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SPATIAL AND TEMPORAL VARIATIONS' OF CHARACIDAE HABITAT, CASE STUDY IN ABRAS DE MANTEQUILLA WETLAND, ECUADOR

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ABSTRACT

A central component of predictive ecology in wetlands is the analysis of species distribution as a function of their biotic and abiotic environment. This analysis is normally used by decision-makers in biodiversity conservation, species monitoring and environmental planning, among others. Habitat suitability modelling is a major component of the process of making the analysis, however, temporal and spatial variations of hydrological, hydrodynamic and environmental variables are normally not well known and overall values are assumed. In Abras de Mantequilla wetland (Ecuador) we find a tropical situation where the hydrodynamics of inflows seem to play an important role on the stability of the ecosystem. The habitat suitability in wetlands is driven by hydrodynamic, physical and biological interactions that are not fully understood. This research explores the habitat changes in space and time of a fish community in this tropical wetland, identifying extremes using constant habitat index (thresholds in a range) and one variable index (fuzzy rules) and a fuzzy combinations of hydrodynamic model variables. The main goal was to quantify the extension of the habitat areas were the index was high enough to be considered as suitable habitat, based on the hydrodynamic features and on spatio-temporal changes in the habitat index. The hydrodynamic variables water depth and velocity were modelled with DELFTFLOW software. A change of spatial distribution of the habitat for this group is related to the velocity and water depth. Results from the habitat model determined that the peak of the wet season was the period with a higher percentage of suitable areas for this fish assemblage, given the hydrodynamic variables selected. Thus, it would appear that the habitability of the Characidae in the littoral area is reduced when low flows occurred. Despite this fact, it is essential to acknowledge that other physical, chemical and biotic variables may play an important role in the presence of this community and therefore should be gradually included in future studies for an integrated ecological habitat assessment.

Keywords: *Habitat, temporal variability, littoral fish, depth, velocity*

1. INTRODUCTION

Wetlands are among the most productive environments in the world. They are crucial for the maintenance of biological biodiversity, providing water and primary production upon which numerous species of fauna and flora depend for survival (Halls, 1997; Ramsar, 2013). Tropical rivers associated to floodplain areas provide dynamic habitats for fish (Winemiller and Jepsen, 1998), and contribute in the maintaining of the biodiversity of the whole river ecosystem, provided that connectivity is maintained. Connectivity is a key issue in floodplains, since richness and diversity of species decrease with decreasing hydrological connectivity (Aarts et al., 2004).

Tropical floodplains faced gradual drying due to anthropogenic activities such as dams, and irrigation, causing impacts on fish communities. A reduction in the inundated areas of floodplains decreases the habitat availability for fish communities. Reduction in habitat areas in turn produce an increase in fish densities (per unit surface area), intensification in species interaction and competition for resources (Winemiller and Jepsen, 1998). In Southamerica, designation of aquatic protected areas has recently started, and fish studies have been focused more frequently at local rather than at river basin scale (Barletta et al., 2010). Several studies acknowledged the importance of littoral areas as habitat for fish communities (Arrington and Winemiller, 2006; Teixeira-de Mello et al., 2009), and the association of fish to the macrophytes present in these littoral areas (Agostinho et al., 2007; Meerhoff et al., 2007; Meschiatti et al., 2000).

The development of habitat suitability analysis has to be related to the fact that species are distributed according to their preferences for feeding and reproduction (Teresa and Casatti, 2013). Furthermore, the selection of species as ecological indicators is based on the ecological health approach that focused on habitat assessment (Funk et al., 2013). Linking the target species with their physical, chemical and biotic conditions is the base of habitat assessment.

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Physical aspects include hydrology and geomorphology, and hydrological indicators can explain physical, chemical and biological processes in wetlands (Funk et al., 2013). Thus, hydrologic conditions are key drivers for the wetland's structure and function. Hydrology influenced several abiotic factors that determine which biota will develop in the wetland. "Hydrology is probably the single most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes" (Mitsch and Gosselink, 2007).

Specific mesohabitat characteristics such as depth and velocity have been found to play an key role in explaining fish communities structure (Arrington and Winemiller, 2006), with several studies considered them as main variables for fish habitat analysis (Freeman et al., 2001; Schneider et al., 2012; Teresa and Casatti, 2013; Wolfshaar et al., 2010).

