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Advances in water management of southern Brazilian sub-tropical wetlands using bio-indicators

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Abstract This study presents a new criterion for water management in southern Brazilian sub-tropical wetlands through the use of biological indicators. The emergent aquatic macrophyte giant grass *Zizaniopsis bonariensis*, was used to define a suitability index. Hydrological scenarios were combined with the suitability index, allowing the selection of good habitat water levels. The results showed the importance of biological indicators' inclusion in the criteria list for water management. Under some conditions predicted by traditional hydrological procedures this emergent macrophyte species would be stressed.

Key words bio-indicators; sub-tropical; water management; wetlands; *Zizaniopsis bonariensis*

INTRODUCTION

Around the world wetlands are losing area and resources to agricultural crops. From the 1960s the Brazilian southern sub-tropical wetlands area decreased considerably, contrasting with the expansion of irrigated rice areas. An example of this type of ecosystem is the Banhado do Taim (Taim Wetland), a coastal freshwater wetland with approximately 315 km^2 and a large biodiversity.

This wetland was declared as a federal environmental conservation unit in 1978. However, the drainage basin remained shared with irrigated rice fields. Over the summer large amounts of water (~100 $m^3 s^{-1}$) are lost to agriculture, inducing alterations in Taim's natural hydrological regime. In 1996 it was shown that the ecosystem would not support the increasing water abstraction due to the long-term water level alterations (IPH, 1996). Consequently, some water management rules were defined for the area based on statistical analysis and scenarios simulations. However, ecological criteria were not included as criteria.

A small reduction in the water level in wetlands is known to promote changes in biological communities that depend on specific habitat conditions to thrive or survive. If the stress promoted by water level changes exceeds certain limits, there is the probability of reduction of specimen numbers and biodiversity or even elimination of some key species.

Emergent aquatic macrophytes are among the most affected species due to water level alteration. Besides food supply, habitat and refuge for a great number of species, the macrophytes play an important role in the Taim Wetland hydrodynamics and carbon metabolism. In the interface between the Taim Wetland and the adjacent Mangueira Lake, the giant grass *Zizaniopsis bonariensis* (Bal. & Poit) Speg. is dominant. The stands of this grass increase the hydraulic roughness in that region, reducing water velocity, and consequently reducing water and material changes between Mangueira Lake and Taim Wetland (Paz *et al.*, 2005). In this ecosystem the presence of *Z. bonariensis* is related to a specific water level range, frequency and duration (Motta Marques *et al.*, 1997; Giovannini & Motta Marques, 1999). Any hydrological alteration can promote large changes in Taim Wetland's vegetation cover patterns.

In Brazil, some works are being developed that are trying integrate the environmental needs through hydric resources management (Collischonn *et al.*, 2006). However, the main focus has been given to the ecological hydrograph in rivers, and there are few studies in ecological hydroperiods in wetlands. Using the concept of habitat suitability index models (USFWS, 1981), this work presents the procedure applied to incorporate biological indicators (Manoliadis, 2002; Müller & Lenz, 2006; Venturelli & Galli, 2006) in water level management criteria emphasizing environmental quality boundaries for an emergent aquatic macrophyte, the giant grass (Bal. & Poit) Speg., in the Taim Wetland (Banhado do Taim/RS, Brazil).

METHODOLOGY

Regions inside Taim Wetland where *Z. bonariensis* was dominant were initially delimited through 21 LANDSAT TM and CBERS satellite images (1973–2005) classified by supervision (Guasselli, 2005; Tassi, 2006). The regions were checked for field truth.

Z. bonariensis is affected by hydrological factors such as the water depth, and the associated seasonality and duration. The understanding of the relationship between hydrology and this species was obtained by previous research work (Giovannini, 1997, 1999; Galleti, 2001; Guasselli, 2005; Ferreira, 2005) and a 44-year hydrological time series analysis from regions covered by *Z. bonariensis*. Together these works allowed limits of water depth for good and bad habitat conditions to be set.

