water bodies.

Table 2 Increase in coastal water bodies by sea level rise of about 1m in north eastern coastal region of NSW

Wetland type	Flooded area created by SLR
Coastal upland water bodies	2,306 hectares
Estuarine water bodies	688 hectares

This influx of saline water from sea level rise to estuarine and coastal upland water bodies would increase the salinity of estuarine and coastal upland water bodies. This may tend to displace or extinct some existing plant and animal communities and also alter the functioning in these ecosystems. Plant communities, such as mangroves may migrate into adjacent wetland communities such as saltmarshes apparently due to sea level rise. This phenomenon of landward migration of mangroves has already been recorded in south-east Australia (Saintilan & Williams, 1999). In Louisiana, sea level rise and salt water intrusion have been identified as factors in the decline of coastal bald cypress (*Taxodium disticum*) forest (Krauss et al., 2000; Melillo, et al., 2000).

According to Saenger (2002), increased sea level rise from climate change would have negative effects on wetlands such as mangroves by increased in saline intrusion and erosion. From the erosion modelling carried out in this study, potential soil loss sites of less than 1t ha^{-1} yr^{-1}, 1-10t ha^{-1} yr^{-1} and more than 10t ha^{-1} yr^{-1} were identified along the coast. A subset of the map showing part of the Tweed Heads region was selected as shown below (Fig.5 & 6)

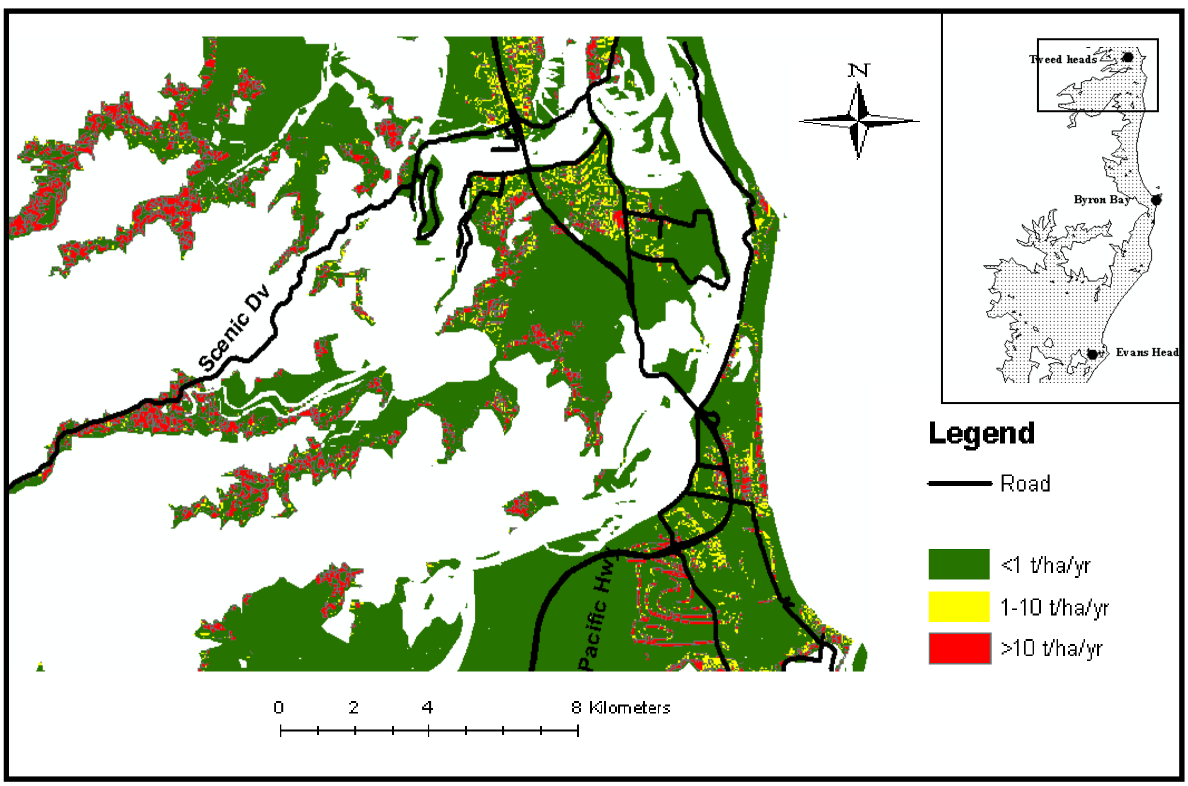

Fig.5 Potential soil loss based on Revised Universal Soil Loss Equation (RUSLE)

