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## Human-threatened ecosystem: new signs of groundwater connection between Yacyreta reservoir and Ibera wetland (South America)

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Short communication

# Human-threatened ecosystem: new signs of groundwater connection between Yacyreta reservoir and Ibera wetland (South America)

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**Abstract**

Ibera wetland is one of the most pristine and singular ecosystems of South America. Satellite-derived thermal analysis of its lacustrine system supported the existence of a groundwater connection with the Yacyreta reservoir through basaltic fractures located along the ancient river bed of the Parana. The groundwater outflow would be located on the geological discontinuity of the eastern border of Ibera wetland, concretely around *Laguna Iberá* and *Laguna Luna–Disparo*. This new sign of connection comes on top of the hydrological signs which already exist. A call to prudence recommends not extending the recently projected increase of the water level of Yacyreta reservoir. Deeper hydrogeological studies should analyze the hypothesis emerged from this study before modifying the water level of Yacyreta.

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*Keywords: Esteros del Iberá*; Yacyreta reservoir; Groundwater input; Satellite-derived temperature

*Esteros del Iberá* is one of the largest freshwater wetlands of South America (14,000 km$^2$). It may be described as a vast subtropical plain composed by a mosaic of marshes, swamps and open water bodies. Ibera macrosystem is delimited by High Parana, Middle Parana and Uruguay watercourses (Del Plata Basin), although it is not fed by running superficial waters (Fig. 1a). In the Pliocene, the Parana River flowed towards the High Uruguay River. Then, the water flow shifted towards the Middle Uruguay across of Aguapey and Miriñay Rivers, and the Ibera plain was directly connected to the Parana River (Fig. 1b). As a geological uplifting of the eastern border of Ibera occurred at the end of the Pleistocene, the Parana

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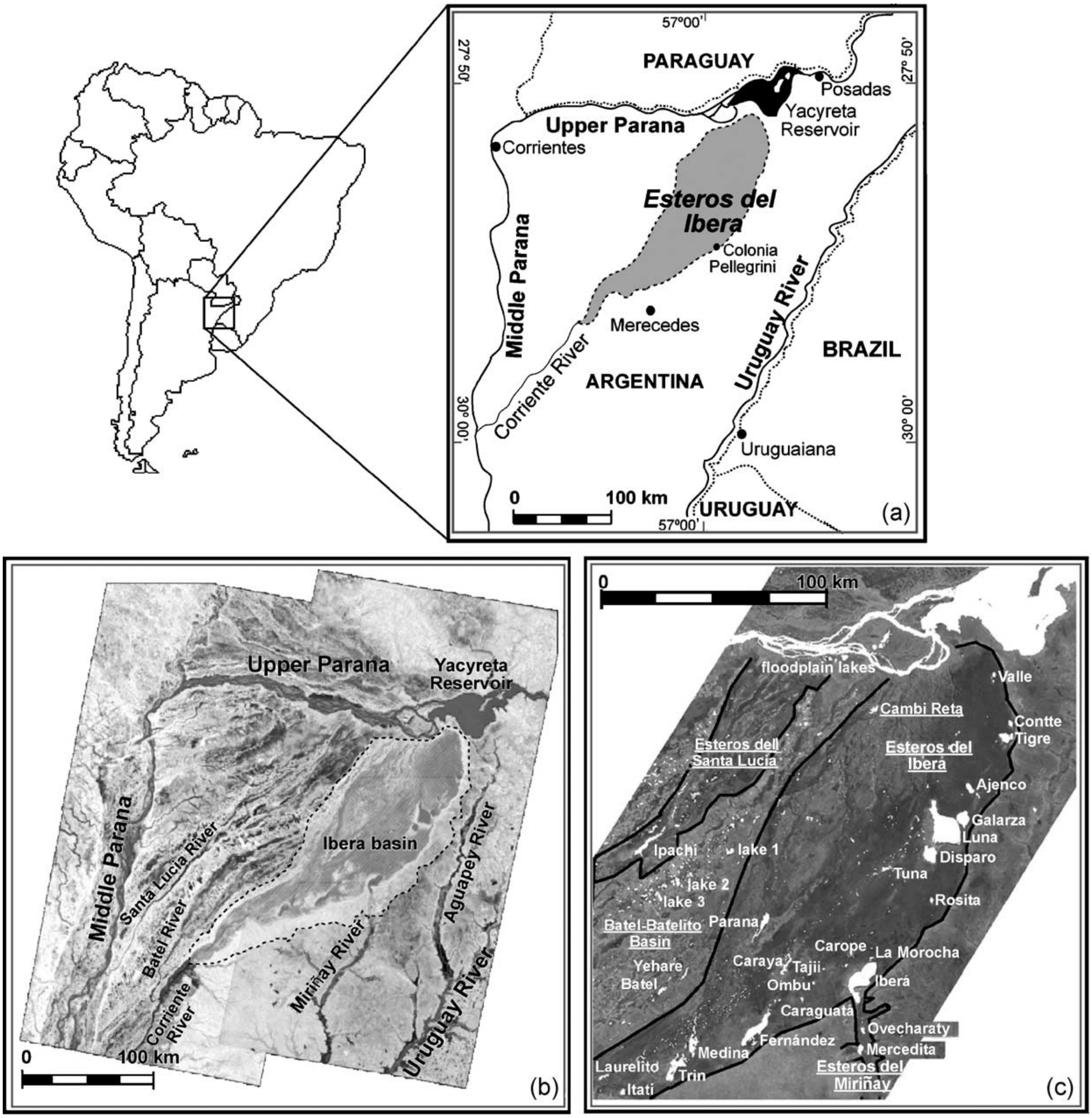


