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# Priority wetlands for conservation of waterbird´s diversity in the Mirim lagoon catchement area (Brazil-Uruguay)

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**Abstract**. The objective of the present work is to classify and select priority wetlands for the conservation of waterbirds in the international transboundary catchment area of the Mirim Lagoon (Brazil-Uruguay) and surrounding ecosystems. Layers were integrated within a GIS framework to select 97 priority areas that were classified in eight groups of importance for conservation of waterbirds. The following variables were considered: presence of waterbirds, type of productive activities with significant environmental impact, areas indicated as priority areas for conservation of biodiversity by the Brazilian government, wildlife areas in Uruguayan territory, areas indicated as "protected" in Uruguayan territory, connectivity based on the proximity between wetlands, wetland fragment shape, pollution load received by wetlands, and land use pressure in areas surrounding the wetlands. It was also possible to classify areas under higher vulnerability and to select priority areas under high threat and in need of actions to recover and restore sub-basins or areas surrounding the wetlands.

**Key words:** landscape ecology, international drainage basins, locational study, geographic information system

**Resumo**. **Áreas úmidas prioritárias para a conservação da biodiversidade de aves aquáticas na bacia hidrográfica da lagoa Mirim (Brasil-Uruguai).** O objetivo do presente trabalho é indicar e classificar as áreas úmidas prioritárias para a conservação de aves aquáticas na bacia hidrográfica transfronteiriça da Lagoa Mirim (Brasil-Uruguai) e seus ecossistemas associados. Os planos de informação foram integrados em um SIG para selecionar 97 áreas prioritárias que foram classificados em 8 grupos de importância para a conservação de aves aquáticas. As seguintes variáveis foram adotadas: ocorrência de aves aquáticas, ocorrência de atividades produtivas de maior impacto ambiental, áreas indicadas como prioritárias para a conservação da biodiversidade pelo governo brasileiro, áreas de vida silvestre no território uruguaio, áreas indicadas como "protegidas" no território uruguaio, conectividade baseada na proximidade entre as áreas úmidas, índice de forma do fragmento, carga poluidora recebida pelas áreas úmidas, pressão antrópica no entorno das áreas úmidas. Foi também possível classificar as áreas sob maior vulnerabilidade e assinalar as áreas prioritárias sob maior ameaça e que necessitam de ações de recuperação no seu entorno e na sub-bacia de contribuição.

**Palavras chave:** ecologia da paisagem, bacia hidrográfica transfronteiriça, estudo locacional, geoprocessamento

## Introduction

Wetlands are among the most productive ecosystems in the planet (McCartney 2005). They present high biodiversity due to water inflow and outflow regimes and the consequent concentration of nutrients required by riparian vegetation and by some species of birds, particularly migratory birds (Halls 1997). Wetlands hydrology is wavy, resulting in pulsing hydroperiods. During flooding periods there is a prevalence of anaerobic conditions in wetland soils because oxygen is depleted faster than it can be replaced by diffusion. Consequently, carbon, nitrogen, phosphorus, iron, manganese, and sulfur biogeochemical cycles are transformed, establishing a very especial environment for living beings. Wetlands can function as sources, sinks, or transformers of these materials, depending on inflows, outflows, and internal cycling rates. Because of their importance, many wetlands are often recognized as important conservation or restoration targets. Besides this, wetlands in general are under the protection of the Ramsar Convention, an international treaty aimed at conserving wetlands and the ecosystem services they provide (Cherry 2011).

According to USEPA (1995), more than one-third of the threatened or endangered species in the United States of America live solely in wetlands. So, studies have been conducted to record the presence of avifauna associated to wetlands, and to assess the habitat requirements of waterbirds throughout the world (Froend *et al.* 1997, Yallop *et al.* 2004, Tozer *et al.* 2010). A general overview of the neotropical waterbirds can be found in López-Lanús & Blanco (2005).

Most of the wetlands present increasing land use pressure due to the expansion of food production activities. Such activities often use water from wetlands to promote irrigation. In some cases, crops are located inside the wetlands, disturbing the original water regime and diminishing the water surface area. Impacts of these uses are related not only to the local avifauna but also to the migratory waterbirds, since migration depends on ecological stepping stones and wetlands in general fit well to such role (Blanco *et al*. 2006, Acosta *et al*. 2010). So, environmental changes in these areas can reduce the amount of food for migratory birds, magnifying their vulnerability (Lagos *et al.* 2008, Dar & Dar 2009).

Sustainable management of such areas depends upon a good understanding of the drainage system, flood pulses, and the role of wetlands on biodiversity maintenance. When wetlands extend over international borders, the management of the whole drainage basin becomes more complex, as it involves two or more countries, with different cultural and political contexts and interests.

This is the case of the Mirim Lagoon wetlands complex, shared by Brazil and Uruguay. The Mirim Lagoon is the second largest freshwater lake in South America. It is surrounded by several small wetlands, corresponding to a mosaic of terrestrial and aquatic habitats. The geographic location of Mirim Lagoon also favors the migration of birds, such as *Tachycineta meyeni* and *Charadrius modestus*, from the southernmost region of the continent, including southern Chile, Patagonia, Malvinas Islands, and Tierra del Fuego. The wetlands complex around Merin Lagoon is a reproduction site for birds that migrate northwards during the winter (Bencke *et al*. 2007). The Mirim Lagoon region is also the confluence of several other migratory fluxes, which are recognized as eight different routes, connecting biodiversity and lands from the extreme North to South America.

In Brazil, the Mirim Lagoon floodplains sustain a rice production of about 500,000 tons per year. In Uruguay, the production is over 350,000 tons per year (IRGA 2003). Thus, the Mirim Lagoon catchment represents an important rice farming area for both countries. However, rice production implies a strong demand of water, fertilizers and pesticides, which cause strong negative impacts on the ecosystem (UNDP 2010). Such impacts can compromise its stability and diminish its capacity for sustaining these migratory birds. According to Dias and Burguer (2005), the number of individuals in some bird species has been reduced due to the expansion of irrigated rice farming.

This study aims to identify priority wetlands for the conservation of waterbirds diversity in the Mirim Lagoon catchment area. The study considers both countries, Brazil and Uruguay, and the whole extension of the ecosystem in the catchment area, as opposed to traditional approaches that conduct analyses within political borders.

The advantage of a broad scanning approach is to offer the possibility to find out locations by rational criteria that can be unsuspected at local level perception.

## Materials and Methods

### *Study Area*

Located on the Atlantic Coast of South America, the Mirim Lagoon catchment area (Figure 1) covers about 55,110 km². The climate is subtropical with an annual average rainfall from 1,200 to 1,500 mm.

