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GIS-based modelling of vulnerability of coastal wetland ecosystems to environmental changes: Comerong Island, southeastern Australia

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ABSTRACT

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Sustainable management of coastal zones has become a complicated issue. The majority of the human population lives along the coast, where their activities, together with a range of environmental changes, have altered the natural ecosystem processes and caused changes in coastal wetlands. To ensure sustainable use of coastal resources, a comprehensive set of modelling tools can help managers to make decisions. This study uses Comerong Island (southeastern NSW, Australia) as a case study to demonstrate the importance of modelling modifications to environmental change. Several data-based modelling approaches are employed to explore how human activities have altered this estuarine island setting over the last sixty years (1949 – 2014). Multi-temporal changes in land cover, shorelines and sediment delivery are estimated from remote sensing data, GIS analysis, and laboratory tests on water and sediment samples (grain size, X-ray diffraction and loss on ignition and water analysis). Results show there are significant changes to the areal extents and elevation of mangroves, saltmarshes and shorelines in the wetlands on Comerong Island over the time period of analysis, including northern accretion (0.4 km^2), eastern, middle and southern erosion (0.7 km^2) of the island. The implementation of modelling using GIS tools, water and sediment samples to monitor ecosystem processes, such as sediment transport and erosion/deposition, will allow resource managers to make more informed decisions by evaluating the potential consequences of the existing situation.

ADDITIONAL INDEX WORDS: *eco-geomorphology, sediment transport, erosion, human modifications.*

INTRODUCTION

Coastal wetlands are among the most productive, sensitive and responsive ecosystems affected by climate change and human influences that control most of the eco-geomorphological processes and pressures (DSE, 2007). Human and natural hazards that have influenced coastal wetlands should therefore be monitored, whether for the direct threats of loss to the wetlands itself or indirect loss to its catchment. Particularly within New South Wales, coasts and their hinterlands have been substatially modified after European settlement.

Early civilizations inhabited coastal areas (e.g. Mesopotamia; Postgate, 1992) and nowadays 70% of the human population and 86% of Australians live along the coasts for ecological and economic reasons (Cherfas, 1990; Neumann *et al.*, 2015). Human-induced stressors that resulted in challenges of degradation have increased since last century and caused loss of coastal ecosystems, particularly within coastal wetlands (DSE, 2007). Wetland studies across the globe have indicated the negative effects of human activities on wetlands (Ehrenfeld, 2000).

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In addition, modifying the catchment and its water usage has caused many problems. For example, 60% of fresh water has been diverted from coastal NSW, Australia, since the start of European settlement (Saintilan and Imgraben, 2012). Kingsford (1990) revealed that direct and indirect human influences can change estuarine habitats, which can then affect the conservation of shorebirds.

Background

The NSW coastline is a great natural asset, making an enormous contribution to the economy. Although conservation rules are strictly applied in Australia, many studies have estimated significant indirect destructive impact of human activities in Australian wetlands. Thus, examining the existing situation and modelling the current modifications to natural processes is important for any applicable study site. Comerong Island (Figure 1) represents an ideal example of this context that reflects disturbed regimes.

Comerong Island Nature Reserve is located approximately 170 km south of Sydney and 11 km to the east of Nowra. It is situated between the Shoalhaven River mouth-entrance, Greenwell Point and Orient Point (see Figure 1). The nature reserve consists of coastal sand barrier, tidal flats and islands built up of river silt behind the dune barrier sands within the Shoalhaven River delta.

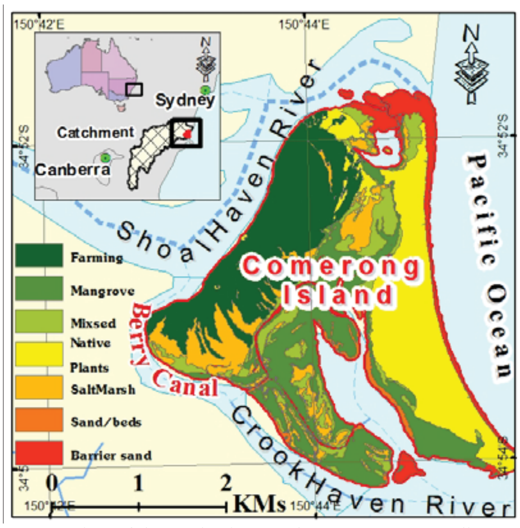

Figure 1. Location of the study site, southeast NSW, Australia.