Fig. 1. (a) Location of *Esteros del Iberá* wetland. (b) Catchment area of the Ibera basin and surrounding watercourses in a Landsat-7 image. (c) Open water bodies of the *Esteros del Iberá*, *Esteros del Santa Lucía*, *Esteros del Miriñay* and *Batel–Batelito* Basin. The water bodies were highlighted in white through the spectral analysis of the near-infrared band of ETM sensor (Landsat-7). The lakes with names indicate the main water bodies used to determine the thermal spatial pattern.

River moved towards the west to form the present riverbed. This eastward displacement generated diverse wetlands (e.g., *Esteros del Iberá*, *Esteros del Santa Lucía*) from the floodplains associated to the displaced watercourses. Currently, the Ibera basin is mainly fed by rain and drains only towards the Middle Parana through Corriente River in the south of the wetland.

Ibera wetland is generating an increasing social interest as a result of the striking rises of the water level reported by the inhabitants (Blanco and Parera, 2001). Thanks to the existence of a nearby small village (Colonia Pellegrini), a series of water level data from 1968 is available for *Laguna Iberá*, one of the permanent lakes of the wetland (Fig. 1c). The analysis of the series revealed a sudden increase of 80 cm in 1989 (Fig. 2). Canziani et al. (2002) and Ferrati and Canziani (2004) built a water balance model to analyze the possible causes of this rise. The model showed as neither the actual tendency of increasing precipitation (derived from the climate change and last ENSO events) nor an eventual obstruction of the Corriente River can fully explain the observed change. They concluded that the water level change would be related with changes in the groundwater system and proposed the analysis of the existence of a new groundwater connection generated since the construction of the Yacyreta hydroelectric dam in the High Parana (Argentina–Paraguay border). The artificial Yacyreta reservoir is located at the north of Ibera wetland, separated by a thin strip of land (4–12 km wide). The event of water level rise coincided with the closing of the main branch of the Parana River during the dam construction. At present, Ibera wetland has maintained the elevated water level. A new hydrodynamic equilibrium seems to be reached.