Littoral areas of Abras de Mantequilla wetland (Ecuador) are principally populated by small sized fish from the Characidae family (Alvarez-Mieles et al., 2013). Characids are an important source of food for higher trophic levels (top fish predators which have a value for local communities) and important seed dispersers in Neotropical floodplains. Previous studies in the wetland and associated basin "Guayas River basin" reported the presence of this family (Florencio, 1993; INP, 2012; Laaz et al., 2009; Prado, 2009; Prado et al., 2012). Some species of this family are common in all the western basins of Ecuador (Gery, 1977; Glodek, 1978; Laaz et al., 2009; Loh et al., 2014), but others are endemic of the "Guayas Basin' (Laaz and Torres, 2014; Roberts, 1973). However, information about the ecology or the evolutionary history of most fish species in the region is very limited and even lacking (Aguirre et al., 2013). Littoral fish assemblages in Abras de Mantequilla wetland included both common and endemic species. At middle and low wetland areas endemic species as *Phenacobrycon henni, Landonia latidens, Iotabrycon praecox, Hyphessobrycon ecuadoriensis* have been collected (Alvarez-Mieles et al., 2015), thus the importance of assessing the habitat conditions in this tropical wetland.

Our study proposes a methodology to quantify the extension of suitable habitat areas for the littoral fish communities of Abras de Mantequilla wetland based on hydrodynamic features. A measure related to the percentage of suitable habitat areas (PSA) is proposed, as a tool to explore the variability of the habitat. We suggest that by protecting the habitat of this community, lower trophic community levels (e.g. macroinvertebrates and plankton) that also inhabit these littoral areas would be also protected.

2. METHODOLOGY

2.1 Study area

The Abras de Mantequilla wetland is located at the centre of the Guayas River Basin in the Coastal Region of Ecuador (Figure 1). The wetland was declared a RAMSAR site in 2000 due to the important role in conservation of bird fauna biodiversity, and especially because it supports three migratory species of birds (Ramsar, 2014). The wetland part of the Chojampe sub-basin consists of branching water courses surrounded by elevations of 5–10 m (Quevedo, 2008). Due to land conversion to agriculture in the last decades, original forest coverage around the wetland is less than 3%. Agriculture in the surrounding wetland area mainly consists of short-term crops (rice, maize). Littoral areas of the wetland are covered by banks of macrophytes populated by small Characids (Figure 2d). Collected species included common ones like *Astyanax festae*, and endemic as *Landonia latidens* and *Hyphessobrycon ecuadoriensis* (Figure 3).

