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Abstract
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SHOALHAVEN RIVER MOUTH: A RETROSPECTIVE ANALYSIS OF BREACHING USING AERIAL PHOTOGRAPHY, LANDSAT IMAGERY AND LIDAR

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ABSTRACT
The Shoalhaven river, located on the wave-dominated south coast of eastern Australia, has the 6th biggest catchment area (7,151 km²) that debouches in NSW waters. Although the river mouth is breached during floods, most of the time the normal flow is diverted through an artificially dug canal and only reaches the ocean at Crookhaven Heads. A search throughout LandSat archives and aerial photographs from 1949 has shown not only that the river mouth was opened in 1961, 1974-1980, 1988-1994 and at the end of 1999, but also revealed that dune vegetation has been developing as increasing sand closes the river mouth. Nowadays, the river outlet is sealed by a 200-m wide sand deposit that ranges in elevation from 2.1 to 5.4 m above mean sea level. Historical comparison of LiDAR data also demonstrated the widening of Berry’s canal as erosion takes place on its flanks. These findings provide useful evidence for a sediment budget approach to coastal management to be developed in this coastal compartment.

Keywords: Remote sensing, sediment budget, sand deposition

INTRODUCTION
Coastal systems are evolving over varying time scales, and the form of the shoreline is responding to the major processes acting upon it (Woodroffe and Leon, 2010). Multispectral and medium spatial resolution remote sensing data have been broadly applied to address a variety of coastal issues (Wang, 2010). Landsat images and air photography have been used in coastal applications for decades allowing measurements of biophysical characteristics of coastal environments over time. Active remote sensing such as LiDAR (Light Detection and Ranging), has proven to be very effective for analysis of morphological change, due to its capacity to provide spatial details for mapping the coastal landscape (Wang, 2010).

Sediment budgets are a fundamental element of coastal sediment process studies encompassing many applications (Komar, 1998) in geomorphology and engineering. It involves understanding of the sediment sources, sinks, magnitude and transport for a selected compartment of the coast, within a period of time, providing useful insights for coastal management.

After the destructive effects of storms in 1967, 1972 and 1974, there has been increased awareness of the importance of management of the coast in NSW, Australia. The embayed wave-dominated coast of southeastern Australia is subject to both coastal erosion and deposition of sand restricting or sealing certain types of estuaries off from the sea (Chapman et al. 1982).

The Quaternary plain of the Shoalhaven river is an example of a mature stage estuary. The natural course of the Shoalhaven river (Fig.1) has been modified and its flow was artificially diverted to exit at Crookhaven Heads, after the construction by Alexander Berry of a 200-m long channel in 1822 forming Comerong island (Young et al. 1996; Umitsu et al. 2001). Since then, Berry’s channel continues to widen (Woodroffe et al. 2000) and directs the flow of the Shoalhaven River to exit at Crookhaven Heads. The former mouth of the river at Shoalhaven Heads has been impounded by the deposition of a sandy berm. Following major floods, the outlet is breached temporarily while the river flows naturally to the Tasman Sea, with the beach berm gradually reestablishing over time. Another major modification has been introduced after the construction of the Tallowa dam, upstream of Nowra, smoothing the flash flooding of the river considerably (Short and Woodroffe, 2009).
This study provides preliminary insights into the exchange of sand at Shoalhaven Heads, as well as, identifying areas of erosion on Berry’s channel, extending the works initiated by Chaffer (1998) and Thompson (2012). The extended air photography database, Landsat images and LiDAR data provided a time series of estuarine source and sink of sediments for analysis.

**METHODOLOGY**

The historical retrospective was developed using Landsat imagery and air photography. Individual LandSat images were retrieved from the archived dataset downloaded from [http://earthexplorer.usgs.gov/](http://earthexplorer.usgs.gov/). A total of 89 images for the 090Path/084Row from satellites Landsat 1, 2, 5, 7 and 8 were used (Table 1). RGB Composites were created for each passage, excluding Band 6. The Spatial resolution improved from 60m (Landsat 1 and 2) to 30m (Landsat 5) and finally 15m (Landsat 7) after merging the medium-resolution multispectral bands with the high-resolution panchromatic Band 8 (Pan-sharpening). Landsat 8, newly released to the public, provided two images for 2013.

This study used airphotography that started in 04/04/1949 and finished in 24/03/2002, and were acquired by several organizations including Australian Survey Office, AWACS, LIC and Air Maps Australia, at different scales (Table 2). These images were scanned and rectified using a 1st order polynomial transformation.

**Table 1: Historical Landsat archive**

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Date</th>
<th>Sensor</th>
<th>Resolution</th>
<th>Satellite</th>
<th>Date</th>
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<th>Resolution</th>
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<td>MSS</td>
<td>60</td>
<td>L5</td>
<td>29/09/1991</td>
<td>TM</td>
<td>30</td>
</tr>
<tr>
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<td>MSS</td>
<td>60</td>
<td>L5</td>
<td>02/12/1991</td>
<td>TM</td>
<td>30</td>
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<tr>
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<td>MSS</td>
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<td>L5</td>
<td>18/12/1991</td>
<td>TM</td>
<td>30</td>
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<td>MSS</td>
<td>60</td>
<td>L5</td>
<td>19/01/1992</td>
<td>TM</td>
<td>30</td>
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<td>Date</td>
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<tr>
<td>04/04/1949</td>
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The Light Detection and Ranging (LiDAR) data were provided by two sources: the Shoalhaven Council and the NSW Land and Property Management Authority (LPMA). The Shoalhaven Council contracted AAM Hatch Co. to collect the data from a fixed wing aircraft on 21/08/2004, while the LPMA started a standard LiDAR survey on 17/12/2010 and finished on 13/04/2011.