The effects of the exceptional flooding of Ibera have reported dramatic ecological (e.g., Blanco and Parera, 2001, Cózar, 2003) and economic consequences (e.g., Blanco and Parera, 2001, Simonit et al., 2004). The distribution of habitats in Ibera macrosystem strongly depends on the topography and the water level. Neiff (1981) identified different types of environments according to the flooding regime. A succession of habitats occurs from the open water bodies to the "islands", where the terrain slightly rises and allows the development of wooded vegetation. The wide spectrum of biological niches has generated varied adaptation strategies in the animal and vegetal communities. Indeed, the Ibera macrosystem has been considered a world reservoir of biodiversity (Olson et al., 1998). The water level rise has dramatically transformed the distribution and extension of the different types of environments. Consequently, the wetland is tending to a reduction of the heterogeneity of habitats. The negative impacts on the animal community increase from the amphibious species to those with a higher dependence on the terrestrial habitats. Rare or threatened species of aquatic birds (comb duck) and reptiles (caiman, yellow anaconda) are losing their nesting areas. The populations of more terrestrial species, such as marsh deers, are being confined in small isolated areas or displaced to the wetlands borders, where compete with the cattle. The freatic level rise has also directly affected to the economic activities because of the flooding of the productive areas (ranching, farming, forestry) of the lower lands of the wetland borders.

In order to meet the economics requirements of the costs of the dam construction, the governments of Argentina and Paraguay have recently projected a new increase of the water level of the Yacyreta reservoir from the present 76 m to 83 m m.s.l. for the end of this year. If the Yacyreta–Ibera connection exists, this

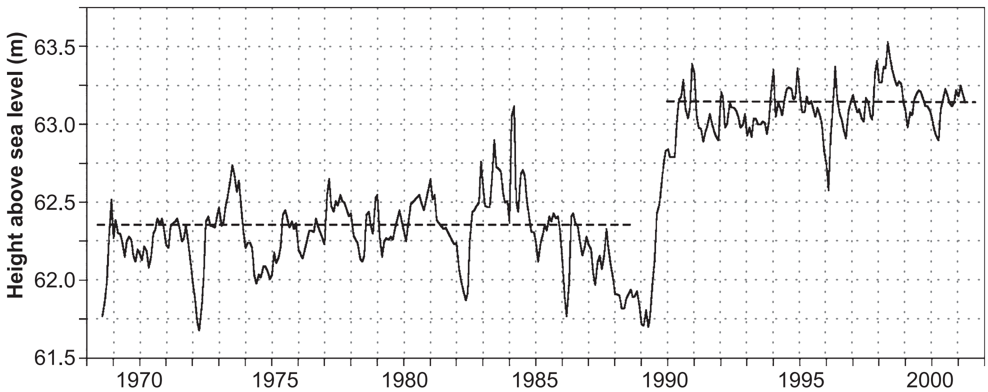


Fig. 2. Hydrometric levels measured at *Laguna Iberá*. The dashed straight lines show the averaged hydrometric levels before and after the construction of Yacyreta dam.