Comerong Island is part of an infilled coastal deltaic estuary and is mostly made of sediments derived from the Shoalhaven River catchment associated with its ocean sandy barrier built up from marine sand during the Holocene transgression (Woodroffe *et al.*, 2000; Wright, 1970). The Shoalhaven River has a 7177 km^2 of catchment area, which is the sixth largest catchment in NSW (OWA, 2010). This large catchment provide abundant sediment during high flood flows which move down to the delta. This has resulted in the estuary becoming infilled during the past 7000 years (Umitsu *et al.*, 2001; Woodroffe *et al.*, 2000). In 1822 Alexander Berry built a canal that linked the Shoalhaven and Crookhaven Rivers (Figure 1) as an alternative entrance since the Shoalhaven Heads. This entrance had become very shallow causing higher water levels that threated the estuary and all associated human settlements (Thompson, 2012). The area encompassed by the two rivers and the canal became Comerong Island (Umitsu *et al.*, 2001). After the construction of the Berry Canal both the Shoalhaven and Crookhaven (5 km south) entrances act as discharge points to the sea. Berry Canal was originally only 190 m long and 5.5 m wide, but erosion pressure on the banks and bed of the canal has increased its width to 250 meters (Thompson, 2012; Umitsu *et al.*, 2001).

The study site on Comerong Island has faced strong human modifications since European settlement that have caused a series of sediment availability and transport problems and have negatively affected natural processes. Water flow and sediment transport have been further modified since the construction of Tallowa Dam in 1976, Figure 2 (SCA, 2015). The dam has blocked most of the water and its sediment derived from the upper catchment making it effectively inactive (Figure 2). Moreover, 35% of the catchment has been used for agriculture and a further 11% for forestry (OWA, 2010; Figure 2).

Human activities are placing unprecedented pressure on these coastal resources. Studies conducted on the effects of human activities on wetlands indicate the multiple needs of wetlands for different purposes, such as urban development, business, agriculture, tourism, recreational and conservation (Shahbaz *et al.,* 2009). The Shoalhaven River floodplain, which covers approximately 5% of the catchment, has a reputable history of being one of the richest dairy areas in NSW (NPWS, 1998). Other significant industries include commercial fishing, oyster growing and vegetable farming (Shahbaz *et al.*, 2009). Additionally, the tourism industry is one of the main human activities, where recreation fishing, surfing and boating are the order of the day (NPWS, 1998). The floodplain is also experiencing considerable urban and industrial growth, particularly in and around Nowra (OWA, 2010). To protect the marine and coastal wildlife, artificial wetlands have been constructed to provide additional habitat (Murray *et al.*, 2013).

This exploratory study investigates the effects of human activities on the ecosystems and biodiversity around Comerong Island. The study is based on a literature review augmented by sampling and subsequent GIS modelling to provide a qualitative outcome that can be used to offer possible sustainable management solutions.

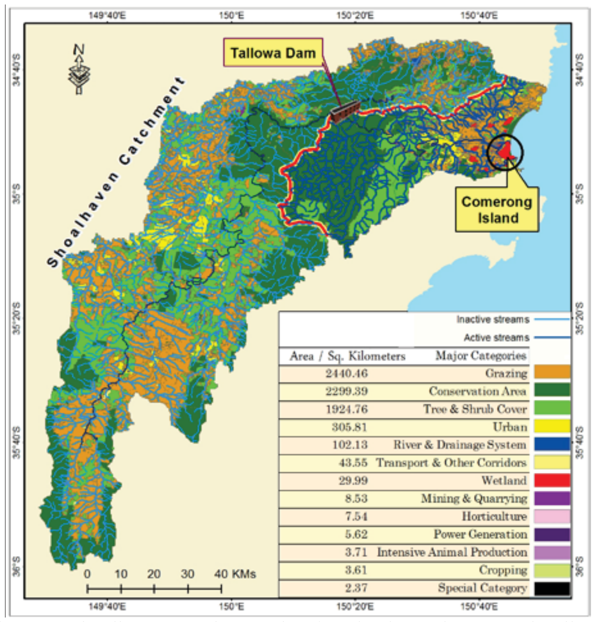

Figure 2. Shoalhaven Catchment showing; land use classes' and Tallowa Dam that separates the upper and lower catchments.