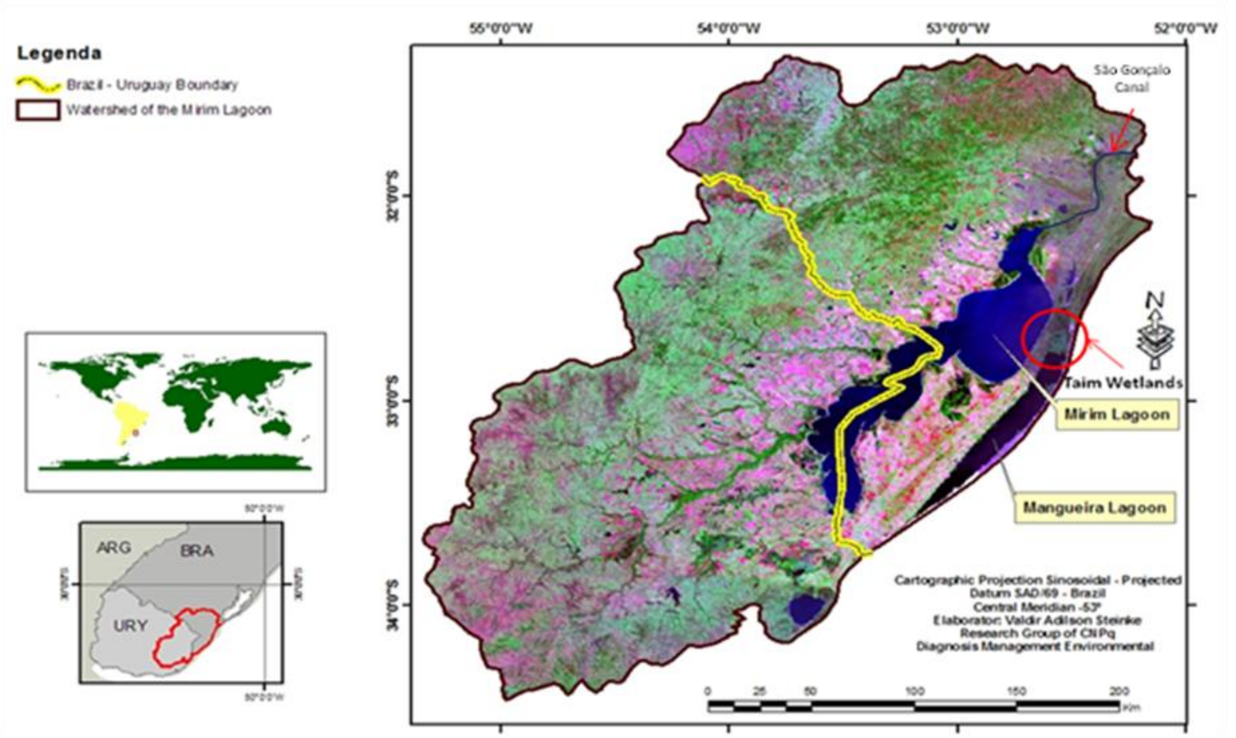


**Figure 1.** Location of Mirim Lagoon and its catchment area in Brazil and Uruguay.

This region was modeled by marine regression processes during the Holocene, which produced a set of small lakes and the Mangueira Lagoon. Around 230,000 years ago, the Precambrian crystalline basement was covered by the ocean. Further oceanic oscillations created sand barriers towards the south and a semi-lagoon channel between sand bars. This originated the Mangueira Lagoon and isolated the Mirim Lagoon once again from the ocean. The hydrological connection between Mirim Lagoon and Mangueira Lagoon is established by the Taim wetland, which is a protected area in Brazil. Mirim Lagoon and Patos Lagoon were connected to each other by the erosion processes of the Pleistocene terraces situated in the north of the Mirim Lagoon from the Patos Lagoon. Nowadays, the São Gonçalo canal drains the Mirim Lagoon to the Patos Lagoon (Schwarzbold 1984, Vieira & Rangel 1988, Clapperton 1993, Ab'Sáber 2003, 2006). Surrounding Mirim Lagoon there is a floodplain system, including riparian habitats such as gallery forests, swamps, small lagoons, and coastal dunes composing a wetlands complex. There are also remnants of Atlantic Forest in riparian corridors (Berlinck *et al.* 2004).

The total catchment area of Mirim Lagoon is 55,110 km². Inside this area, it can be distinguished a coastal plain strip between the east margin of the Mirim Lagoon and the Atlantic Ocean, which has a different drainage behavior (with no regular and conclusive direction of stream flow) because of the absence of significant elevation degree. Consequently, the real contribution area to stream flow represents the total catchment area minus this coastal plain strip area (55,110 km² - 7,748 km² = 47,362 km²). Presently, Mirim Lagoon is a closed coastal lagoon without any direct marine influence. So, the hydrodynamic behavior of the Mirim Lagoon depends mostly on catchment internal flow dynamics, including water entrance in the system and water retention by the wetlands complex. Water residence time is close to 205 days (Santos *et al*. 2004). The climate is classified as Cfa according to Köppen-Geiger Climate classification, with a well-distributed rainfall during all the year, and strong influence of northeast winds. The macrophyte vegetation is species rich, with over 120 species in different biological forms and strategies of occurrence in the environment (Gazulha 2004).

Regarding Mirim Lagoon and coastal plain of Rio Grande do Sul State, different authors have addressed the composition and distribution of waterbirds. Studies conducted by Antas *et al.* (1990, 1996), Antas (1994), Dotto *et al*. (1998), Nascimento *et al*. (2000), and Menegheti *et al.* (1990, 1993, 1995, 1996, 1997, 1998, 2002) are especially relevant.

The project "Use of remote sensing technologies for the development of multilateral treaties on ecosystem management", focused on agricultural impacts to the biodiversity of Mirim Lagoon wetlands complex, was held by researchers from IBAMA (Brazil), Probides (Uruguay) and Columbia University (United Sttates of America) in 2004. Based on rapid ecological assessment in two areas of 40km², located in Brazil and Uruguay, during March and October 2004, the researchers concluded that in Brazil, due to the production of rice and the limited presence of native woods, the number of waterbirds species (species richness) was approximately 7% lower than that from Uruguay (Berlinck *et al*. 2004).

The main land use in the region is the production of rice. The catchment area is scarcely urbanized with a population of less than one million people, with two main cities (Pelotas and Rio Grande, both in Brazilian side, which however have no direct influence upon Mirim Lagoon because their effluent discharge are in São Gonçalo channel and Patos Lagoon estuary, respectively (Santos *et al.* 2004).

*Methodological Approach*

In order to select priority areas for wetland protection, a case study was carried out based on spatial analysis. A set of thematic maps were selected as primary data and combined according to scientific, legal, logical and heuristic rules.

The hydrographic and topographic maps were generated from digital elevation models gathered by the Shuttle Radar Topography Mission (SRTM/NASA). The soil and geology maps were obtained from Brazil (IBGE, 2003) and Uruguay (PROBIDES, 1999).

The land use map at 1:100,000-scale was derived from LANDSAT-TM5 satellite data (2005, orbit-point 222-82, 222-83, 222-84, 223-83, and 223-84). The images were segmented by the region-growing method available in the SPRING 4.3.2 software package and classified by the supervised classification technique (Lillesand & Kiefer 2000; Samaniego & Schulz 2009). The resulting land use map was validated according to the maps produced by PROBIDES (1999), MMA (2006) and Berlinck *et al.* (2004) field data. These procedures were necessary because the Uruguayan land use data were old and there was a need for more recent re-evaluation combined with ground truth (Thomas & Ayuk, 2010; Saradeth *et al.* 2010).

The analysis was based on three major steps (Figure 2).