increase would threaten the existence of the Ibera wetland. A call to prudence, given the scarcity of data, recommends not extending the project. New studies should analyze the hypothesis emerged from the hydrological analysis. As a result of the relevance of this matter, we analyzed the distribution of water temperature of the lacustrine system of Ibera in order to determine the possible allocation of the suggested groundwater outflows. The abundance of permanent lakes in Ibera allows the spatial analysis of the thermal distribution of the macrosystem. The single use of the open water bodies to infer a thermal distribution minimizes errors derived from edaphic or vegetal-cover differences (e.g., humidity grade, reflection coefficient). A possible relation between the existence of anomalous areas of cold water and the allocation of the groundwater outflows could be hypothesized on the basis of three main factors. (i) The subterranean outflow must have a considerable magnitude to maintain the actual hydrodynamic equilibrium. (ii) Horizontal flows have a much lesser importance than the vertical hydrodynamics (rainfall, evaporation, or groundwater) in the wetland (Neiff, 1999). The drainage is slow due to the flatness (about 1:10,000) and the huge vegetation accumulated in the basin. Therefore, new groundwater outflows could cause localized thermal anomalies without relevant horizontal dispersion. (iii) The characteristics of the lacustrine system would favour the appearance of the thermal changes in the lakes if a cold groundwater outflow exists. The water temperature of this subtropical lacustrine system is relatively warm, around 20 °C of annual average (Cózar, 2003). The lakes are shallow (around 2.5 m) but also lie on the most marked depressions of the basin (Neiff, 1981). The combination of these factors allows, a priori, a suitable exploration of the allocation of the groundwater outflow from the thermal characteristics of the lacustrine system.

The collaboration with the Argentine space agency (CONAE) allowed the use of a recent series of satellite images to the study of the Ibera wetland. Landsat-5 (TM sensor) and Landsat-7 (ETM sensor) images with low cloud cover were available at 27 dates from March 1997 until November 2001 (Cózar et al., 2004). The spectral radiance on the infrared band of TM and ETM sensors was used to infer the thermal spatial pattern. The images were processed with ERDAS 8.5 software and using radiometric models created for each satellite. Digital numbers were transformed to radiances on the sensor according to the calibration data for each scene. The effective temperature ($T^e$) was calculated from the spectral radiance according to NASA indications (http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html). The effective temperature is the temperature estimated through the Planck equation considering the atmosphere as a black body and using the calibration constants of prelaunching. To build a consistent time-averaged thermal distribution, we obtained an averaged effective temperature from each lake larger than 0.5 $km^2$ in each image. For the large water bodies of the macrosystem (>4 $km^2$), the lake was subdivided into sections (central, northeast, northwest, southeast and southwest sections). Data of permanent water bodies just beyond the wetland borders were also included for comparison purposes (Fig. 1c). Thus, a grid of 63 lake sections of a total of 25 water bodies was used in each image.

The data of each lake section were converted into spatial anomalies ($\Delta T^e$) subtracting and dividing by the average $T^e$ of each image. Although $T^e$ considers the atmosphere as a black body, the effect of the different atmospheric conditions (e.g., aerosols) between dates is removed in $\Delta T^e$ if we assume a homogenous reduction of the transmittance for each scene. Then, a monthly $\Delta T^e$ variation during an average year was obtained averaging the images acquired in the same month of the year. A time-averaged $\Delta T^e$ was extracted for each lake section from the monthly data of this average year. An excessive influence of the months with higher number of images on the time-averaged $\Delta T^e$ is avoided with this method. The distribution of this spatial anomaly showed a longitudinal thermal variation (Fig. 3). Coldest waters appear in the eastern areas of *Laguna Luna* and *Laguna Disparo*, and the northeastern area of *Laguna Iberá*. Highest temperatures appear in the Batel–Batelito Basin, probably because of the different nature of these lakes (located out of the wetland areas). A spatial difference of 0.01 units of $\Delta T^e$ is equivalent to approximately 0.2 °C. Thus, the thermal difference between the warmest and coldest waters is higher than 1 °C.

The factors influencing the thermal spatial pattern may be diverse. Longitudinal or latitudinal climatic

