20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013
www.mssanz.org.au/modsim2013

A Dynamic Habitat Mudflat Model for The Coorong, South Australia

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Abstract: The Coorong is a 2-3 km wide lagoon running parallel to the coast for approximately 100 km from the Murray Mouth in South Australia. It provides an important habitat for a wide range of bird species, and in particular has been listed as a Ramsar wetland due to its exceptional importance for migratory waterbirds. Using an extensive dataset of high resolution bathymetry data with the outputs of a CSIRO hydrodynamic model detailing hourly water level and salinity along the Coorong for given flow scenarios, we developed a dynamic habitat model for key bird species. The GIS-based model predicts the availability and viability of mudflats, defined as soft sediment areas that are either immersed or covered by no more than 12 cm of water, where most waterbird foraging occurs. Mudflat availability varies spatially and temporarily along the Coorong, and is influenced by tide, wind, rainfall and evaporation, some of which are dependent on the distance from the Murray Mouth and are affected by seasonal variation. The modelling of mudflats at different water levels suggests that an average water level of 0.12 m AHD gives the maximum average mudflat area across the majority of the Coorong.

We present a model that can be run for any given flow scenario over any time period for any site along the Coorong. However, this model can be easily modified for use in different environments where water level-habitat interactions are important. For the Coorong, it is important for managers to understand the influence of both water level and salinity on mudflat habitats as well as the aquatic habitats for fish, macrophyte and infauna. The spatial model developed for this study allows managers to readily quantify these habitats for specified flow scenarios, and supports informed decisions on the amount and frequency of barrage outflows from the Lower Lakes when excess water is available for environmental improvement and maintenance of the Coorong.

Keywords: *Habitat modelling, hydrodynamics, bird habitat, Coorong*

1. INTRODUCTION

The Coorong lagoonal system (Figure 1) forms part of one of the largest estuaries in Australia and has been recognized nationally and internationally for its ecological, social and economic significance (Seaman 2003; Edyvane 1999). The ongoing drought conditions in the Murray Darling Basin have led to a situation where virtually no freshwater flows have entered the Lagoon since 2003 (CLLAMM 2008). The ecology of the Lagoon and surrounding region has been negatively affected by rising salinity and reduced water levels, particularly in the South Lagoon (Geddes 2005a; 2003). Consequently, ecosystem degradation in the Coorong is threatening many iconic bird and fish species. For example, salinities in the South Lagoon have risen to become hypersaline (100-160 g/L) in recent years, and key plant species like *Ruppia tuberosa* (Tuberous tassel) can no longer survive and have become restricted to the North Lagoon (CLLAMM 2008).

Before the recent ecological degradation associated with the Millenium Drought (2000-2010), the Coorong supported a diverse array of interconnected habitats driven by salinity and water level. Lamontagne *et al.* (2004) acknowledged salinity and water level as the key ecological drivers of the system. Based on the salinity gradient, the habitats in the Coorong can be differentiated into freshwater around the Murray Mouth, estuarine in the upper North Lagoon and marine in the lower North Lagoon and South Lagoon. Specific biological communities of macrobenthos, fish and phytoplankton colonised these habitats, depending on their salinity tolerance.

In the Coorong, water level and periodic inundation also play a key role in defining spatial extent for fish habitats as well as availability of mudflats. These mudflats constitute highly productive feeding grounds for wading birds and attract large numbers of local and intercontinental species (Rogers and Paton 2009a; Wilson 2001), resulting in the region's designation as a Ramsar Wetland of International Significance. As a consequence, Australia is obligated to maintain the area in the state that it was in at the time of declaration. However, Wilson (2001) reported a drastic reduction in the number of waterbirds in the Coorong since early 1980s. In the past three decades, the largest flock of birds (234,543) counted in 1982 while 48,425 birds were counted in 2001. The number of Sharp-tailed Sandpipers, Red-necked Stints, Curlew Sandpipers, Red-necked Avocets and Red-capped plovers declined sharply over the period (Wilson 2001).