METHODS

This study is based on a continuous assessment of multi-temporal changes in landcover, shorelines, and elevation stability. The reduced or increased areas of wetlands have been assessed by measuring the landcover on aerial photographs and satellite images over time. Analysis of the shoreline has determined the changes in erosion/accretion rates around Comerong Island. Changes of mangrove and saltmarsh areas (as a landcover function) illustrate the shoreline position and elevation stability in the Comerong coastal wetlands. This approach has been achieved through continuous monitoring methods. This project entails the assessment of threats, such as shoreline erosion and sediment delivery problems. In addition, effects of artificial modification in the catchment are the principle element addressed.

Achieving the project targets was done on several levels. It started with GIS and RS-based analysis to identify and classify the landcover and shoreline changes at this specific study sites depending on recent and historical records of aerial photography, satellite and LiDAR data. This was combined with sampling of the water, soil and sediment. The main objectives of the paper are to monitor and measure the coastal wetland shorelines, land cover and elevation changes/trends in order to model potential modifications for rehabilitation of the wetlands. To achieve these aims, this study divided the methodology into three parts as seen in Figure 3.

Data Collection

Various data have been collected to achieve the study aims. Remote sensing (RS) and GIS data were used to classify land use classes. LiDAR (2004 and 2010) and SRTM (2011) data have been used in ArcGis10.2 to create DEMs.

Field work recovered 113 sediment and soil samples from Comerong Island. Grain size analyses, X-ray diffraction (XRD) and loss on ignition (LOI) tests on these samples yielded the grain size and proportions of minerals and organic matter. A Yeo-Kal 615 multi-parameter water quality analyzer was used in the field to measure water samples in real time to test it for pH, conductivity, dissolved oxygen (DO), salinity and turbidity.

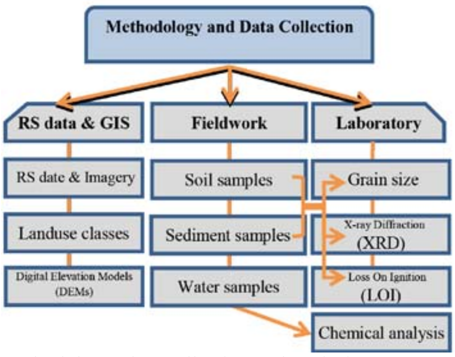

Figure 3. Methodology; data collection and analysis sequences.

RESULTS

Results showed significant coastal wetland challenges of degradation and change, which caused losses that are addressed as follows:

The multi-temporal analysis of remote sensing (RS) and GIS data indicates that Comerong Island and its environment have suffered a significant loss of wetlands (aproxmatly 0.3 km^2). Additionally, it indicated that some of the saltmarsh areas were converted to agricultural usage, and the mangrove cover lost ground as a result of shoreline erosion (Figure 4). This study also determined the effects of human modification within the wetland's catchment and assessed the extent of the human activities impact during sea level rise stresses.

DEMs have shown significant elevation changes over time on Comerong Island (Figure 5). So far, the western, mid and southern sides of the island have eroded as mapped in red on Figure 5. Meanwhile, accretion has expanded the northern region with minor erosion in the middle of that area.

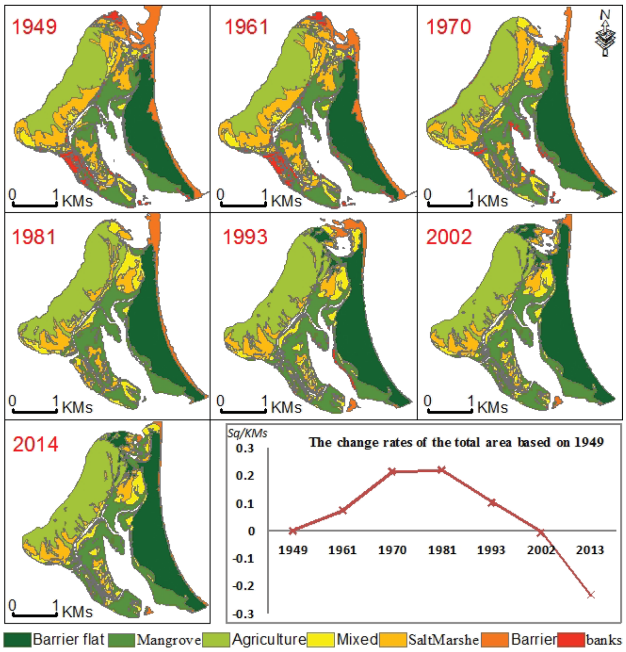

Figure 4. Multi-temporal imagery (1949 – 2014) showing significant changes of land cover, shorelines and total area.