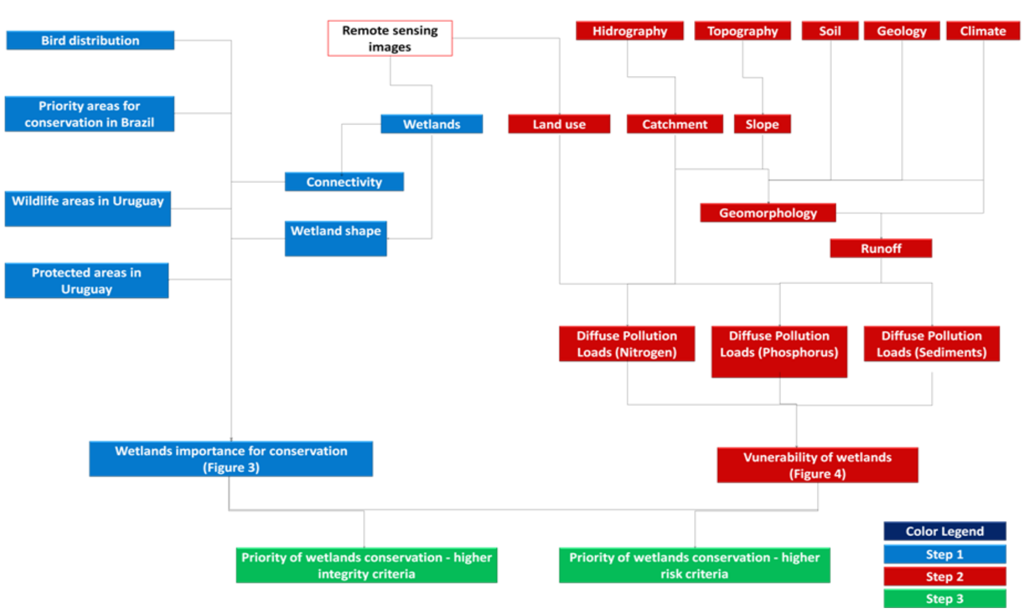


**Figure 2.** Flowchart of the methodological approach used to determine the priority wetlands for conservation in the Mirim Lagoon catchment area. The three major steps are indicated in different colours

In each step, parameters were considered as ordering vectors in which classes of the parameter (corresponding to legends of the thematic map) were ranked from 0 to 10 scores, according to its importance to the analysis (Xavier-da-Silva *et al*. 2001, Xavier-da-Silva & Carvalho-Filho 2004, Teles & Saito 2009). This procedure establishes a uniform range (scores) of internal values for all the parameters. Eventually, parameters received different weights depending on their relative importance. Because maps were handled in a GIS environment, they were considered as raster databases where each pixel is considered a cell in a matrix of lines and columns with a specific geolocation system. The combination of these ordering vectors, representing a mathematical procedure of maps overlay, resulted in new evaluative maps, which can be intermediate or final maps (Xavier-da-Silva, 1992). The mathematic expression which corresponds to the maps overlapping procedure is the following:

*Equation1:*

$$A_{ij} = \sum_{k=1}^{n} (P_k \cdot N_k)$$

Where:
$Aij$ = cell of the matrix;
$n$ = number of parameters involved;
P = weight score attributed to the parameter, normalized to 0 - 1 range; and
$N$ = ordering score in the scale of 0 to 10, attributed to the category (class of information, corresponding to the legend type of the parameter) associated to the cell.

N corresponds to a heuristic evaluation of each legend type or class of information according to its contribution to the purpose of analysis. The heuristic evaluation includes both scientific literature-based criteria and expert own personal experience. Table I and 2 presents the ordering scores and weights used in the present study. The cell of the matrix is described by the combination of lines and columns ($i$ and $j$ index, respectively) and $Aij$ represents the final content of that cell. So, $Aij$ in Equation 1 will correspond to the sum of each numerical evaluation of all the parameters at this particular cell, spatially identified by its geographic coordinates.

It is important to indicate that this approach fits in a general category of the weighted linear combination in opposition to the boolean technique, according to Baban & Wan-Yusof (2003). These authors defend that an element of subjectivity associated with the allocation of map weights and scaling should be recognized and valued, because allows "flexibility to the planners to incorporate varying degrees of importance to each criterion based on their experience" (Baban & Wan-Yusof, 2003 p.15).

*Step 1 (The conservation criteria, map of importance for conservation)*

The first analysis aimed to determine the priority wetlands classified according to six conservation criteria related to biological and management parameters of the protected areas located within the Mirim Lagoon catchment area. The goal here was to identify those wetlands more important in terms of biological conservation perspective. Thus, the parameters considered were the presence of waterbirds, wetlands shape and their spatial relationship, and their inclusion in national protected areas. The set of ranking procedures inside the conservation criteria are detailed as follows:

*1a) Criterion 1: Areas with presence of water birds.*

The bird distribution map is a consolidated map, generated from several research data obtained by Antas *et al.* (1990, 1996), Antas (1994), Dotto *et al*. (1998), Nascimento *et al*. (2000), and Menegheti *et al.* (1990, 1993, 1995, 1996, 1997, 1998, 2002) for both countries. These studies were based on periodic censuses of birds with special emphasis on records of geographic coordinates of main agglomeration sites. Inventories were made annually, and for the purpose of the present study, were considered the results for bird distribution between 1990 -2000. The census was conducted using a *ca.* 12 km linear transect and a buffer of 50 meters at both sides of the transect. Distance between transects was 2 km. Special attention was given to the presence of marrecão (*Netta peposaca*) and marreca naneleira (*Dendrocygna bicolor*). They follow a west-east migration route, from the lower Paraná river to the coastal zone of the State of Rio Grande do Sul and Uruguay. The wetlands that overlapped those areas were registered as positive waterbirds occurrence sites and they received the maximum grade in a scale ranging from 0 to 10. The focus on waterbirds is due to the vital importance of the wetlands for them, justifying wetlands conservation priority. For this criterion it was applied a boolean approach (Table I).

*1b) Criterion 2: Priority areas for waterbird conservation in the Brazilian territory*

In 2006, the Brazilian Ministry of the Environment indicated the country´s most relevant areas for biodiversity conservation (MMA 2006). The study area was the only area considered as priority for conservation in the Pampa Biome. The classes defined by MMA (2006) were: extremely high, very high, and high priority for conservation (same classification as in this paper). However, in our study, grades varying from 1-10 were given to each class (Table I).

*1c) Criterion 3: Wildlife areas in the Uruguayan territory*

Wildlife areas are natural areas created by governmental acts aiming to protect wildlife species. These areas are important due to their high biodiversity. Thus, they are essential for the indication of priority wetlands for conservation. The evaluation of this criterion was done based on whether the wetlands were classified as wildlife areas according to PROBIDES (1999), following a boolean approach (Table I).

*1d) Criterion 4: Protected areas in Uruguayan territory*

In Uruguay, besides wildlife areas, there are other ones considered as protected areas. There is permission to have some human activities, similar to the protected areas of sustained use in Brazil. The evaluation of this criterion was also carried out in a binary format (Table I). Wetlands with the presence of waterbirds were classified as belonging or not to some protected area (PROBIDES 1999). Therefore, this was similar to the Criterion 3. Although they could be joined as a single criterion (with criterion 3), we preferred to maintain it separated in order to keep track of different types of protection of wetlands.