Restoration and conservation of all these habitats are considered highly significant for the biological diversity and ecological sustainability of the region. Variations in water level are primarily attributed to the timing and volume of freshwater input over the barrages, Upper South East Drainage (USED) flow, and the opening of the Murray Mouth (Webster 2007). The seasonal variation in water levels is mainly caused by rainfall and evaporation, while wind and tide have a higher frequency temporal effect. In the summer, the Coorong and surrounding region receive low rainfall (average < 22 mm per month at Meningie) with very high evaporation (average > 225 mm per month for the Lakes) compared to the winter season rainfall (average >40 mm per month at Meningie) and evaporation (average < 60 mm per month for the Lakes). High rainfall with less evaporation in July is likely to favour higher water levels than in January. On a shorter time-scale, the tide has diurnal or semi-diurnal effects in areas around the Murray Mouth and up to 15 km from the Mouth in the North Lagoon, whereas wind influences water levels both in the North and South Lagoon (Webster 2007). Although the volume of the water inputs, season (time), rainfall, evaporation, tide and wind all act together to determine water level at any point in time, the seasonal variation in the water levels is due primarily to rainfall and evaporation in no/low flow situations, resulting in high and low water levels in winter and summer, respectively. Spatio-temporal variation in all these factors impact on salinity and water levels along the lagoons. In response to fluctuations in salinity and water levels, the available habitats are subjected to change, which ultimately affects the composition and productivity of biological communities.

The restoration of the diverse ecosystems of the Coorong is of utmost importance to maintain its status as a Ramsar listed wetland as well as its iconic site status under the Federal Living Murray Initiative. It has been acknowledged that a detailed understanding of the ecology of the Coorong is necessary to prescribe a decision-support framework for an effective intervention, which would aim to restore the vital lagoonal ecosystem in the Coorong. The necessity of ecological knowledge at the local level and, in particular, understanding of the relationships between species and their environment, have been widely acknowledged by many ecologists as key to the successful conservation and management of ecosystems (Carter *et al.* 2006; Gibson *et al.* 2004).

Water level and salinity are the key ecological drivers in the Coorong, and influence the overall distribution of biological communities and the state of the ecosystem as a whole. Changes in water level influence the availability of mudflat habitats for waterbirds (Rogers and Paton 2009a) and their main food source by impacting on distribution of *Ruppia tuberosa* (Rogers and Paton 2009b) and macroinvertebrates. Salinity has been recognized as the most critical factor for the ecological sustainability of the Coorong, impacting directly on the aquatic biological communities (fish, vegetation and macroinvertebrates) and indirectly on the waterbirds through influencing their primary food source (*R. tuberosa*) (Rogers and Paton 2009b; Rolston and Dittmann 2009).

The accelerated degradation of ecosystems and biodiversity in the Coorong require a detailed understanding of the species-environment relationships for iconic bird and fish species to predict their habitats at varying salinity and water levels. Our model predicts mudflat availability for waterbirds by quantifying available mudflat areas up to 12 cm water depth, where the majority of waterbird foraging occurs (Rogers, pers. comm.; Wildlife Habitat Management Institute 2000). The accessibility of mudflats for waterbirds is likely to be determined by their size. As the average size of the major waterbird species does not exceed 21 cm (for Sharp-tailed Sandpiper), the shallower mudflat areas are generally available for foraging. The model integrates digital elevation models (DEMs) and hourly water level data from Webster's (2007) model to predict foraging ground up to 12 cm water depth; a part of the mudflat specifically utilized by waterbirds in the Coorong. The model generates mudflat habitat maps for hourly water level data showing the availability of mudflats in any given area and allows for the application of a salinity threshold.