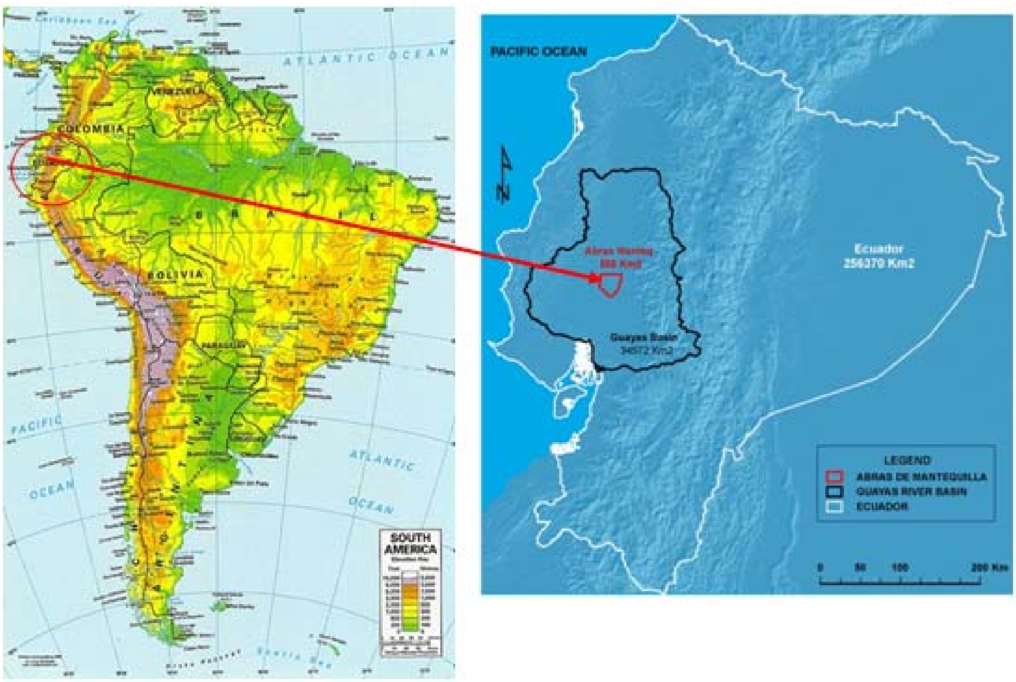


Figure 1: Study area: Abras de Mantequilla wetland location

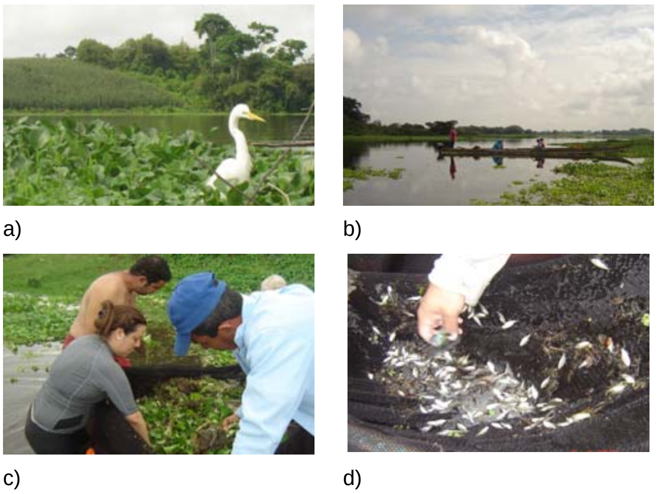
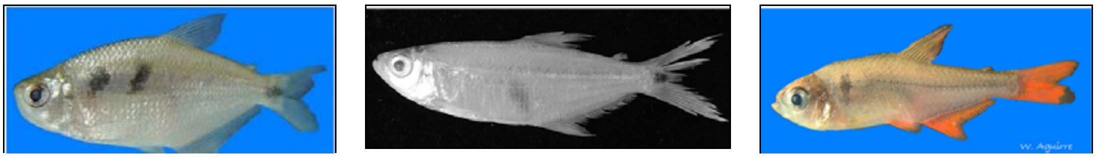


Figure 2: Study area: Sampling sites located in the upper (a) and middle (b) wetland areas.
Fish sampling (c, d)



Astyanax festae *Landonia latidens* *Hyphessobrycon ecuadoriensis*

Figure 3: Some species of Characidae family collected in Abras de Mantequilla wetland. Photos source (Aguirre, 2014)

The wetland is flooded during the wet season (January-May). The main inflow to the wetland is the Nuevo River that flows through the Estero Boquerón and contributes with 85% of the total wetland inflow. During a strong rainy year like El Niño, the inflow discharges from Nuevo River to the wetland can reach values around 650 m^3/s, while during a dry year, maximum discharges are up to 260 m^3/s. The wetland also receives rainfall-run off from the Chojampe subbasin with a contribution of around 15% (Figure 4). These contributions slightly fluctuate according to the type of year (dry or wet). During the dry season (July– November), the water level in the wetland decreases considerably, and water remains only in the deep central channels, reducing the inundated area to around 10% compared with the wet season. Current land uses around the wetland and hydropower projects in the upper catchment are expected to be the main constraints for the future health of the wetland.

2.2 Modelling the hydrodynamics of the wetland

The 2D model of the wetland was built based on a 1:10000 topography and considering the wetland extension and the location of the discharges. According to this topography, the wetland area recorded levels between 6 and 34 m.a.s.l. The boundary conditions for Nuevo River (inflow to the wetland) were estimated based on a HEC-RAS model (Arias-Hidalgo, 2012) and correlations with an upstream gauging station (Quevedo en Quevedo station). While, the boundary conditions for Nuevo River (outflow of the wetland) were estimated based on the total discharge flowing outside the wetland system and a rating curve. The boundary conditions for the four tributaries of Chojampe subbasin were determined using HEC-HMS a rainfall-runoff model built for this purpose. The grid was set up with a cell size of 75 x 75 m, with a total of 7163 cells (Galecio, 2013). The total modelled wetland area was 4029 hectares (40,3 km^2). To illustrate the extension of the inundation areas of the wetland during the flooding season, figure 5 presents the minimum and maximum inundated areas for the wet season 2012.