The habitat quality for *Z. bonariensis* and water depth were linked through a suitability index curve (USFWS, 1981; Tarboton *et al.*, 2004), developed specifically for this species. Water depths out of species' acceptable limits received suitability index values near zero, while appropriate values of water depths receive value near 1. Different water depths allowed construction of a relationship curve, the suitability index and the hydrological variable. The curve may be combined with water management regulation once it is known, allowing the estimation of the resultant habitat quality.

The great advantage of using a suitability index is the possibility of evaluating impacts of water management scenarios on species conservation, without the need to model it. These relationships are adaptive; as soon as more knowledge about the species is available the relationship can be altered.

To evaluate if the suitability index curve was correctly defined, each hydrological condition found in the past was used to set the habitat quality, through the suitability index. A total of 528 months were correlated with the suitability index. After simulations, to verify if environmental quality was compatible with the found index,

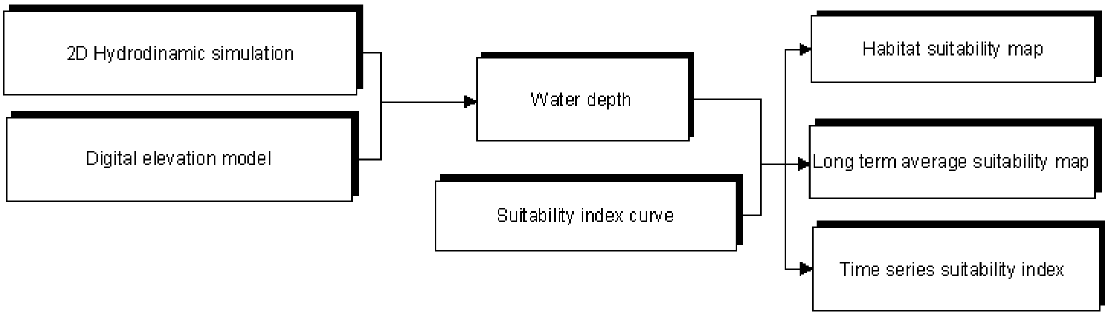

Fig. 1 Model flowchart to find best habitat conditions for the giant grass *Z. bonariensis.*

monthly suitability maps were qualitatively compared with Normalised Differentiated Vegetation Index (Narumalani *et al.*, 1997; Jakubauskas *et al.*, 2000; Mendiondo *et al.*, 2000; Díaz e Blackburn, 2003; Rendong & Jiyuan, 2004; Xin, 2004) for the same date. Besides this procedure, photographs, samples and field observations were used in the same way.

The simulations were performed with a model in FORTRAN language, developed during this work (flowchart presented in Fig. 1). Geoprocessing principles were used to develop this model. This approach allows for the direct use of hydrological information generated by a 2D hydrodynamic model calibrated to Taim Wetland (Villanueva, 1997; Villanueva *et al.*, 2000), and the suitability index established for the species. The hydrological information is related to a DEM (100 × 100 m) to determine the water depth for each pixel, and the corresponding suitability index is obtained from the pre-defined suitability index curve. This analysis can be done on all Taim Wetland areas, or only inside the specific boundaries. Also, the model can supply information as average suitability index for each pixel and regional monthly average suitability index. The developed model also supplies a suitability map in a colours scale, which represents the habitat quality.

The same model was used to evaluate different water levels, searching for water levels that produce good habitat conditions for *Z. bonariensis*. In this sense, the historical hydrological regime was again combined with checked suitability index. Hypothetical scenarios could also be used in this step.

RESULTS AND DISCUSSION

In the polygons (Fig. 2(a), white dashed-lines) where *Z. bonariensis* was dominant, the suitability index must be appropriate to keep the species for different hydrological scenarios. According to the literature review, the hydrological needs of *Z. bonariensis* are:

(1) at least 10 cm water depth (Giovannini, 1997; Giovannini & Marques, 1999);
(2) water level absence is unfavourable to growth and development of the species (Giovannini, 1997; Giovannini & Marques, 1999);
(3) water depth oscillation between 20 and 70 cm favours the growth, development and permanence of *Z. bonariensis* (Galleti, 2001);