*1e) Criterion 5: Connectivity, based on the distance between wetlands*

The connectivity criterion aimed to establish a view of groups of wetlands around the areas of presence of waterbirds. A wetland influence zone was established considering a 6-km buffer from the center of each wetland. Using this distance, all wetlands can be joined in a single polygon. The use of buffer zones to group adjacent fragments and then define sites of interest was also addressed by Lee *et al.* (2002). In this connection zone, a 6-km of total buffer, composed by small buffers of 2-km were established and classified according to the degree of proximity. Areas closer to the center received higher scores (Table I). Rodrigues (2001) and Rodrigues & Saito (2001) also used such procedures to assess the capacity of forested fragments to promote genetic exchanges of metapopulations of primates when they identified priority sites for fauna release during a hydroelectric dam reservoir´s filling. Regarding waterbirds on wetlands, Tozer *et al.* (2010) found that the size of wetland patches and the amount of wetlands in the surrounding landscape were positively correlated with the number of red-winged blackbirds fledglings per successful nest, suggesting that this connectivity criterion was correctly added in our spatial analysis. Such connectivity has a key role in the maintenance of food replacement for waterbirds. Two sub-criteria were also analyzed. The first was the distance between the wetland fragments and the presence of waterbirds, representing the proximity to food and water. The second was associated with the number of fragments found according to distance, representing the wetland crowds and the subsequent capacity to supply birds with food and water.

*1f) Criterion 6: Index of the fragment shape*

This index is directly related to the landscape structure, which takes into account the influence of border effect on the use of wetlands by waterbirds. The role of this criterion was to analyze the shape of the fragments according to the ratio between area and perimeter (interior/margin). The longer the fragment, the higher the border effects. Consequently, there will be more restrictions to the maintenance of some species. Due to the significant ecological impact, these wetlands with low index were considered of low priority (Cemin *et al*. 2005). From another point of view, one can argue that wetlands with low ratio between area and perimeter can present greater habitat heterogeneity and so could be more important for conservation purpose.

The 6 maps obtained were combined (overlayed) to produce the map of wetlands importance for conservation (Figure 2). Overlays resulted from the sum of the grades (scores) obtained by each separated criteria at all individual points in the map (pixel cell in a raster grid) according to the weighted linear combination (Equation 1). All the criteria were equally weighted. The resulting maps were one of the inputs to step 3 of the analysis.

*Step 2 (anthropic pressures criteria, map of vulnerability)*

The second analysis aimed to identify wetlands under anthropic pressure. Vulnerability was determined by the type and extension of land uses. Two main criteria were used in this step: incoming pollution load and land use pressure in surrounding areas of the wetlands.

**Table I.** Scores of conservation criteria of the wetlands in Mirim Lagoon

| Criteria | Class | Score |
|---|---|---|
| Presence of waterbirds | Yes<br>No | 10<br>0 |
| Protected areas in Brazil | High<br>Very High<br>Extremely High | 6<br>8<br>10 |
| Wildlife areas in Uruguay | Belonging<br>Not Belonging | 10<br>0 |
| Protected areas in Uruguay | Belonging<br>Not Belonging | 10<br>0 |
| Connection (distance) | < 2 km<br>2 - 4 km<br>4 - 6 km | 10<br>6<br>4 |
| Connection (number of areas) | 1 -3 areas<br>4 -6 areas<br>> 6 areas | 4<br>6<br>10 |
| Fragment shape | 0.8000 to 1.0000<br>0.6001 to 0.8000<br>0.4001 to 0.6000<br>0.2001 to 0.4000<br>0.1001 to 0.2000<br>0.0000 to 0.1000 | 10<br>8<br>6<br>4<br>2<br>0 |

*2a) Criterion 1: Wetlands classified according to the incoming pollution load*

Diffuse pollution is an important threat to water bodies in general, including wetlands, and it needs to be estimated (Environment Agency, 2007; Elmaci *et al*. 2009). In order to identify the wetlands receiving the highest amount of diffuse pollutions, we first determined the boundaries of sub-basins in the study area. Only the basins whose waters run into the wetlands and water pools were considered. The delimitation of sub-basins was done based on the topography information of the sub-basins of the Mirim Lagoon and the information from surface runoff. The diffuse pollution loads were estimated applying the correlation model between the Use of the Soil and Water Quality – MQUAL used in the Development and Environmental Protection Plan of the Guarapiranga basin (SMA 2003). As in Steinke *et al*. (2004), the pollution loads were estimated upon the result of the surface area of each land use type and its respective coefficient of exportation of each parameter (phosphorus, nitrogen and sediment) for water quality (Table II). Final diffuse pollution loads were calculated in terms of the annual average of each parameter (units in $kg.d^{-1}$), and they were ranked to the purpose of proceeding another weighted linear combination according to Equation 1 (Table III).

*2b) Criterion 2: Land use pressure in areas surrounding the wetlands*

With this criterion, we tried to identify the pressure level due to land use transformation in the wetlands surroundings, mainly by farming and cattle rising. A 6-km buffer area was established in the surroundings of each wetland, calculated from its external boundaries. The buffer area was overlapped to the land use map to show the level of pressure that these areas were subdued to and how they could be connected to the remaining original vegetation. For that, the percentage of natural vegetation or water ponds and the anthropic land use inside the buffer area was evaluated (Table III). The 6-km distance was established due to the high level of connectivity among the wetlands. In other words, within this buffer, 100% of the wetlands should be in a continuous mosaic surrounding the Mirim Lagoon. The result was used in the weighted linear combination according to Equation 1.

**Table II.** Land use type and their pollution loads in MQUAL

| Land use type | Measuring Unit | Total Nitrogen | Total Phosphorus | Total Suspended sediment |
|---|---|---|---|---|
| Urban | Kg/km²/day | 1,274 | 0,034 | 50 |
| Agriculture | Kg/km²/day | 2,950 | 0,346 | 230 |
| Field | Kg/km²/day | 0,500 | 0,028 | 30 |
| Pasture | Kg/km²/day | 0,500 | 0,028 | 30 |
| Grassland/Forest | Kg/km²/day | 0,600 | 0,039 | 20 |
| Forest | Kg/km²/day | 0,600 | 0,039 | 20 |
| Water | Kg/km²/day | --- | --- | --- |
| Wetland | Kg/km²/day | 0,700 | 0,034 | 10 |
| River grove | Kg/km²/day | 0,550 | 0,034 | 25 |
| Field-plate | Kg/km²/day | 0,500 | 0,028 | 30 |

Source: based on SMA (2003).

The maps from these two criteria were combined according to the weighted linear combination (Equation 1) to produce the map of vulnerability of the wetlands (Figure 2). The two criteria were equally weighted. Resulting maps will also be one of the inputs to step 3 of the analysis.

*3) Step 3 (Final evaluations, priority wetlands for conservation)*

The third analysis aimed to indicate the priority wetlands for conservation. To do that, a classification matrix was produced that combined the results of steps 1 and 2 (Figure 2). In this study, it was established two different ways for defining hierarchies (priority areas classified according to their level of importance for conservation purpose): the first one, based on the criteria of ecosystem integrity, and the second, based on the vulnerability of the ecosystem. The first approach is based on the idea that areas of higher integrity will better represent the original characteristics of the wetlands ecosystem and should be prioritized for protection. The second approach is based on the idea that higher vulnerability increases the risk of disappearing. See Table IV for higher integrity and Table V for higher vulnerability.

