An ecological-hydrodynamic approach for the sustainable management of a brackish wetland

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ABSTRACT

Maldonado River is located on the Eastern coast of Uruguay and flows into the Atlantic Ocean. Close to its mouth, the river flows through the city of Punta del Este. At the lower end of this river, a saltmarsh is formed. Due to its size and high biodiversity, this ecosystem is unique in a coastal stretch of about 700 km, and constitutes a vital environment for many migratory species. This wetland is currently experiencing intense pressure due to the urban expansion of Punta del Este and Maldonado cities. In this paper, an integrated eco-hydraulics approach for the sustainable management of this wetland is presented. A numerical hydrodynamic model of the stream system was developed and then an ecological characterization of the environmental units was done. The results of the model, in combination with the evaluation of the environmental units, allowed setting up recommendations for the sustainable management of the area.

INTRODUCTION

It is well known that all around the world population growth near water courses and shores creates an intense demand of natural resources as well as a rapidly growing tourism industry. The consequence of these processes is the rapid transformation of the original ecosystems with important losses of biodiversity and destruction of natural habitats. Te coastal zone of Uruguay has experienced a constant growth of its tourism industry during the last years. This process, like in other parts of the world, commonly occupies areas of high ecological value and can also displace traditional land uses as extensive cattle ranching. For those reasons, it is important to develop an interdisciplinary approach for the integrated management of basins and coastal zones.

In particular, the region near Punta del Este and Maldonado cities has experienced an accelerated tourism development due to its natural characteristics. Punta del Este is at present one of the most important tourism resorts in South America. Maldonado River flows into the Atlantic Ocean and its mouth is adjacent to Punta del Este and Maldonado cities. At the lower reach of this river, a salt marsh is formed, alternatively receiving the inflow of salt water from the ocean and the discharge of fresh water from upstream. Due to its size and high biodiversity, this ecosystem is almost unique in the Uruguayan coast, and constitutes a vital environment for many migratory species. This wetland is currently experiencing intense pressure due to the urban expansion of Punta del Este and Maldonado cities, and the development of the tourism industry. Furthermore, another city, San Carlos, is located 20 km upstream from the river's mouth, and suffers recurrent flooding from Maldonado River. All these factors make a complex environmental situation that claims for an interdisciplinary vision, targeting the integrated management of the basin and its associated coastal zone.

The target of this approach is to facilitate decision-making for sustainable use, development and protection of biodiversity. In this paper we summarize the biodiversity values of Maldonado stream, describe it hydrological functioning and propose integrated managing recommendations. The results of this study are the basis for the integrated management of the basin and particularly for the lower zones close to the Atlantic Ocean.

METHODOLOGY

Integrated eco-hydraulics analysis

The importance for biodiversity protection of this system necessary led to an integrated analysis of the river engineering and the biological viewpoint. The study of Maldonado River discharges and the water levels dynamics were integrated with the biological features of the ecosystem. The results obtained allowed to broaden the knowledge of the wetland behavior and to establish land management guidelines consistently with the preservation of this important ecosystem. A hydrodynamic model was used in order to determine the hydrodynamic characteristics of the wetland. Water levels, discharge frequencies and flooding curves were calculated. The ecological approach consisted of the identification of the environmental units that build up the wetland and their ranking according to their relevance for conservation. Superposition of the flooding curves obtained from the hydrodynamic model with the map of environments and biodiversity values was used for the definition of recommendations for the sustainable management of Maldonado wetland. The development of a Geographical Information System was crucial for the spatial integration of the information and build up of interdisciplinary recommendations.

Ecological Characterization

Maldonado River saltmarsh is the larger of Uruguay coast, followed by Laguna José Ignacio located 30 km to the East (Isaach et. Al 2006). Particularly, Maldonado River saltmarsh is the most characteristic, because it has the typical saltmarsh species. It contributes with 19 km^2 of the 2133 km^2 of the extensive saltmarshes along the Southwestern Atlantic coast (Isacch et al. 2006), which belongs mainly to Patagonia and Buenos Aires Province coast. Due to the great gap between Argentinian, Uruguayian and South of Brazil saltmarshes, this system is crucial for migratory birds and for the specialist Orlog´s Gull (*Larus atlancticus*).