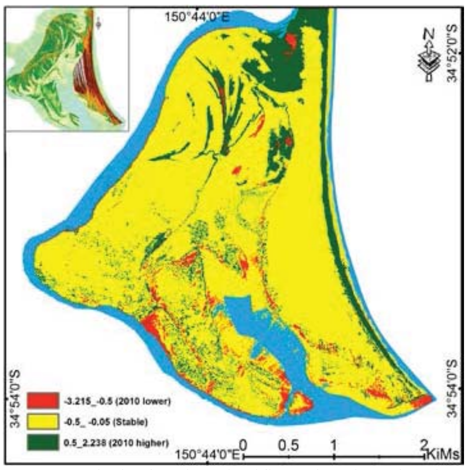

Figure 5. DEMs analysis showing significant loss in red and accretion in green while stable areas are shown in yellow (LPI, 2004 & 2010).

Soil and sediment samples have been checked for their grain size using a Mastersizer 2000 laser diffraction particle size analyzer, which generated results shown in Figure 6.

Most of the island is made of sand, especially along the north, east and south sides, where wave energy has built those parts of the island (Figure 6). The silt and clay present along the western side of Comerong Island have been derived from the Shoalhaven

River catchment. The rates of sedimentation and types of sedimentary sequences could then be related to events such as the flood history records.

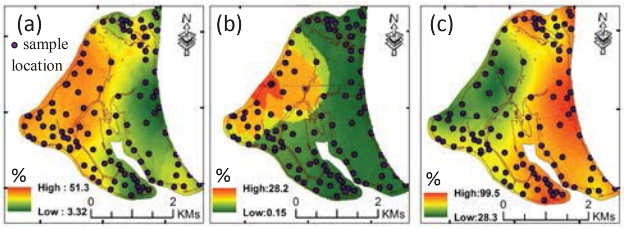

Figure 6. Soil, sediment samples and grain size analysis from Comerong Island; (a) clay proportion, (b) silt proportion and (c) sand proportion.

Twenty four samples tested with X-ray diffraction (XRD) showed that all samples are dominated by quartz, especially along the eastern beach and barrier where wave action has eliminated most of the softer minerals and clays (Figure 7). Along the western and southern sides of Comerong Island and in the active channel areas feldspar and lithic sand grains form a prominent component representing fluvial sands derived from volcanic, volcaniclastic and mudstone rocks in the source area. Clay content in the samples is highest in the low energy environments around the island, but also occurs in the fluvial lithic sands through the diagenetic alteration of feldspar and lithic sand grains.

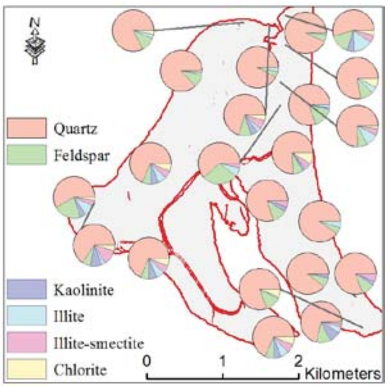

Figure 7. Mineral content of sediment samples / around Comerong.

Twenty samples chosen from an east-west cross-section were analyzed for organic matter using loss on ignition (LOI). this has been applied to check how much the biotic and abiotic components playing roles in changing the elevation. LOI data show two main areas have the highest proportion of organic matter; one positioned in the very muddy section in the middle of the island represented by mangrove area, and the other occurs in the area with the highest density of native plants in the eastern part of the island. LOI data was also used to evaluate changes in elevation with respect to the water table.

The average discharge of the Shoalhaven River has been below five megalitres per day from 1914-2014 with the exception of flood related events. However since these gauging stations are located in the upper reaches of the river system, they do not reflect the situation downstream, thus eight samples from below Tallowa Dam have been collected and tested. Water samples from the Shoalhaven River show very low amounts of suspended sediment downstream from Tallowa Dam (Figure 8).

The water samples show a significant increase in conductivity, dissolved oxygen and turbidity downstream from the dam reflecting an increase in suspended sediment and salinity. These results clearly prove there is less sediment delivery and high rates of bank erosion in these downstream areas, which leads to increasing turbidity and siltation in the adjacent wetlands.