LiDAR is a technology that determines the distance to a surface using laser pulses. Distance is computed by measuring the time delay between transmission and detection of the reflected signal. The provided data was organized in 2x2 km tiles and the data processing consisted of converting LAS files into multi points, then to single points and finally creating TINs. The data was processed using any returned values with a minimum point density of 1 point/m².

The 2004 and 2010/2011 data were used to assess net erosion on Berry’s channel. A comparison between TINs derived from different years was done in order to identify and quantify the widening of the artificial channel. The Shoalhaven Heads area was surveyed only by the LPMA in 2010/2011 and was used to calculate sand volume.

RESULTS AND DISCUSSION

The Landsat archive and aerial photographs (Figs. 2 and 3) have shown that the river mouth was opened in 1961, 1974-1980 and 1988-1994. The oldest photo taken in 04/04/1949 shows the river mouth closed but the consecutive one taken in 21/09/1961 is the first register of the breached outlet. The sand barrier was breached in the southern part, towards Comerong Island. The next photograph showed a closed mouth and unfortunately was taken only in 16/04/1970, a long time-span in between records to determine how long it remained opened. Another flight 37 days after that day still shows the deposition of sand widening the beach and deforming the concave shape of the Shoalhaven beach-Comerong island embayment.

The photo taken in 01/07/1972 shows that the action of the waves has transported sand deposited on the shoreline and surf bars are observed in the air photo of 23/05/1970.

In 05/11/1972 the first Landsat image capturing Shoalhaven Heads is acquired.

The effects of the storms of May-June 1974, that affected the coast of NSW was apparent in the photo taken in 29/12/1974, which shows the ~ 700-m wide-open entrance. The Landsat 2 image and photos of late 70s and early 80s show the gradual closing of the entrance. The Landsat image of 15/09/1980 is the last to register of the closing mouth, while the photograph taken on 12/02/1981 shows a completely closed entrance.

During the 80s the entrance remained closed until it appears to open again in the image of 18/07/1988. This time the estuary-shoreface exchange of water was restricted to less than 150m. The closing took about 2 years as identified in the 24/07/1990 Landsat 5 image. However, the next satellite passage in 09/08/1990 showed the entrance breached again (370m wide). The following process of closing took ~ 3.5 years, as the mouth remained opened till the Landsat image of 24/01/1994. In 30/04/1994, the outlet appeared closed, while the images in between these two dates were covered with clouds.

Between 30/04/1994 and 20/05/2013 the mouth appeared open in only one image recorded in 30/11/1999. This image shows a small strip of flow in the south part of the Shoalhaven Heads. We don’t know exactly when it opened, but we can assume that it happens after 10/08/1999 and was closed by 02/02/2000.

The broad image retrospective presented in this study including more than 100 images capturing the morphology of Shoalhaven Heads adds important information to the understanding of sediment availability to the coast discussed by Wright (1970) and the morphodynamics of its river mouth (Wright, 1976). In an overall perspective it resulted in a rate of 1.6 image per year during the 66 years period. However, some important time gaps constrained our capabilities to estimate the mouth state during the 50s, when no image was acquired and 60s, when only one image was taken.

LiDAR (2010/2011) revealed that dune vegetation is developing as increasing sand closes the river mouth. Nowadays, the river outlet is sealed by a 200-m wide sand deposit that ranges in elevation from 2.1 to 5.4 m above mean sea level (Fig. 4).
Fig. 2: Historical archive: Landsat 1 (05/11/1972), Landsat 2 (15/09/1980), Landsat 5 (18/07/1988 and 24/01/1994), Landsat 7 (30/11/1999) and Landsat 8 (20/05/2013)

Fig. 3: Air photography of Shoalhaven Heads. First remote sensing image of the river mouth was acquired in 04/04/1949
Fig. 4: Sand accumulated in the river mouth - DEM originated from LiDAR (2010/2011) with air photo on the back.

Fig. 5: TIN Comparison of Berry’s channel (LiDAR data 2004 and 2011). Positive (Negative) values indicate erosion (deposition).
Historical comparison of LiDAR data demonstrated the widening of Berry’s canal as erosion takes place on its flanks (Fig. 5). In the entrance of the channel erosion takes place on both banks, with a prominent loss of sediments between 2004 and 2010/2011 especially on the right margin, which retreated by more than 10 m. Significant erosion occurred downstream as well, on the northern end of Apple Orchard Island and along the opposite bank on Comerong Island, in accordance to results presented by Thompson (2012).

CONCLUSIONS
This work was performed in the human-modified catchment of the Shoalhaven River, southern NSW, Australia. The use of both passive and active remote sensing data has proven to be an important tool in the reconstruction of recent past modifications that occurred in the river mouth as well as, in Berry’s channel.

The gathering of LandSat archive combined with air photography has created a historical perspective of periods of close entrance alternated with open states, when the deposition of sand by wave action was inferior to the river power to breach the entrance. Since 1949, the river mouth appeared breached in 1961, 1974-1980, 1988-1994 and at the end of 1999.

LiDAR data provided the topographic information to quantify depositional and erosion processes and will be important in estimating the balance of volumes of sediments, so significant for the management of the coast.

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