Initially, the study area was determined. Secondly, using Landsat and Google Earth Pro images of the zone, topographic maps and following ecological and botanical criteria according to Fagúndez & Lezama (2005), six environments were identified. The third step was the definition of seven biodiversity criteria: 1) Endemic or rare species, and/or with restricted distribution; 2) Species at risk of extinction, 3) Migratory species, 4) Priority species for the National System of Protected Areas, 5) Charismatic species; 6) Species involved in ecosystem processes; 7) Species with another values. Mammals, birds, reptiles, amphibians, fishes, aquatic and terrestrial invertebrates and superior plants were considered. Those species that fulfill any of the seven conservation criteria were assigned to each environment. For this, bibliographic records, specialists records, ONG`s database and scientific collections were consulted. Lastly a geographic information system was developed in order to analyze the spatial distribution of the environments, their biodiversity values and superimpose them to the flooding curves generated by the hydrodynamic model.

Hydrodinamic model

Software Hec-Ras 4.0 (US Army Corps of Engineering's, 2006) was used to develop the hydrodynamic model. The system is made up by the Maldonado River and San Carlos River (Figure 1 left). Upstream limits are the intersections of the rivers with the National Route 9 and downstream limit is the river mouth on the Atlantic Ocean. Three major reaches can be identified: San Carlos River, Maldonado River upper reach and Maldonado River lower reach. San Carlos River reach is 5 km long between the upstream boundary and the rivers junction. Maldonado River upper reach is 8.5 km long and its lower reach is 15 km long, where the salt marsh is located.

Water levels records in San Carlos and Maldonado Route 9 bridges (Table 1) were used as the upstream boundary condition. On the other hand, the Atlantic Ocean water levels records in Punta del Este harbor were used as the downstream boundary condition. Energy balance was chosen to calculate the flow profile in the river confluence. This approach is recommended when flows are in a sub critical regime.

Figure 1. River system (left) and the location of hydrometric stations (right) in Maldonado and San Carlos rivers system.

Table 1. Hydrometric information for Maldonado and San Carlos rivers system.

Hydrometric Station	Code	Data	Period	Data frequency
San Carlos River, Route 9 bridge	46.1	Water level and rating curve	1/1/83 - 31/12/05	2 - 4 records per day
			1/4/05 - 25/6/05	hourly
Maldonado River, Route 9 bridge	174	Water level and rating curve	1/1/83 - 31/12/05	2 a 4 records per day
			12/4/00 -31/7/00	30 min
			1/4/05 - 25/6/05	30 min
Punta del Este Harbor	183	Water level	1/1/85 - 7/9/06	Maximun daily
			12/4/00 - 31/7/00	15 min
			1/4/05 - 24/6/05	15 min
			15/6/85 - 9/7/85	hourly
			1/8/86 - 25/8/86	hourly
Arroyo Maldonado, Puente de la Barra	153	Water level	30/7/82 - 30/11/94	1 - 3 records per day

Calibration and validation model results were fitted with:

- Rating curves of San Carlos and Maldonado rivers in the cross sections corresponding to Route 9 bridges.
- Flooding curves registered in San Carlos City.
- Water levels measurements in the Barra Bridge (Figure 1).

The Manning roughness coefficients obtained are shown in Table 2.

Table 2. Manning roughness coefficients for San Carlos and Maldonado rivers.

	San Carlos River		Maldonado River	
	Non-urban floodplain	Urban floodplain	Upper Reach	Lower Reach
Main Channel	0.11	0.11	0.15	0.075
Overbank	0.11	0.55	0.15	0.09

RESULTS AND DISCUSSION

Six environments were identified. The most important environments for biodiversity protection were the saltmarsh, the coastal prairies and the floodplain, with higher values for most biodiversity criteria. The environments are shown in Fig. 2 (right) and in Table 3 with the number of species that fulfill the biodiversity criteria.

One of the largest crab *Chasmagnathus granulata* populations of the coastal area of Uruguay is located in these saltmarsh. This community supplies larvae to the whole Uruguayan coast and is believed to contribute with populations of southern Brazil and Argentina (Giménez 2003). Also the crab *Cyrtograpsus angulata* is present at this saltmarsh. Both crabs species are an important food resource for the Orlog´s Gull (Herrera et al. 2005), which is vulnerable for IUCN (Aldabe *et al*. 2006). The population of this gull is decreasing due to the lost of feeding sites. In arroyo Maldonado saltmarsh, this species is often observed in large groups (Aldabe et al. 2006). Also *Ch. granulata* represent a food source for many commercially valuable fish like the white croaker (Rodríguez-Graña et al. 2008).

Table 3: Number of species that belongs to each biodiversity criteria, for each environment.

Environment	Number of species that belongs to each biodiversity criteria						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Channel	9	14	6	14	9	10	30
River mouth	0	14	12	15	12	12	43
Saltmarsh	24	14	7	23	5	3	4
Fluvial Islands	8	5	1	5	1	0	0
Coastal praires	23	8	6	22	2	0	3
Floodplain	15	19	10	32	2	0	2

In figure 2 (left), the flooding curves obtained with the hydrodynamic model are shown. Statistical analysis of the hydrometric data and model running allow obtaining these curves. The dotted line corresponds to a one year flooding event, the continuous black curve to 10 years flooding event (10 yr) event and the continuous grey curve to a flooding event of 100 years of returning period (100 yr).