Final identification of wetland priority areas resulted in two different maps, according to two possibilities: i- the axis of vulnerability was scored with higher priority (high score level) when wetland patches were exposed to low pressure (option 1, Table IV); ii- the axis of vulnerability was inverted and scored with higher priority (high score level) when they were exposed to high pressure (option 2, Table V).

Once the methodology is based on a broad scanning and locational integration, the final ranking of wetlands for conservation purpose will be an overview of all the wetlands in the Mirim Lagoon catchment area.

**Table III.** Scores of the vulnerability criteria for wetlands in Mirim Lagoon

| Criteria | Class | Score |
|---|---|---|
| Pollution loads into the sub-basin | Very Low | 10 |
| | Low | 8 |
| | Moderate | 6 |
| | High | 4 |
| | Very High | 2 |
| | Extra High | 0 |
| Land use in areas surrounding wetlands (2-km buffer) | < 10% of land use | 10 |
| | 11 - 20% of land use | 8 |
| | 21 - 40% of land use | 6 |
| | 41 - 50% of land use | 4 |
| | 51-a 60% of land use | 2 |
| | > 60% of land use | 1 |

**Table IV.** Matrix for classification of wetlands combining biological importance and vulnerability, prioritizing the integrity

| | | Vulnerability classification | | | | | |
|---|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very High | Extremely High |
| **Biological importance** | Score | 10 | 8 | 6 | 4 | 2 | 0 |
| Extremely High | 10 | 20 | 18 | 16 | 14 | 12 | 10 |
| Very High | 8 | 18 | 16 | 14 | 12 | 10 | 8 |
| High | 6 | 16 | 14 | 12 | 10 | 8 | 6 |
| Moderate | 4 | 14 | 12 | 10 | 8 | 6 | 4 |
| Low | 2 | 12 | 10 | 8 | 6 | 4 | 2 |
| Very Low | 0 | 10 | 8 | 6 | 4 | 2 | 0 |

* The numbers in the intersection cells represent the resulting scores of the combination each class weighted on step 1. The cells above the diagonal (in light blue) are positively evaluated, the cells at the diagonal (in white) are neutral, and cells below the diagonal (in orange) are negatively evaluated.

**Table V.** Matrix for classification of wetlands combining biological importance and vulnerability, prioritizing the vulnerability

| | | Vulnerability classification | | | | | |
|---|---|---|---|---|---|---|---|
| | | Extremely High | Very High | High | Moderate | Low | Very Low |
| **Biological importance** | Score | 10 | 8 | 6 | 4 | 2 | 0 |
| Extremely High | 10 | 20 | 18 | 16 | 14 | 12 | 10 |
| Very High | 8 | 18 | 16 | 14 | 12 | 10 | 8 |
| High | 6 | 16 | 14 | 12 | 10 | 8 | 6 |
| Moderate | 4 | 14 | 12 | 10 | 8 | 6 | 4 |
| Low | 2 | 12 | 10 | 8 | 6 | 4 | 2 |
| Very Low | 0 | 10 | 8 | 6 | 4 | 2 | 0 |

* The numbers inside intersection cells represents the resulting scores of the combination each class weighted on 1. The cells above the diagonal (in light blue) is recognized as positive evaluated, the cells at the diagonal (in white) is neutral, and the cell below the diagonal (in orange) is recognized as negative evaluated.

## Results and Discussion

The first result obtained from the analysis under the conservation criteria (step 1) in the Mirim Lagoon catchment area showed that 43 wetlands from a total of 97 (around 45%) were classified as high, very high, or extremely high priority for conservation (Figure 3). Nevertheless, these wetlands represent more than 65% of the total area of the wetlands in the study area. Table VI presents the wetland surface areas per class of priority.

The second step analysis showed the levels of vulnerability of these areas (Figure 4). Table VII presents the quantitative data according to the vulnerability classification. The results consider the estimated pollution loads due to land use in the catchment area and the percentage of land use coverage in the areas surrounding the Mirim Lagoon. According to these data, 73% of the wetlands are under strong impact and the waterbirds are highly vulnerable.

The analysis of this step was based on DeLuca *et al*. (2004). They developed an index to evaluate the bird communities and environmental conditions in order to understand how human activities would influence the bird species that depended upon the wetland areas. These authors observed that the index along with the identification of the different types of land use was easy to interpret and also it facilitates the "communication" of complex ecological data. The authors highlighted relevant aspects of ecological studies, the scale and approach of the analysis.

**Table VI.** Wetlands importance for conservation (Step 1)

| Priority | Number of Wetlands | Area (km²) |
|---|---|---|
| Extremely High | 8 | 194 |
| Very High | 19 | 1.859 |
| High | 16 | 571 |
| Moderate | 19 | 596 |
| Low | 22 | 525 |
| Very Low | 13 | 237 |
| Total | 97 | 3.982 |