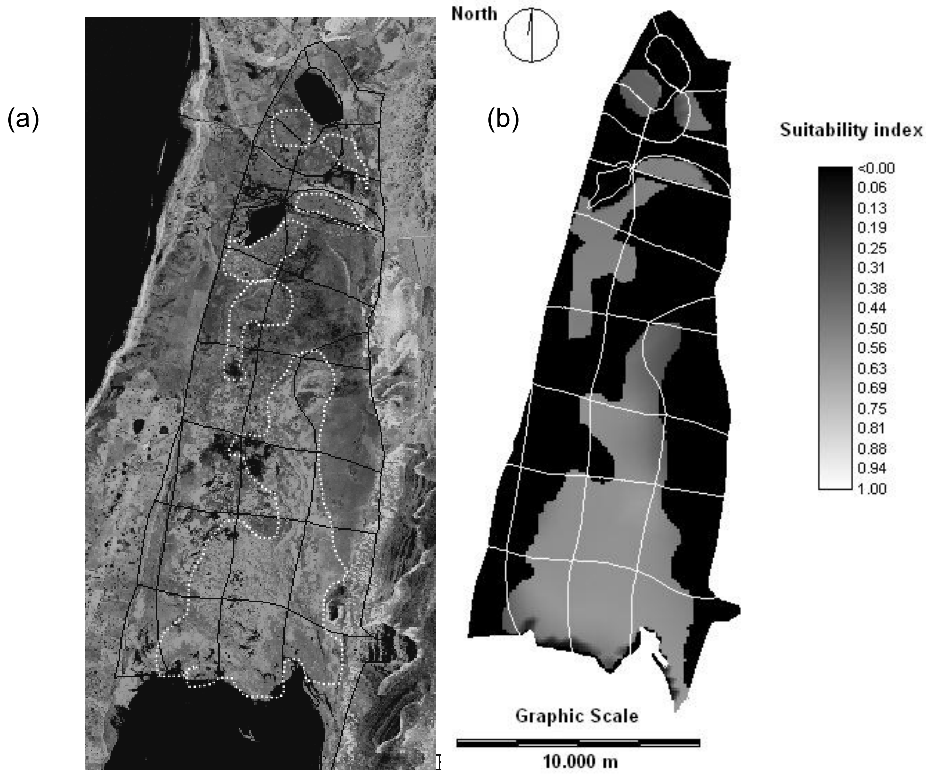

Fig. 2 Regions in the Taim Wetland (Banhado do Taim, Brazil) where *Z. bonariensis* is dominant (Landsat TM, 5R4G3B), July 1987 (a), and long term suitability index for *Z. bonariensis* (b).

(4) in Taim Wetland *Z. bonariensis* is found where the water depth oscillates between 20 and 70 cm (Ferreira, 2005, 2006).

From these reviews, water depth boundary conditions for *Z. bonariensis* range from "zero" to 70 cm. However, the information on *Z. bonariensis versus* water level were not comprehensive enough to define a detailed suitability index curve. As a result it was decided to use the literature values and to obtain a new index relationship from hydrological information.

Taking advantage of the fact that this macrophyte is adapted to Taim Wetland's hydrological conditions, the time series water level was analysed in regions where *Z. bonariensis* was dominant. This procedure allowed the construction of a water depth's frequency histogram (Fig. 3). The frequency histogram shows asymmetric distribution of the water depth, with values between 20 and 70 cm being predominant, as expected for this species. As such the procedure was considered appropriate. This procedure allows finding substitutes to define the detailed suitability index curve, once this water depth's frequency histogram was used in association with literature values.