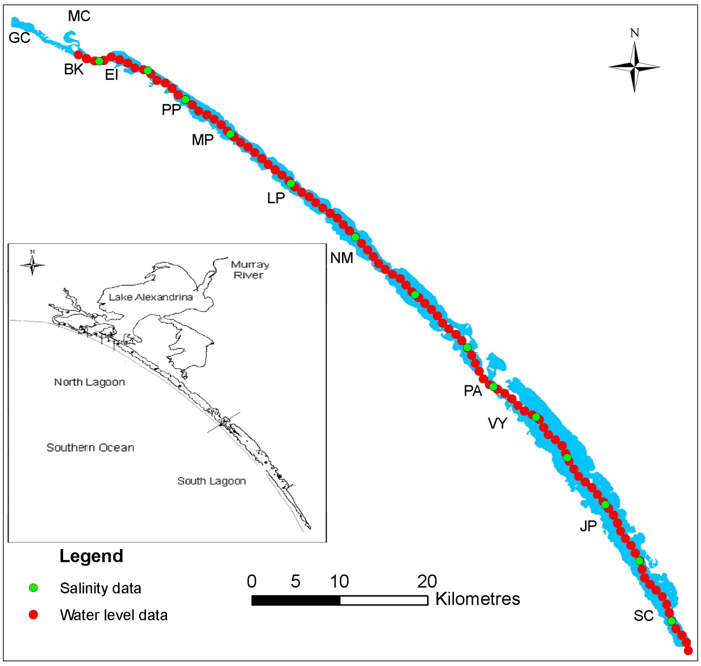

Figure 1. Locations of water level and salinity data points generated through the hydrodynamic model in relation to the CLLAMMecology reference sites. (GC = Goolwa Channel; MC = Mundoo Channel; EI = Ewe Island; BK = Barker Knoll; PP = Pelican Point; MP = Mark Point; LP = Long Point; NM = Noonameena; PA = Parnka Point; VY = Villa dei Yumpa; JP = Jack Point and SC = Salt Creek. Inset shows lakes/lagoon system.

The habitat model was developed within a GIS framework in ArcGIS (v10.1) (Environmental Systems Research Institute 2012), written in Python (v2.7.2), and iteratively applies hourly water level and salinity data generated by the hydrodynamic model. It is not a truly dynamic process model as it neither simulates the physical process for predicting habitat change nor uses outputs of previous iterations as input to the subsequent iteration (Environmental Systems Research Institute 2012). However, the model uses hourly data on water level and salinity from the hydrodynamic model and delivers hourly habitat maps depicting the dynamic influence of these ecological factors on habitat availability in the Lagoon.

2. METHODS

2.1. Datasets

The bathymetry data generated for studying mudflat geomorphology and availability was gathered from a variety of surveys for use in the model. However, any bathymetric data can be used as inputs. Depth data for the North Lagoon were collected by the South Australian Water Corporation (SA Water) using an echo-sounder and GPS mounted on a boat. However, such a survey was not feasible in the South Lagoon due to the shallow water depth. The high resolution (1m) DEMs were constructed from detailed bathymetry available from SA Water, detailed surveys of mudflat morphology using a SOKIA SET5 30RK Surveying Instrument, complemented by Differential Global Positioning System (DGPS) surveys and at deeper water depths by watercraft-mounted sonar. Other areas were surveyed by airborne Lidar during low water levels in the Coorong. At all sites, mudflat topography was interpolated from supplied and field-collected data using radial basis functions in the Geostatistical Analyst extension of ArcGIS.

Webster (2007) developed a hydrodynamic model which simulates water levels and salinity within the Coorong as these respond to barrage flows, Upper Southeast Drainage System flows, sea level changes, wind, evaporation, precipitation and exchange through the Murray Mouth. This one-dimensional model outputs time series of simulated water level and salinity for each of 102 and 14 cells, respectively, along the centreline of the Coorong between the Murray Mouth and the southern end of the Lagoon. Water level is output at one km intervals, whereas salinity is output at intervals of 5 to 10 km (Figure 1).

The hydrodynamic model was originally developed using barrage flows derived for a single climatic and development scenario from the CSIRO Sustainable Yields (SY) Project. Synthetic time series of flows were constructed by analysing the daily time series of climatic data for the period 1891-2008 in combination with an inflow model run using the current state of agricultural development and current water management rules (Chiew et al. 2008). The scenario we use is a flow time series based on the historical climate sequence and inflows adjusted to the current level of development. This represents the baseline scenario.