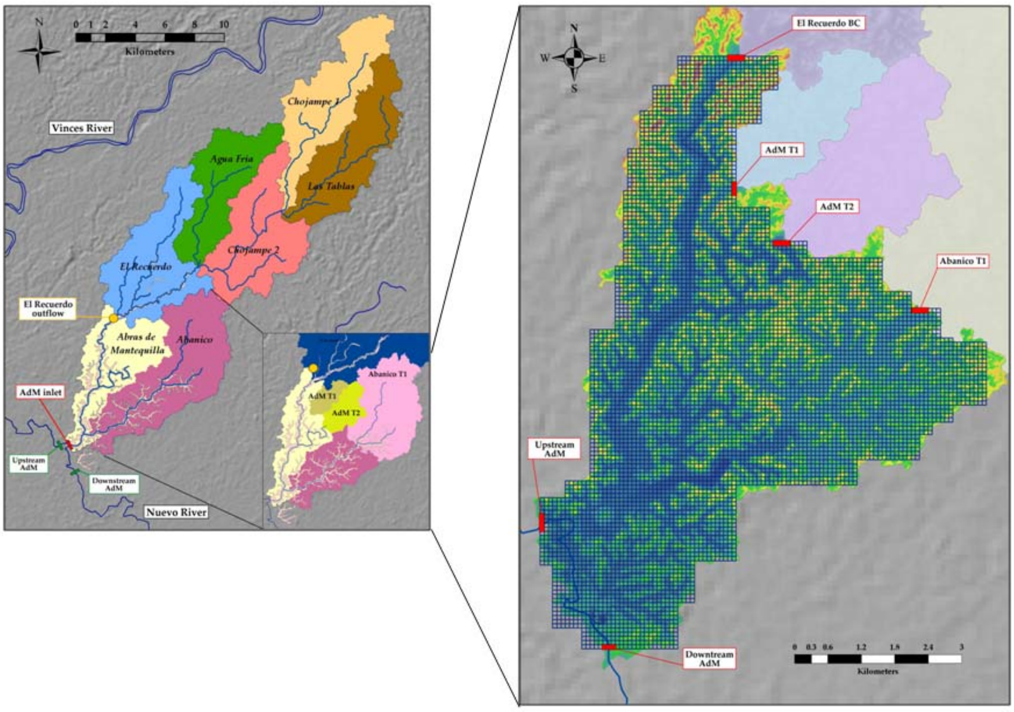
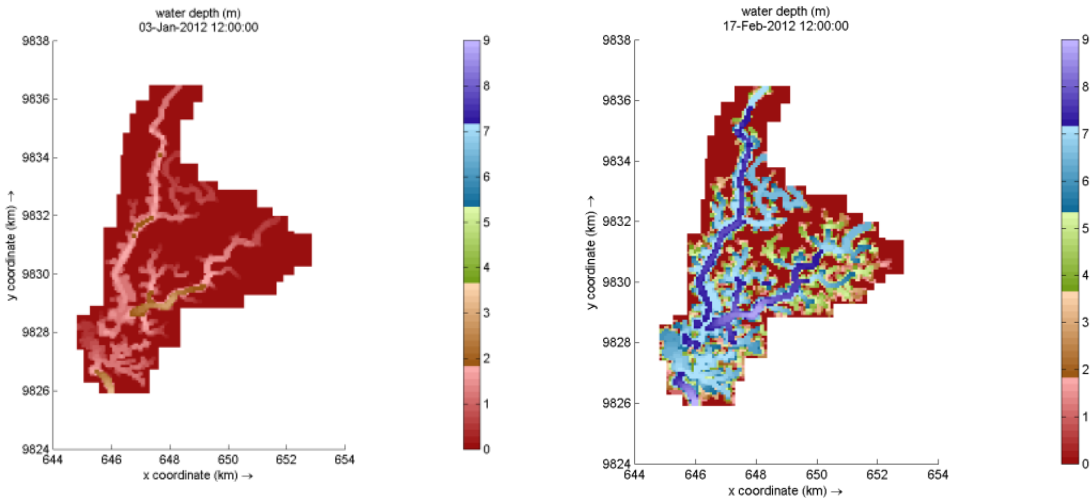


Figure 4: Abras de Mantequilla wetland - main inflows and Hydrodynamic model schematization. Left: "El Recuerdo" (yellow dot) collect the run off of the five contributing microbasins from Upper Chojampe Sub-basin. Abras de Mantequilla wetland area (in light yellow). Right: Hydrodynamic model schematization - Abras de Mantequilla wetland grid (from DELFT3D). Boundary conditions (red lines). Low boundary condition (Upstream AdM) represents the main inflow to the wetland "The Nuevo River-Estero Boquerón". Upper boundary conditions (El Recuerdo, AdMT1, AdMT2 and Abanico T1) collect the run-off from Chojampe subbasin. Source: (Galecio, 2013)



a) 580 ha b) 2682 ha

Figure 5: Inundation areas year 2012. a) Minimum inundated area: 5,8 km^2; b) Maximum inundated area: 26,8 km^2