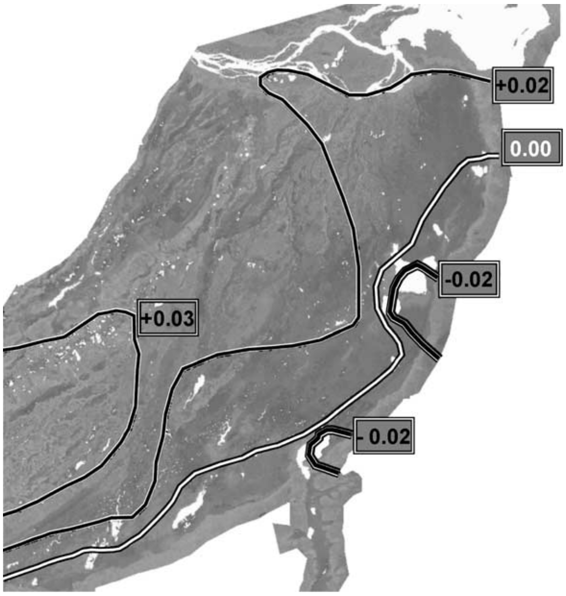


Fig. 3. Spatial distribution of the time-averaged thermal anomaly ($\Delta T^{e}$) in the open water bodies of the Ibera macrosystem and the surrounding environment. A spatial difference of 0.01 units of $\Delta T^{e}$ is equivalent to approximately 0.2 °C.

gradients, lake dimensions, renewal times or groundwater outflows could intervene on the temperature of the water bodies. The comparison of the air temperature means (from 1968 to 1999) in cities located at the northern (Posadas and Corrientes, 21.3 °C) and southern borders (Mercedes 19.7 °C) of Ibera showed considerable differences. The historical means in cities located at the eastern (Posadas 21.4 °C) and western (Corrientes 21.2 °C) sides did not show, however, significant differences. Therefore, longitudinal thermal variation observed in the water bodies of Ibera could not be explained by geographical climatic gradients. A Landsat-5 image of 1986 was acquired to explore the effect of the latitude during the period before the water level rise. The latitude and the relative temperature of the water bodies of Ibera showed a significant linear correlation ($R$=0.6926, $P$<0.01), explaining the 48% of the thermal variability. However, this north–south gradient of water temperature does not exist currently along the Ibera macrosystem. The linear correlation between latitude and the present temperature only explained the 1% of the variability.

The effect of the drainage of the wetland (from north to south) could also induce differences of temperature along the wetland. However, this effect would not explain the existence of the coldest waters in the middle-eastern border of Ibera. As the water from all the wetland flows towards Corriente River, the southern sector shows a larger catchments area. The retention times of the lakes towards the south would be shorter and shorter. The different morphology of the large lakes along the wetland (elongated lakes in the south and round-shaped lakes in the north) supports the mentioned spatial differences in the water drainage of the basin. In many cases (e.g., *Laguna Itatí*, *Laguna Carayá*), the southern lakes are more similar to slow rivers instead of static lakes, having inflowing streams at north and outflowing streams at south. Therefore, the analysis of different limnological properties (optical variables, macrophytes development, fish composition) of the Ibera lacustrine system showed a general north–south gradient, which was explained by the mentioned differences derived from the wetland drainage (Cózar et al., 2004).

The lake volume intervenes in the lake renewal and, indirectly, could also influence the thermal regime of the water bodies. However, this factor did not explain either satisfactorily the actual thermal distribution of Ibera. Nevertheless, the influence (estimated as linear correlation) of the water volume (measured as lake surface) on the thermal pattern increased from 0.1% (in 1986) to 22% during the period after the water level rise. The increasing of the water volume of the lakes linked to the level rise could also explain these results.