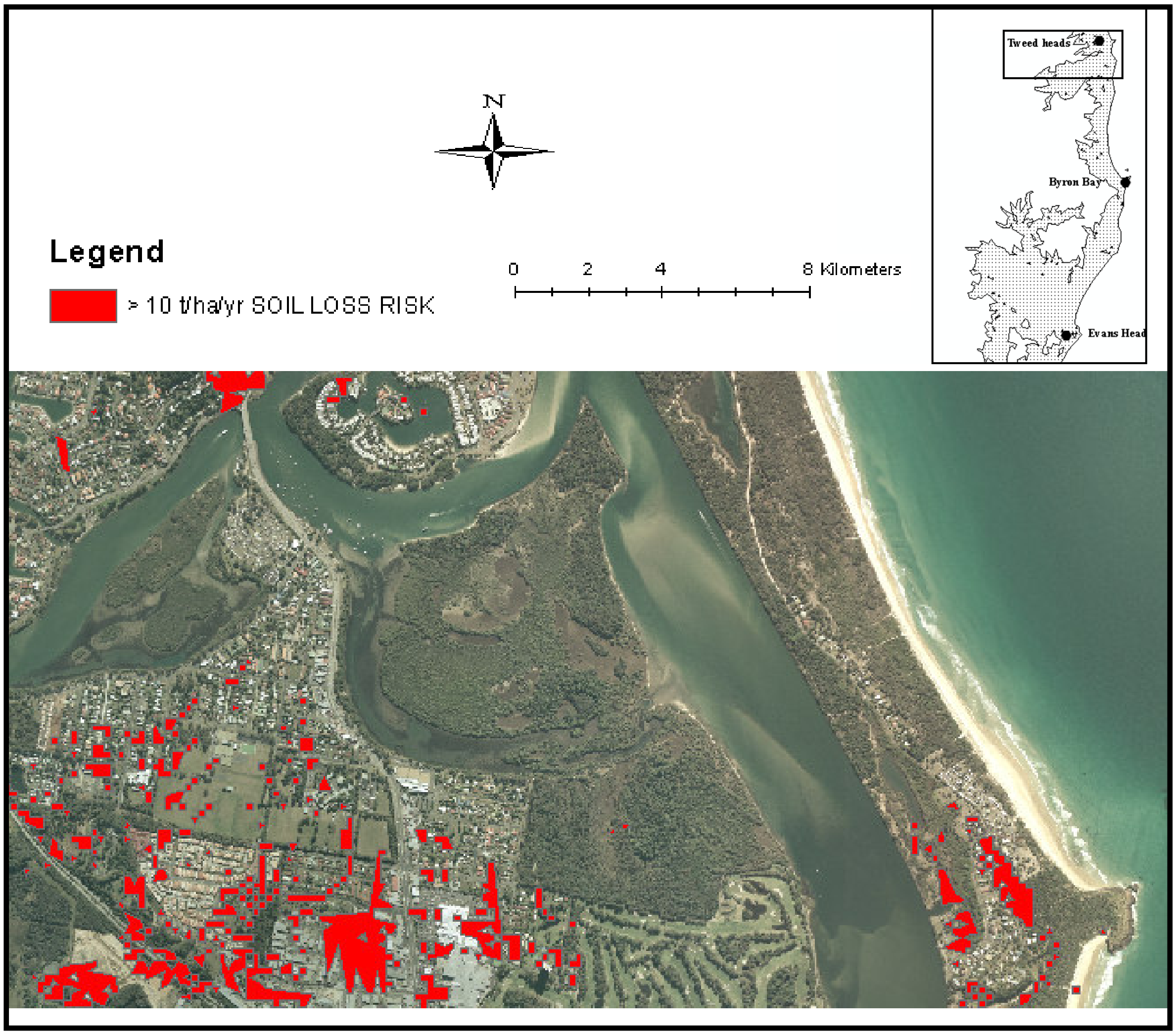

Fig.6 Potential soil loss of >10t/ha/yr based on Revised Universal Soil Loss Equation (RUSLE)