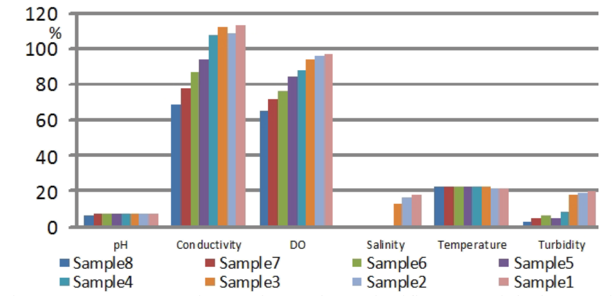

Figure 8. Water samples analyses show significant spatial changes in conductivity, dissolved oxygen and turbidity.

DISCUSSION

This multi-temporal study of the Comerong Island wetland shows a significant loss of coastal wetland in southeastern Australia. The main losses were changes in landcover, shoreline and elevation which resulted from the negative effects of human activities on the wetland's catchment. This comprehensive monitoring, plus other studies conducted by multiple researchers, has revealed the serious negative effects of human activities on the wetlands in and around Comerong Island. A number of spatial and temporal monitoring solutions should be considered for effective coastal wetland management. Significant results include:

1. Modelling aerial photographs and RS data (1949-2014) of the shorelines shows the northern part of the island has expanded by 0.41 km^2, whereas, the western and southern portions have been eroded by 0.73 km^2. This situation has resulted from the sediment delivery and erosion/deposition processes, that are mostly controlled by human infrastructure up stream such as Tallowa Dam, combined with the ocean tidal affected by sea level rise. Together these have caused a reduction in sediment delivery, which cannot balance the erosion/deposition caused by natural processes.

2. Grain size tests show most of the island is composed of sand, with clay in the west and uniform silt contents. Comerong Island is therefore made of soft materials, which are more easily eroded and lost than in other coastal ecosystems that may be more sensitive to rising sea level.

3. XRD tests show the minerals that Comerong Island is made of sediments that originale from both the catchment and the ocean. Northern accretion on the island has been caused by

addition of ocean sediment via the open mouth of Shoalhaven River.

4. Using loss on ignition proves high plant density in the east and mid parts of the island. The high proportion of organic matter included biotic components, such as leaf litter, mangrove debris and roots. This organic matter plays an important role on elevation changes and surface accretion.

5. Construction of the Berry Canal appears to have dropped water levels and reduced the wetland area, especially saltmarshes, on Comerong Island.

This modelling framework could be applied to study coastal wetlands all over the world. This project proved significant, detailed and accurate results of changing coastal wetlands in an eco-geomorphological context for risk assessment, using modern modelling methods. Such information will be essential for government agencies to issue and revise their policies. It will also be important for the general public and scientists who are currently focusing their attention on the best way to preserve wetland ecosystems to achieve conservation targets.

CONCLUSIONS

Both natural and anthropogenic processes control the balance between sediment deposition and erosion rates. The Shoalhaven River has provided high sedimentation rates, historically. These high sedimentation rates and lower erosion rates have controlled the natural accretion processes around Comerong Island. The aerial photographs and RS data (1949, 1961, 1973 and 1982) show that the island has grown constantly. After 1982, however, the island has eroded and its size has declined as shown in the aerial photographs and RS data (1993, 2002 and 2014). The reason behind this change was the building of Tallowa Dam, which blocked most of the sediments collected from the catchment. Thus 80.1% of the catchment (5,750 km^2 of 7177.5 km^2) was converted to inactive catchment geomorphologically. That caused serious sediment transport and availability problems, which changed the positive sedimentation rates to negative values, and favored erosion.

Initially after Tallowa Dam was constructed in 1976, the sediment rates remained high and the island continued to grow. This was due to the new water level within the Shoalhaven River that dropped below the dam (for 58.8 km until it reached Comerong Island) which caused erosion of the river bed and edges providing sediment to the Comerong Island area. This occurred for a few years only, after which the natural processes failed to erode additional sediment resulting in less sediment availability and deposition in the lower reaches. This is reflected in higher erosion rates that now control the site. This study has shown that the shoreline eroded by 0.73 km^2 since 1982 (0.02 km^2 annually). Meanwhile, the northern part of the island has grown significantly (about 20% between 1949 and 2014). This can be related to barrier deposition by natural tidal processes that have affected northern area during periods when the river mouth was open.

To restore the coastal wetland ecosystems fully there is a need to monitor its extent carefully to ensure long-term success. One can choose a natural mechanism that will offer a self-sustaining approach or self-management. By considering the findings from scientific studies, relevant policies need to be implemented to repair the damage from human activities in such wetlands.

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