Here we demonstrate the use of the model for predicting habitat availability for the baseline scenario. The hydrodynamic model simulates water level and salinity for 117 years (the period between 1891 and 2008). Salinity in the South Lagoon was found to be a good indicator of very wet and dry years as this part of the Coorong better reflected the influence of consecutive wet and dry conditions producing 'very low' or 'very high' salinities compared to the North Lagoon. Two 'very wet' and 'very dry' years in the past decades were selected for a comparison of habitat availability under these conditions. Based on the simulated daily average salinities for 1891-2008 under the scenario, we identified 1976 and 1993 as wet years; and 1988 and 2005 as dry years. The hydrodynamic model was run for these years and water level and salinity data were linked to the geographic coordinates of the respective points.

The site boundary up to the high water mark level was digitised from orthorectified aerial imagery to specify the area for analysis. The high water mark signifies the edges on the eastern and western shores of the lagoon. In order to specify the mudflats on either side of the shores, masking layers were created for the eastern and the western shores and applied in the model.

2.2 Spatial Model Development

A spatial model for predicting mudflat availability under various flow scenarios was developed by integrating the water level output from the hydrodynamic model with fine resolution bathymetric datasets. The model was written as a python script to incorporate looping ability so that hourly water level from the hydrodynamic model could be used to generate maps for mudflat availability at the same interval. The model interface is shown in Figure 2.

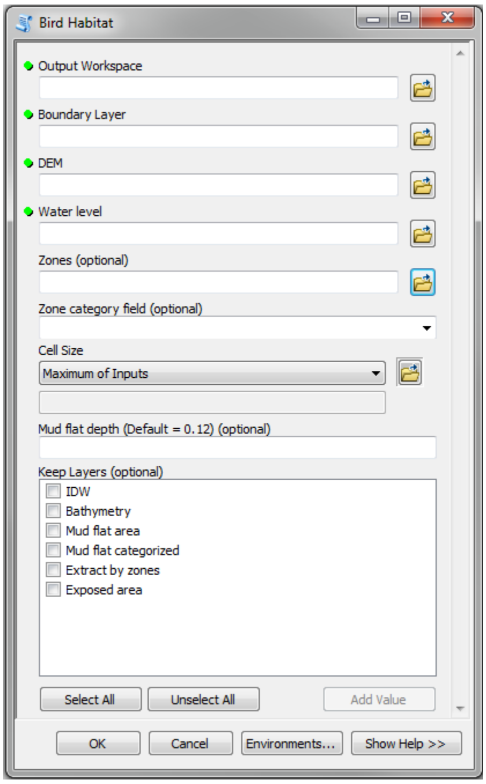

Figure 2. Interface for implementing the model in ArcGIS.

The water level data generated from the hydrodynamic model contains hourly time series data for 102 points distributed linearly along the Lagoon. These data points were first assigned geographic coordinates and a field name was given to each column of water level data. The water level data from the hydrodynamic model at 1cm vertical resolution were interpolated using the inverse distance weighted (IDW) interpolation in the Spatial Analyst extension in ArcGIS (ver 10.1). IDW applies an inverse power weighting function to the distance of the measured points. Nearby points have higher weights and influence than points located at greater distance (De Smith *et al.* 2006). The goodness of fit of the models generated by IDW, radial basis functions and ordinary kriging were compared using the Geostatistical Analyst extension in ArcGIS. The IDW produced the lowest root mean square error. Kriging produced the highest root mean square error of all three methods. Hence, IDW was used for interpolating water level data at specified times to generate a two dimensional water level surface of 1 x 1 m grid cells (Water Level Raster). To expedite processing, the area of interest for raster interpolation is specified by setting the extent to the boundary layer in the model properties. The final outputs from this model show the mudflat availability at 1 cm vertical resolution up to 12 cm depth on both shores of each reference site. We applied the model to DEMs of sites surveyed by Total Station to an accuracy of +/- 2mm.

The above model is highly flexible, in that it can be applied to any input DEM dataset, utilizing any number of scenarios over any time period. Additionally, the boundary layer input allows for a salinity threshold to be applied to filter the results, or the results can be disaggregated based on any particular zone (e.g. eastern and western shores which are geomorphically different, or for different management zones such as replanting and translocation areas) . The model terminates only at the end of the water level data in the dataset and generates outputs for all zones and each water level time step.