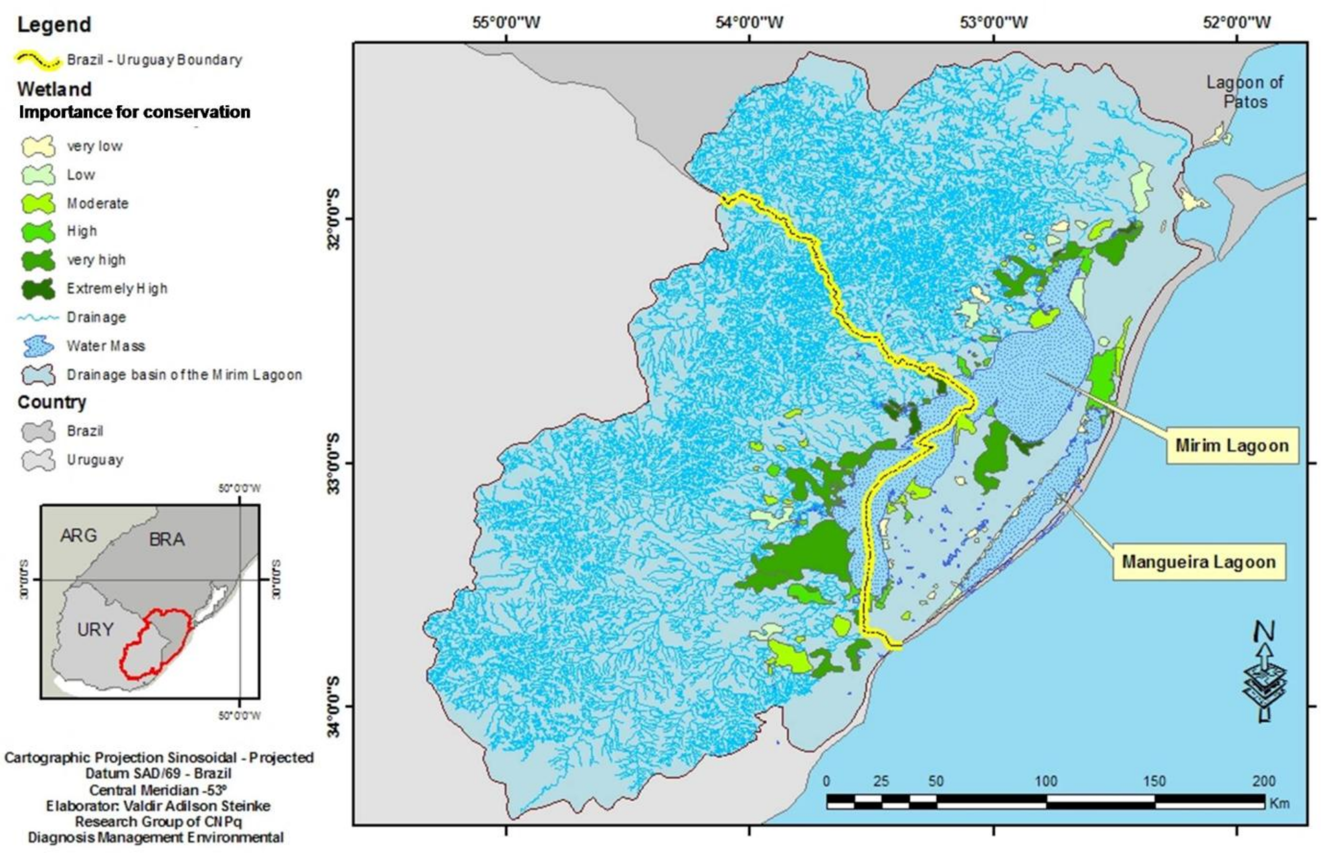


**Figure 3.** Wetlands in the Mirim Lagoon classified according to their importance for conservation

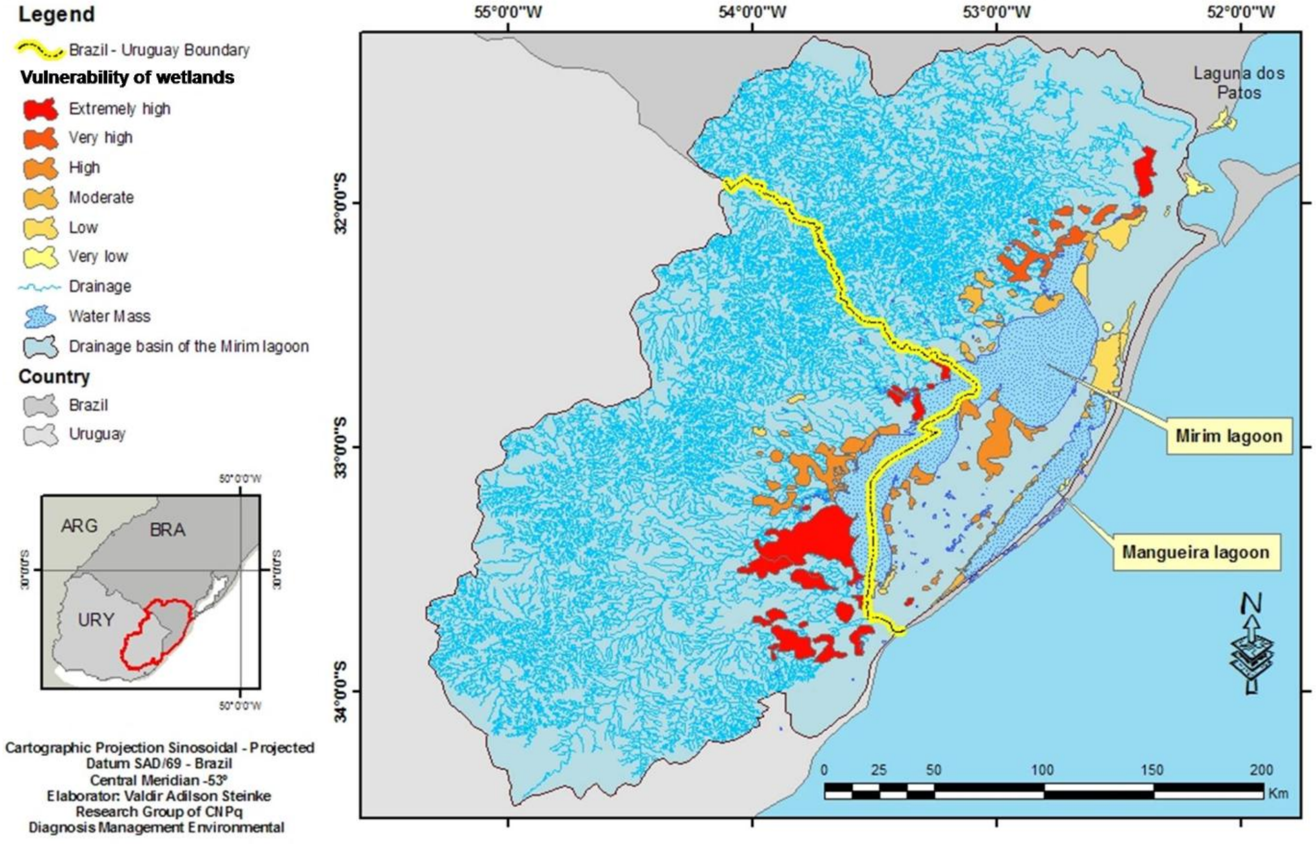


**Figure 4.** Vulnerability of wetlands in the Mirim Lagoon catchment area.

**Table VII.** Vulnerability of wetlands due to land use pressure

| Vulnerability | Number of Areas | Area (km²) |
|---|---|---|
| Extremely High | 20 | 1,528 |
| Very High | 14 | 368 |
| High | 25 | 1,009 |
| Moderate | 22 | 389 |
| Low | 9 | 569 |
| Very Low | 7 | 119 |
| Total | 97 | 3,982 |

For this reason, it was adopted the regional scale as hierarchical level of analysis and it was considered two possibilities for guiding the environmental managers to propose public policies for conservation: option 1 (high integrity criterion) – they should first protect those areas that still preserves natural characteristics and are under low pressure so that they can be easily protected (Figure 5); or option 2 (high risk criterion) – they should first protect those areas that still preserves natural characteristics but are under high pressure so that they will face several difficulties to be protected later (Figure 6). Final identification of wetland priority areas resulted in two different maps, according to the two possibilities, and the number of wetlands classified according to these are presented in Table VIII and IX, respectively. To do that, a matrix of classification between the results from step 1 and step 2 analysis (biological importance and vulnerability of wetlands, respectively) was done in two different ways (Tables VI and VII): the axis of vulnerability was scored with higher priority (high score level) when they were exposed to low pressure (option 1, Table VI); the axis of vulnerability was inverted and scored with higher priority (high score level) when they were exposed to high pressure (option 2, Table VII).

Based on Table IV criteria, 29 areas fit in positive group, highlighted in Table VIII, other 18 areas received grade ten (neutral). The others (up to 50 areas) were defined as negative, which means that 51.5 % of the areas are under high vulnerability. These three groups were reorganized into eight ones: the positive group was decomposed in three classes, the 18 neutral areas were classified as Moderately high and the negative group were decomposed in four new classes (Table X).