Geological analyses have suggested two potential ways for the possible groundwater connection between Yacyreta and Ibera (Blanco and Parera, 2001, Canziani et al., 2002): a potential subsurface connection through the fluvial sands that separate the reservoir and the wetland (between 0 and 30 m deep) and a deeper connection through the basaltic fractures. The limited waterproofing of the southern cutoff of the reservoir (without a bentonite wall like the northern subdams) would facilitate a groundwater connection through the permeable sands. The water transfer would have an effect on the northern border of Ibera macrosystem. However, the sudden water level rise registered in 1989 suggests a free influx through the diaclasas in the basalt rather than a laminar filtration through sands (Blanco and Parera, 2001, Canziani et al., 2002). The basaltic fractures are located in the bed of the Yacyreta Reservoir (in the area of the ancient Apipe rapids) and continue towards the south to the interior of Ibera wetland. Therefore, the potential groundwater outflow would reveal at an intermediate level of the Ibera macrosystem (Canziani et al., 2002). The present analysis would show the transfer through the basaltic fractures as the most relevant connection way. The outflow would be located in the middle-eastern border of the macro-system, concretely in the areas of *Laguna Iberá* and *Laguna Luna–Disparo*. During the geological uplift at the Pleistocene, the shift of riverbed of the ancient Parana–Uruguay river occurred just in the middle-eastern border, which represents a marked geological discontinuity (INCyTH-ICA, 1981). Moreover, the eastern border corresponds to the deepest area in the northern half of the Ibera basin (INCyTH-ICA, 1981).

The present work has not confirmed definitely the groundwater connection between Ibera and Yacyreta, although it presents some indications that recommend to study this hypothesis seriously. This new sign of connection, found with a different methodology, comes on top of the signs which already exist. A new water level rise of the Yacyreta reservoir until 83 m would probably cause dramatic changes in one of the most pristine and singular ecosystems of South America, compromising even the existence of the wetland. Deeper hydrogeologic studies must be planned before modifying the water level of Yacyreta because of the numerous signs of groundwater connection.

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## References

Blanco DE, Parera AP. The silent flood: the increase in water-level in the Iberá marshes, a new threat from the Yacyretá dam. Buenos Aires: Argentine Wild Life Foundation; 2001. 26 pp. (http://www.vidasilvestre.org.ar/ aguadulce/index.asp).

Canziani GA, Ferrati R, Federico P, Canonica A, Ruiz Moreno D, Milano F, Gandini M, Sánchez R. Report of the National University of Buenos Aires. In: Canziani GA, Rossi C, Loiselle S, Ferrati R, editors. EC INCO Project Final Report (ERB I18 CT98 0262), the sustainable management of wetland resources in Mercosur. Italy: Univ. of Siena; 2002. p. 69–86.

Cózar A, Limnological study of the Ibera wetlands (Argentina): basis for the management. PhD thesis, Spain: University of Cadiz; 2003 [in Spanish 225 pp.].

Cózar A, García CM, Gálvez, Loiselle S, Bracchini L, Cognetta A. Spatial and temporal analysis of the lacustrine system of Iberá wetland (Argentina) based on remote sensing imagery. Ecol Model [in press].

Ferrati RM, Canziani GA. An analysis of the water level dynamics in Esteros del Ibera wetland. Ecol Model [in press].

INCyTH-ICA. Study of the Ibera macrosystem. Ministry of Economy, INCyTH—Secretary of Transports and Public Works, Buenos Aires, Argentina; 1981 [in Spanish].

Neiff JJ. Typification of the aquatic and interphase environments in the Ibera macrosystem. In: Bonetto AA, editor. Study of the Ibera macrosystem Ecology, vol. 1. Corrientes, Argentina: Water Institute of Corrientes—CECOAL; 1981. p. 14–43 [in Spanish].

Neiff JJ. Pulse regime in rivers and large wetlands of South America. In: Malvárez AI, editor. Topics of the subtropical and temperate wetlands of South America. Montevideo, Uruguay: UNESCO–ORCYT–MAB; 1999. pp. 97–146 [in Spanish].

Olson D, Dinerstein E, Canevari P, Davidson I, Castro G, Morisset V, Abell R, Toledo E. Freshwater biodiversity of Latin America and the Caribbean: a conservation assessment. Washington, DC: Biodiversity Support Program; 1998. 70 pp.

Simonit S, Cattaneo F, Perrings Ch. Modelling the hydrological externalities of agriculture in wetlands: the case of rice in Esteros del Ibera, Argentina. Ecol Mod [in press].