The study found that most parts of the study area were least sensitive to erosion i.e. potential soil loss of less than 1t ha^{-1} yr^{1} as a result of runoff or rainfall. This is probably because; most part of the region is low lying with less runoff. Also, most of the highly sensitive areas with soil loss of more than 10t ha^{-1} yr^{1} were on areas with high elevation.

Upon integrating the sea level rise and erosion model, the study found wetlands that are most likely to be inundated by sea level rise and are vulnerable to erosion. About 4.01 hectares of forested wetlands are likely to be inundated by sea level rise of about 1m and are sensitive to erosion of more than 1t ha^{-1} yr^{1}. Also, about 1.99 hectares of mangroves and saltmarshes, 3.01 hectares of coastal swamps and 1.54 hectares of dunal wetlands are likely to be inundated by sea level rise of 1m and are sensitive to erosion of more than 1t ha^{-1} yr^{1} (Fig.7).

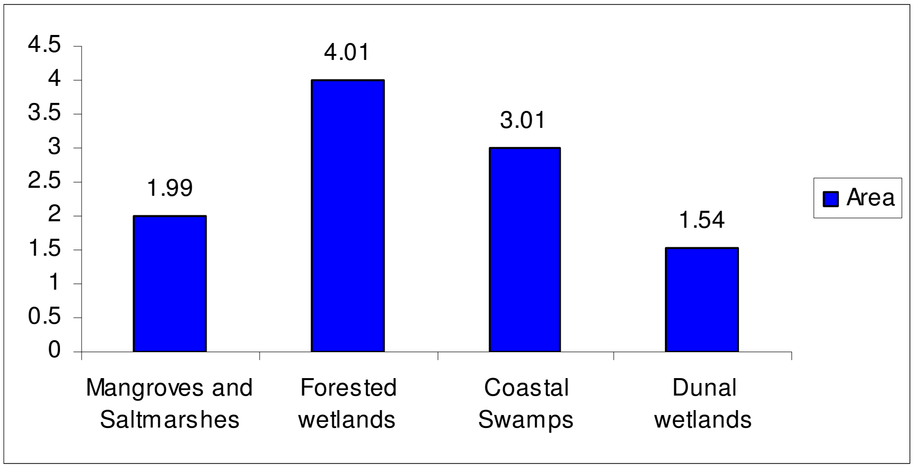

Fig.7 Area of wetlands (ha) susceptible to both inundation by sea level rise and erosion in north eastern coastal region of NSW

The highest value of 4.01 hectares for forested wetlands is most probably due to the fact that they are located at high sensitive erosion areas. The lowest value of 1.54 hectares for dunal wetlands is possibly due to their low erodibility. This is because coarse sand would generate little runoff even though they are easily detachable. Generally, the extent of wetlands vulnerable to both inundation by sea level rise and erosion is very low compared to inundation alone.

Conclusions

Climate change induced sea level rise would significantly affect the coastal wetland communities in north eastern NSW. It would lead to inundation of about 634 hectares out of a total area of 3,656 hectares for mangroves and salt marshes in the study area. About 83 hectares out of a total area of 15,209 hectares for forested wetlands in the region would also be inundated. Furthermore, about 64 hectares of coastal swamps out of a total area of 15,056 hectares found in the study area is most likely to be inundated by sea level rise. In addition, 87 hectares of dunal wetlands out of a total area of 7,337 hectares found in the study area would be inundated by sea level rise. Coastal erosion would also be enhanced by sea level rise but in a relatively low magnitude compared to inundation. This is because the potential soil loss from erosion in most parts of the coastal zone is less than 1t ha^{-1} yr^{-1} as most areas are flat land. However, both inundation and erosion hazard impacts should be considered in planning by coastal managers and local authorities in order to minimize the projected impacts of climate change.

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