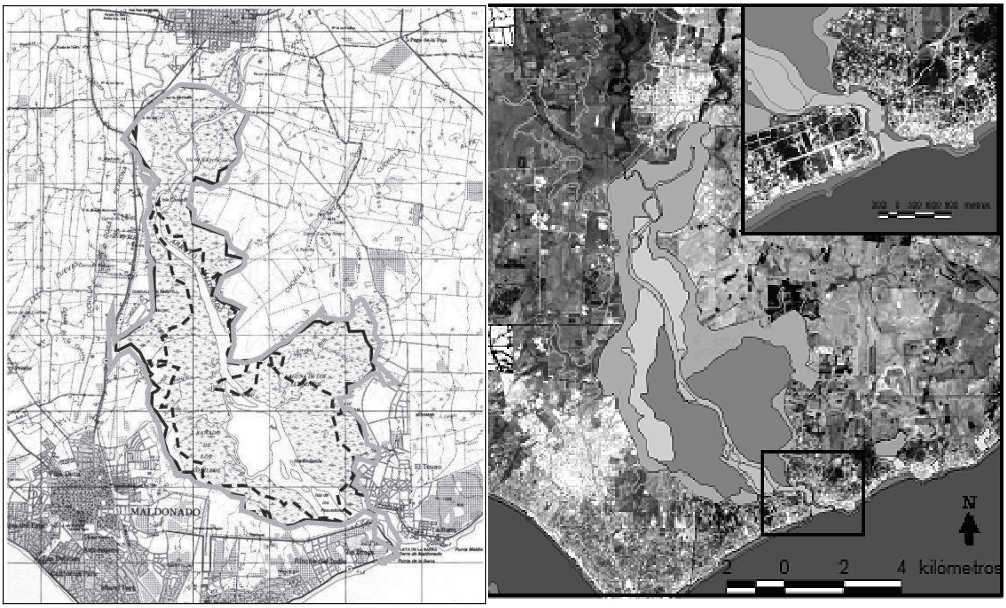

Figure 2: Flooding curves (left) and map of environments (right) for Maldonado wetlands.

It can be observed (Table 3) that the most important environments for biodiversity protection, saltmarsh (dark grey, Figure 2, right), coastal prairies (white, Figure 2, right) and a great proportion of the flood plain (light grey, Figure 2, right) are located inside the 10 yr flooding curve. The boundaries of these environments are close to this curve and coincide in the same points. The proximity between the 10 and 100 yr flooding curves indicates an abrupt change in topography related to a transition between geomorphologic units. Therefore, in this zone humidity conditions change significantly in space, with areas highly influenced by annual floods are close to other areas never influenced by the river. Due to the importance of humidity conditions for the development of the environments saltmarsh and coastal prairies, it is reasonable that their limits are in this transition zone.

CONCLUSION

An integrated ecological-hydrodynamic analysis of the Maldonado brackish wetland was presented. A numerical hydrodynamic model of the stream system was developed and then an ecological characterization of the environment units was done. The integrated methodology results allow establishing the areas where the urban expansion is not admissible, both from a flooding perspective as well as from a conservation perspective.

In line with this statement, the 10 yr flooding curve was defined as an area “not admissible” for urban expansion. This curve contains the saltmarsh, coastal prairie and part of flood plain environments (Figure 3, the most important for biodiversity conservation.

Avoiding urban expansion inside the 10 yr flooding curve allows simultaneously to: 1) protect the environments of highest value for biodiversity protection (saltmarsh and coastal prairies), 2) maintain a buffer zone (flood plain environment 10 yr flooding curve inside) and 3) avoid urban expansion into areas of high flooding risk. The proposed land zoning is shown in figure 3. Nevertheless, in the floodplain outside the 10 yr flooding curves low density urbanization is recommended.

Figure 3: Zoning proposed for Maldonado wetlands. 10 yr flooding curve (black line). Inner curve: area “Not admissible” for urban expansion; outer curve “admissible area” for urban expansion; saltmarsh (dark grey), coastal prairie (white) and floodplain (light grey) environments.

This zoning will allow municipal authorities to carry out a sustainable management plan of the land associated to this wetland, both from an ecological perspective and from an urban infrastructure perspective. The approach and methodology developed in this study constitute essential tools for the sustainable management of high biodiversity ecosystems, particularly when the area is subjected to intense pressure due to the urban expansion.

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