3. RESULTS AND DISCUSSION

3.1. Mudflat availability at reference sites

Using mudflats up to 12 cm water depth, analysis of mudflat availability was performed for the maximum and minimum water levels in both wet and dry years. Water level ranging between -0.30 and 1.25 m AHD, -0.09 and 1.30 m AHD, and -0.15 and 1.09 m AHD were modelled for Barker Knoll, Noonameena and Salt Creek, respectively, although there was not a simple relationship between mudflat availability and water level. Figure 3 shows an example of the spatial extent of mudflat habitat for the Salt Creek reference site.

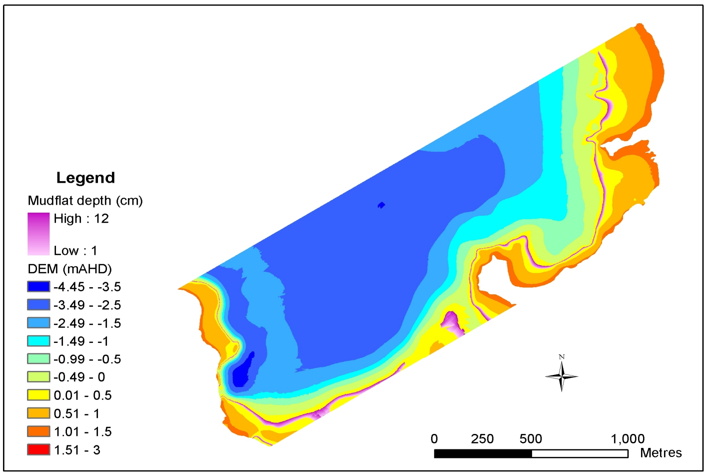

Figure 3. Map of mudflat availability generated by the spatial model at Salt Creek on 9th July 1993 at 7:00 AM: an example.

The availability of mudflat areas accessible to waterbirds is governed by the underwater topography. For a given water level, relatively flat areas provide more available foraging area than steeply sloping areas. A study of the morphology of mudflats in the Coorong (Benger et al. 2009) discussed the mudflat slopes (%) for all reference sites, however, the slopes of the eastern and western shores were not differentiated. In the current study, mudflat areas are estimated as the sum of all areas available on the eastern and western shores, and in the channel in the case of Barker Knoll. Because of differences in the topography (slope), these areas offer varying amounts of mudflat for specified water levels. At Barker Knoll, the maximum area of mudflat (3.19 ha) was available at -0.05 m AHD with more than 75% of available mudflat located on the eastern shore, implying that the eastern shore is relatively flat compared to the western shore. Similarly the maximum mudflat area (6.17 ha) occurred at 0.27 m AHD at Salt Creek with more than 60% found on the eastern shore.

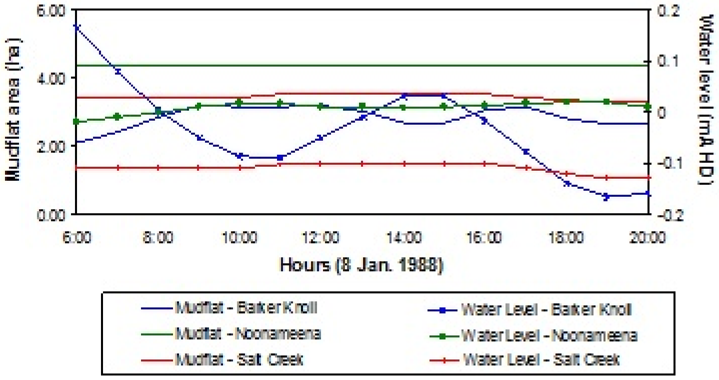

Figure 4. Mudflat availability and water levels between 6:00 - 20:00 at three reference sites on 8 Jan. 1988. The water levels are the average minimums for January in the two dry years on this day.

However, the western shore has a lesser slope at Noonameena and thus contributed about 55% of the maximum mudflat area (6.38 ha).