Figure 5 shows the spatial distribution of wetlands classified according to the combination of biological importance and vulnerability, prioritizing the integrity. This map is very important to start a broader discussion concerning the socio-environmental management of the hydrological complex system of Mirim Lagoon. Nevertheless, according to option 2, a new spatial pattern can be seen, this time due to the priority established by the combination of the axes in which the vulnerability criteria was inverted. In this new procedure, those areas with higher priority from the perspective of conservation and at the same time with higher vulnerability to threats are classified as areas of extreme priority. Table IX shows the quantification of the areas for each class of priority and Figure 6 presents the spatial distribution of these areas.

**Table VIII.** Number of wetlands classified according to the combination of biological importance and vulnerability of wetlands prioritizing the integrity

| | | Vulnerability classification | | | | | |
|---|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very High | Extremely High |
| **Biological importance** | Score | 10 | 8 | 6 | 4 | 2 | 0 |
| Extremely High | 10 | 0 | 0 | 0 | 1 | 2 | 5 |
| Very High | 8 | 0 | 1 | 3 | 6 | 2 | 7 |
| High | 6 | 0 | 3 | 5 | 3 | 2 | 3 |
| Moderate | 4 | 0 | 4 | 4 | 4 | 4 | 3 |
| Low | 2 | 4 | 1 | 6 | 6 | 3 | 2 |
| Very Low | 0 | 3 | 0 | 4 | 5 | 1 | 0 |

* The numbers inside intersection cells represents the quantity of wetlands that fits this combination of line and column. The cells above the diagonal (in light blue) are recognized as positive evaluated, the cells at the diagonal (in white) are neutral, and the cell below the diagonal (in orange) are recognized as negative evaluated.

The two procedures adopted in this study (considering option 1 of priority to integrity of wetlands and option 2 of priority to vulnerability of wetlands) revealed important aspects that can inform decision makers to elaborate environment management plans: the first option takes into account the positive factor presented for areas that area less vulnerable, which might enable actions aiming at the maintenance of the present conditions of these areas. The second option, from the point of view of environmental restoration, the indication of those areas are under strong vulnerability constitutes relevant information to propose mitigating measures. This can contribute to environmental zoning and management, so that specific wetlands and their surroundings could be targeted as ecological restoration zones. This is in accordance to Erwin *et al.* (2004). They examined the alterations in the wetland habitats along the east coast of the United States of America and they identified how these changes affected birds. Their results proved that the identified modifications influenced many bird species that use these areas for feeding, reproduction and resting during the migratory process. Results showed the need for the preservation of such areas, besides their altered state.

**Table IX.** Number of wetlands classified according to the combination of biological importance and vulnerability of wetlands with inversion of the axis of vulnerability

| | | **Vulnerability classification** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Extremely High | Very High | High | Moderate | Low | Very Low |
| **Biological importance** | Score | 10 | 8 | 6 | 4 | 2 | 0 |
| Extremely High | 10 | 5 | 2 | 1 | 0 | 0 | 0 |
| Very High | 8 | 7 | 2 | 6 | 3 | 1 | 0 |
| High | 6 | 3 | 2 | 3 | 5 | 3 | 0 |
| Moderate | 4 | 3 | 4 | 4 | 4 | 4 | 0 |
| Low | 2 | 2 | 3 | 6 | 6 | 1 | 4 |
| Very Low | 0 | 0 | 1 | 5 | 4 | 0 | 3 |

* The numbers inside intersection cells represents the quantity of wetlands that fits this combination of line and column. The cells above the diagonal (in light blue) are recognized as positive evaluated, the cells at the diagonal (in white) are neutral, and the cell below the diagonal (in orange) are recognized as negative evaluated.

**Table X.** Quantification of priority wetlands for conservation, prioritizing the integrity

| Group | Priority for conservation | Number of Areas | Area (km²) |
|---|---|---|---|
| 1 | Extremely High | 1 | 130 |
| 2 | Very high | 7 | 331 |
| 3 | High | 21 | 870 |
| 4 | Moderately High | 18 | 625 |
| 5 | Moderately Low | 19 | 1,171 |
| 6 | Low | 17 | 359 |
| 7 | Very Low | 11 | 304 |
| 8 | Extremely Low | 3 | 191 |
| **Total** | | **97** | **3,982** |

*Final Considerations*

Brazil and Uruguay have international agreements and laws seeking to promote the protection and sustainable use of wetlands. Nevertheless, both Brazilian and Uruguayan sides of the Mirim Lagoon catchment area share similar expectations regarding land use changes in connection to productive and economical activities. This implies a great pressure to transform wetlands and their surroundings, increasing their vulnerability and, thus, the vulnerability of waterbirds that need these wetlands for survival (Menegheti 2010).

Two considerations must be made concerning the final maps (Figures 5 and 6). First, most areas with higher degree of priority are located on the western border of the lagoon. These areas are under strong pressure in Brazil and Uruguay, and this pressure tends to increase in both countries. This can be seen in Brazil due to the indication as potential areas for the installation of cellulose industry and afforestation (mainly *Pinus* and *Eucaliptus* planting). The same situation occurs in Uruguay where there is a trend to have a new critical component: the implementation of a cargo terminal at the gorge of the Cebollati River, within the most relevant wetlands in the region (Timonsur 2003). The future environmental impact of these activities in the Mirim Lagoon is analyzed by Goulart & Saito (2012).