The adjustment of an asymmetrical curve (Fig. 3) was accomplished on the histogram, using some limits such as:

– water depths higher than 2.8 m do not promote conditions for species' growth and maintenance: criteria decided as a function of satellite image analysis, situations with water depths superior to this value promoted the vegetation extinction (gaps) in some areas;

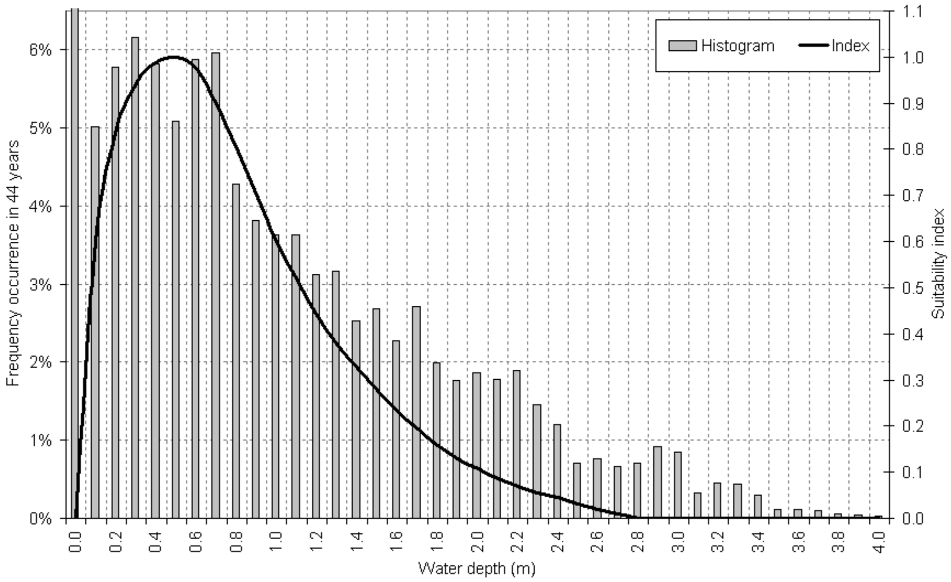

Fig. 3 Water depth's frequency histogram in areas where *Z. bonariensis* was dominant in Taim Wetland, Brazil and suitability index curve proposed for *Z. bonariensis.*

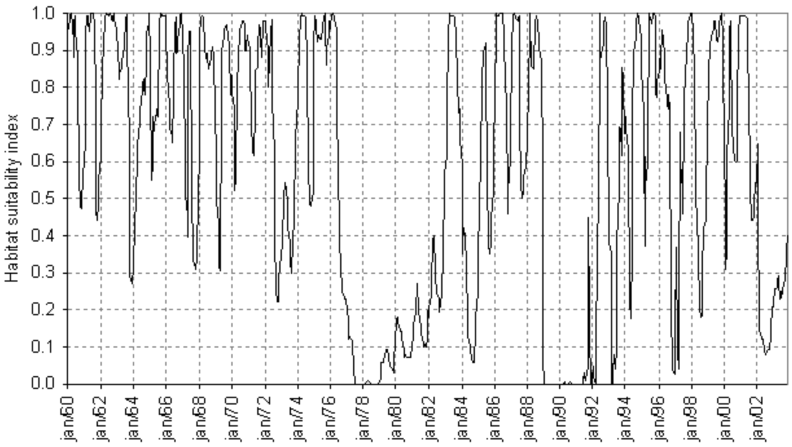

Fig. 4 *Z. bonariensis* time series average suitability index found in Taim Wetland's south zone.

- in water absence conditions, chances for species' maintenance are null: criteria also established through satellite image analysis, dry periods were extremely unfavourable;
- suitability index is maximum when the water depth is 50 cm.

The past hydrological conditions (528 months) were simulated using the suitability index curve defined, and the results showed accuracy. Regions where *Z. bonariensis* was dominant always had suitability indexes greater than 0.3 (Fig. 2(b)). Suitability indexes greater than 0.3 mean that the water level in these areas oscillate for most of the time between 1.23 and 3.26 m (0.05 and 1.25 m depth water, respectively).

Z. bonariensis' time series suitability index found in Taim Wetland's south zone (pixels average) is presented in Fig. 4. This analysis can be used to evaluate species tolerance to unfavourable hydrological conditions, in association with long-term field observations, satellite images and aerial photographs. Associating satellite images and field observations, critical conditions for *Z. bonariensis* were found for suitability index less than 0.2 occurring during two (or more) consecutive years. In situations of criteria "absence", this tolerance interval could be used to admit an adverse condition in Taim Wetland's water management.