Figure 4 shows daily variation in mudflat area and water level for three CLLAMMecology reference sites, on a summer day during a dry year under the baseline scenario. Temporal variation in mudflat area was evident at Barker Knoll due to diurnal or semi-diurnal tidal influences on the water level, whereas Noonameena and Salt Creek had very little change in mudflat area over the period of a day as water level varied little at this time-scale. Although the topography of the Lagoon is a major factor for determining accessible mudflat areas in the Coorong, the water level is the variable that managers can manipulate to maximize mudflat availability. As the water levels vary longitudinally in the Lagoon, it is not possible to maximize mudflat area at all locations at the same time. Based on the three selected reference sites, the highest average mudflat area was observed at an average water level of ~0.12 m AHD on the day with minimum water level in January 1976. The highest mudflat area of 6.17 ha occurred at Salt Creek at 0.26 m AHD followed by Noonameena with 4.43 ha at -0.06 m AHD and the lowest area of 2.64 ha at Barker Knoll at -0.11 m AHD.

3.2. Water level and salinity variations in the Coorong

The monthly barrage flow data used for the scenario modelling showed large fluctuations in the quantity of water released into the Coorong in the past decades. Among the four selected years, the predicted average water level was higher in July than in January except for 1993. High water levels in January 1993 were attributed to almost five times more water (2199 GL) being released into the Coorong than in July. Although the amount of water had a large impact on the water level, it was not possible to find a fixed relationship between the volume of water and the water level in the Coorong. For example, the model predicted a higher water level with about 73 GL released in July 2005 than in July 1993 with 433 GL of water released. Therefore, other hydrodynamic factors present in the Lagoon such as water flow out from the Lagoon, underground leakage, etc. could also play a significant role in determining the water levels in the Coorong.

The water levels vary longitudinally in the Lagoon due to the main hydrological drivers; water volume, timing, Murray Mouth opening and environmental variables such as rainfall, precipitation and evaporation. The average water level in the South Lagoon was predicted to be as high as 8 cm above the water level in the North Lagoon during barrage flows. However, in the summer without barrage flows, the water level in the Lagoon is entirely influenced by sea level and the Murray Mouth opening and drops below 0 m AHD, causing a significant reduction in the water flow at Parnka Point and isolating the South Lagoon. Eventually, further loss of water due to evaporation lowers the water level in the South Lagoon below that of the North Lagoon (Webster 2007). The Coorong did not receive barrage flows in January 1988 or 2005, resulting in average water levels of around 0.12 m AHD in the North Lagoon and around -0.10 m AHD in the South Lagoon.

Salinity levels in the Coorong are influenced by a number of factors including; salty water inputs through the Murray Mouth and USED, their transport and mixing, and evaporation. Freshwater inputs through the barrages tend to raise the water level, compensating for evaporative water loss and eventually reducing salinity levels along the Lagoon if flows are large enough (Webster 2007). For example, about 30 to 40 GL of waterflow over the barrages restored estuarine conditions in areas up to 15 km from the Murray Mouth for about 20 days (Geddes 2005b). During barrage flows in the four selected years, the salinity level was maintained below ~ 20 g/L in the Murray Mouth and in some areas in the North Lagoon, and it did not exceed 56 g/L in Salt Creek at the end of the South Lagoon. However, zero flows in January 1988 and 2005 doubled salinity levels along the Lagoon, reaching ~40 g/L around the Murray Mouth and ~ 126 g/L at Salt Creek.

Since it was first built and through later refinements, the dynamic habitat model has been used for a number of assessments, including the CSIRO Sustainable Yields, and most recently for the ecological assessments associated with the Murray Darling Basin Plan.

4. CONCLUSION

We present a model that can be run for any given flow scenario over any time period for any site along the Coorong. However, this model can be easily modified for use in different environments where water level-habitat interactions are important. For the Coorong, it is important for managers to understand the influence of both water level and salinity on mudflat habitats as well as the aquatic habitats for fish, macrophyte and infauna. The spatial model developed for this study allows managers to readily quantify these habitats for specified flow scenarios, and supports informed decisions on the amount and frequency of barrage outflows from the Lower Lakes when excess water is available for environmental improvement and maintenance of the Coorong.

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