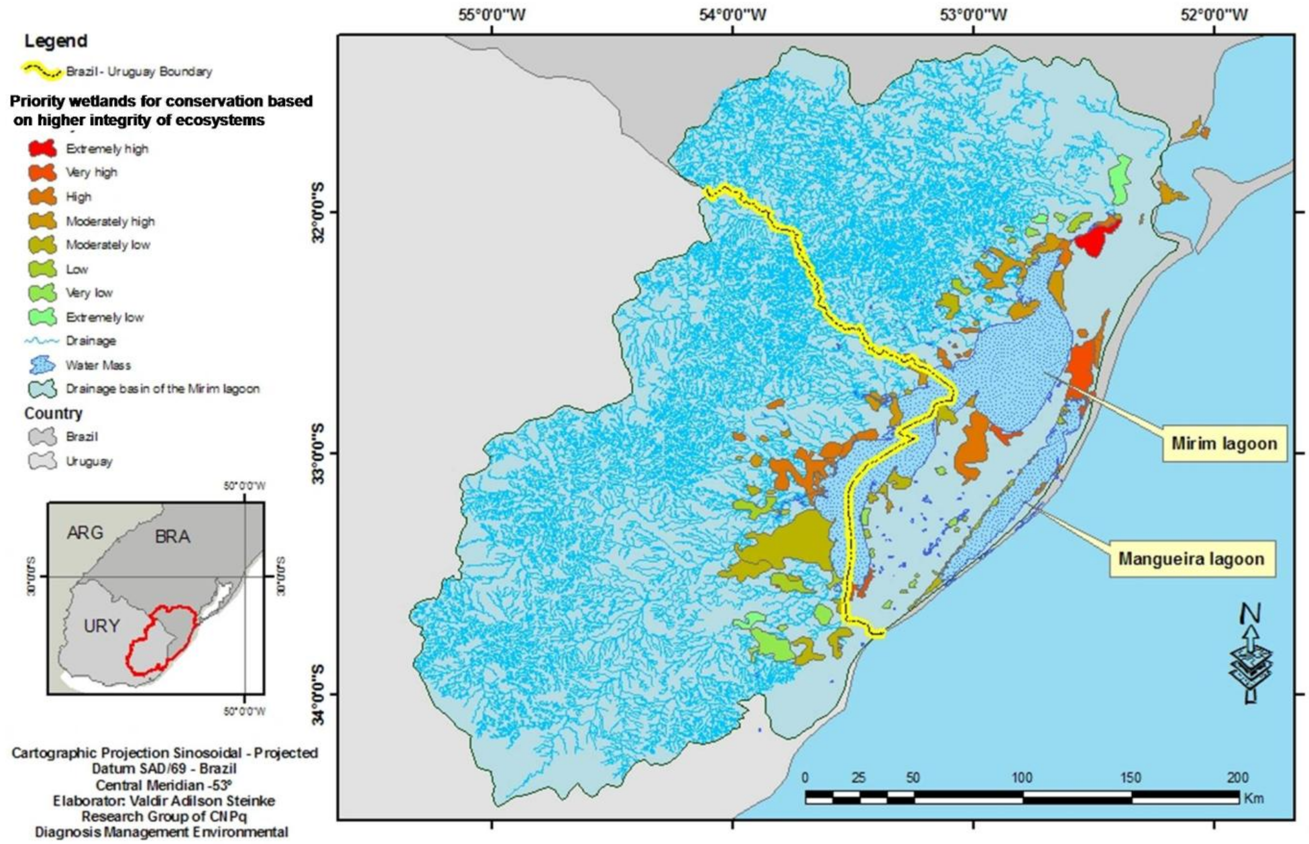


**Figure 5.** Priority wetlands for conservation based on higher integrity of ecosystems. The wetlands were classified according to levels of priority established on option 1 – first protect those areas that still conserve natural characteristics and are under low pressure so that they can be easily protected.

The vulnerability of wetland areas were here evaluated in a framework of the concept of drainage catchment area. This was done because it could consider the estimates of pollution load received by the wetlands. Thus, it is important to say that any type of environmental impact assessment relative to wetlands should take into account the totality of the Mirim Lagoon catchment area and, specifically, its sub-basin area of contribution should be observed. This is true for both of the two approaches presented in this study: focusing on the integrity of wetlands (option 1) or on their vulnerability (option 2), and the consequent policies aiming at establishing areas for conservation or promoting actions to restore ecosystem functionality.

The decision of where to protect more or first is a difficult decision for environment managers and should be based on accurate spatial analysis and scientific criteria. The three steps of spatial analysis done in this study were an attempt to support this decision making process. The map produced in our step 2 spatial analysis indicated that 73% of the wetlands are under strong impact and the waterbirds are under high vulnerability.

Therefore, managing, zoning and planning actions within drainage sub-basins are crucial for future sustainable management of these wetland areas. Otherwise, the vulnerability of those wetlands, which is at first only a probable risk may become tragically true, especially if new economical tendencies are put in practice without appropriate zoning.

Finally, we insist that transboundary waters management should consider the whole extension of the ecosystem in the catchment area, and a broad study based on scanning and locational integration, supported by GIS is fundamental for seeking to gain experience in sustainable and international integrative development.

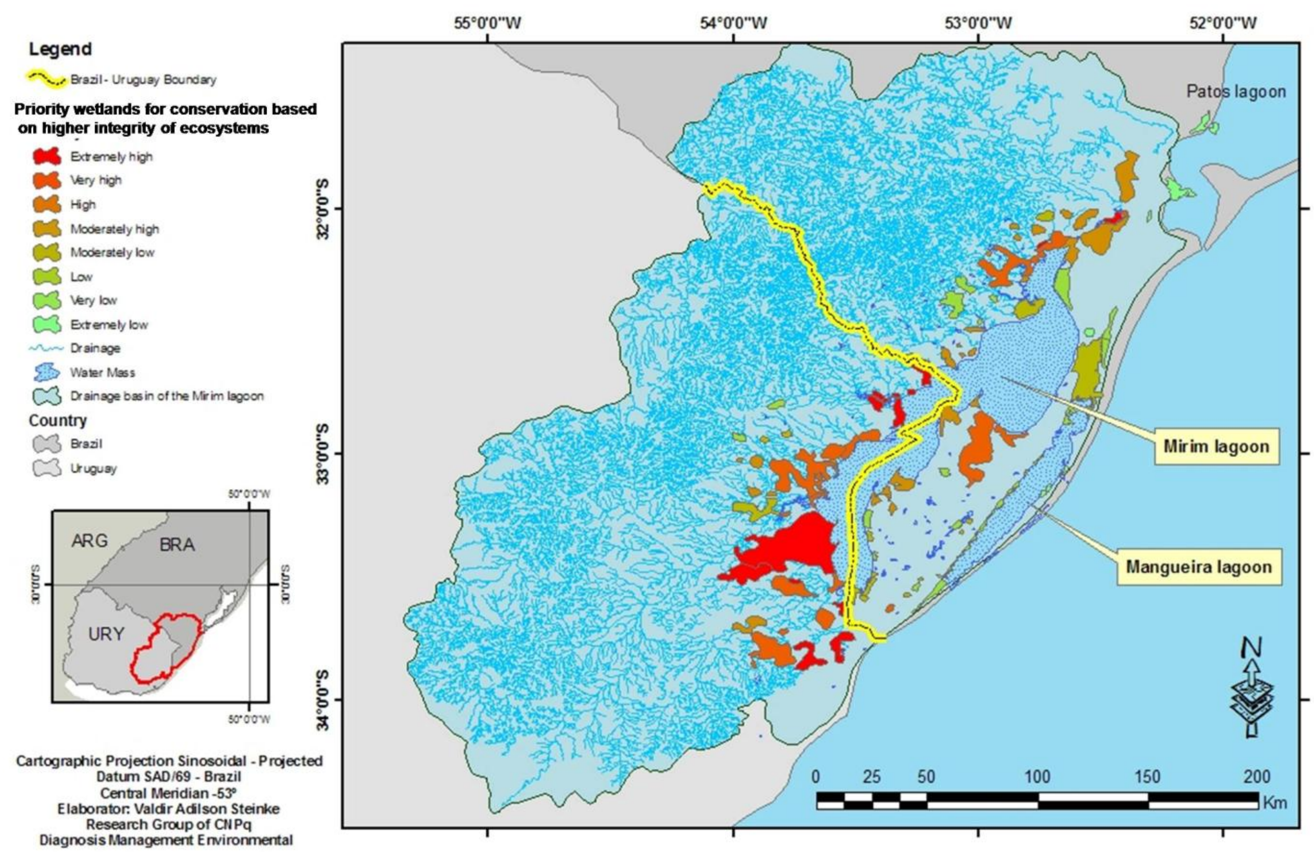


**Figure 6.** Priority wetlands for conservation based on higher vulnerability of ecosystems. The wetlands were classified according to the degree of vulnerability established on option 2 – first protect those areas that still conserve natural characteristics but are under high pressure so that they will face several difficulties to protected them.

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