Figure 5 shows the inferior and superior limits of water level in Taim Wetland after a statistical analysis of monthly long-term average (Tassi, 2006). The dashed-lines show the ideal limits of water level for *Z. bonariensis* integrity using the suitability index procedure.

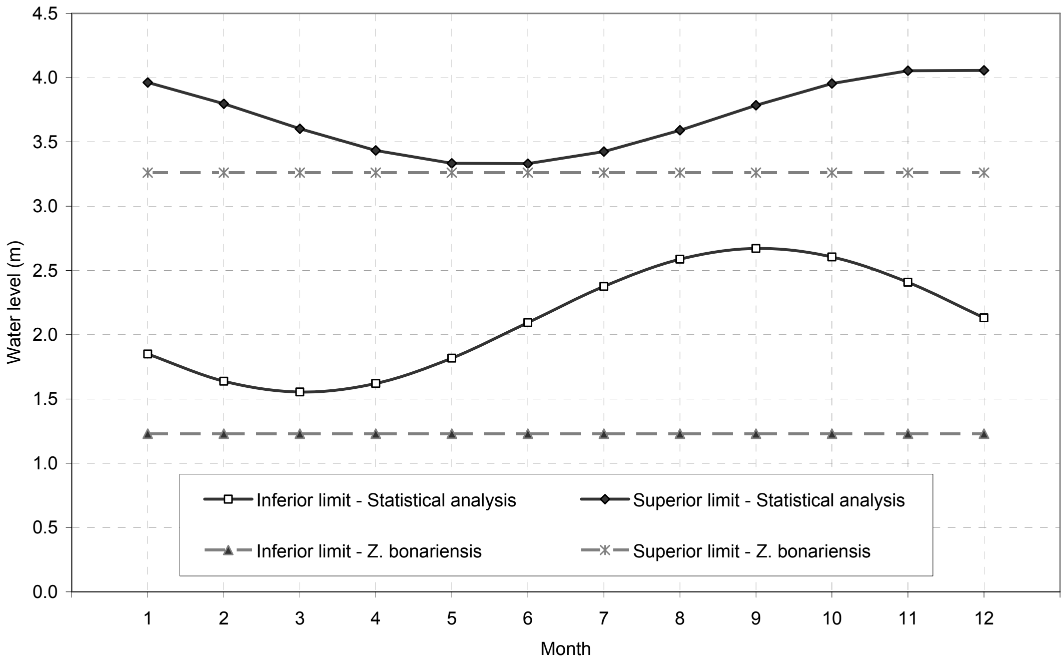

Fig. 5 Hydroperiod seasonal variability and the ideal water level conditions for *Z. bonariensis* in Taim Wetland, Brazil.

The results showed the importance of a biological indicators' inclusion in the criteria for water management. Under some conditions traditionally predicted by statistical analysis (higher water level) this emergent macrophyte species would be under stress conditions.

Several scenarios can be evaluated once these limits are well established, allowing for impact minimization on indicator species, at least for most years, or according to the criteria established on the basis of time series average suitability index. The seasonality hydroperiod definition can be obtained from the statistical analysis of long-term time series, or from the seasonal average suitability index.

The inclusion of a larger number of biological indicators can improve the definition of these limits, and the reliability of derived water management criteria (Tarboton *et al.*, 2004).

CONCLUSIONS

The procedure used to set the habitat quality for the emergent aquatic macrophyte *Z. bonariensis* was effective. High quality scenarios were selected, allowing identification of the appropriate wetland water levels for this species.

The methodology also allows the addition of other biological indicators as a criterion, besides the single hydrological criteria, in the water management of sub-tropical wetlands. Current studies (Tassi, 2006) included species like the large rodent capybara (*Hydrochaeris hydrochaeris*), an alligator (*Caiman latirostris*), a turtle (*Trachemys dorbigni*), a second emergent macrophyte (*Scirpus giganteus*), and also the black-necked swan (*Cygnus melancoryphus*), to define more comprehensive criteria for water management.

The procedure presented allows the management for the coexistence of restrictive conservation units and water for irrigation in the same watershed, with mutual benefit.

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