2.3 The Habitat suitability index

The aim to develop a habitat index is to indicate how suitable an area is for a determined species or group of species. Nevertheless, it has a number of assumptions, for example: it is not clear if an index will certainly indicate the presence or absence of these species nor the quantity of the species. On the other hand, to be able to determine a species habitat is important to know in which time frame a species distributes and if this time frame is logical. Thus, by exploring the space-time variability of an index the presence of these species could be estimated. In this paper, the presence of a littoral fish species in relation to the hydrodynamic variability of their habitat is explored. This habitat analysis consists of the following steps.

The habitat suitability for littoral fish of Characidae family was assessed by relating insitu measurements of depth and velocity with the results of the 2D hydrodynamic model (DELFT 3D-FLOW) of the wetland during the wet season of 2012. This part of the methodology describes the multiple tests performed to determine the level of relationship between the water depth, velocity and the habitat for this fish community:

1. Calculation of the habitat index was based on a general rule and on what was found on the literature for littoral fish communities. Field information and expert knowledge was used to validate this information. Insitu measurements of water depth and velocity were compared with literature values to understand the distribution and habitat preferences of this fish assemblage. As a result, fuzzy logic rules for these two variables were derived (Figure 6).

2. A dynamic HABITAT model was built with the MATLAB toolbox (Figure 7).

3. Output maps of water depth and velocity from the 2D hydrodynamic model (DELFTFLOW) (wet season 2012) were used as an input for the dynamic HABITAT model. The Habitat model runs were performed for the same period when the field measurements were taken (wet season 2012).

4. Then the following tasks were developed:

   a. The behaviour of the variables water depth and velocity through a "Constant Habitat Index", was analyzed independently. For each variable three constant ranges were set up (Figures 8-9). Optimal ranges for both variables were identified. Range 2 was identified as the most suitable given that higher densities of littoral fish communities were found in this range during the sampling time. The calculations were developed at each cell of the grid and the results of depth and velocity for each constant range were expressed in terms of percentage of habitat suitable (PHS).

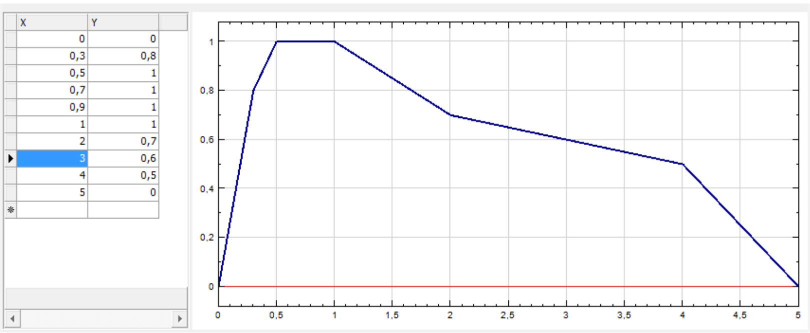
   b. A "Variable Habitat Index" (VHI) was calculated independently for water depth and for velocity (Figures 10-11). In this step, DELFT FLOW output maps of water depth and velocity were combined with their corresponding fuzzy rules (a logic rule for water depth and for water velocity) (Figure 6).

   c. A "Combined Habitat Index" (Comb-HI) was calculated, and the HABITAT model selected the minimum of both habitats index (depth and velocity) from step b (Figure 12).

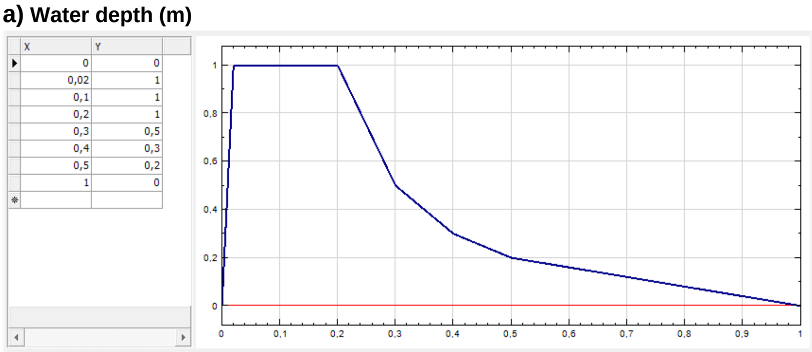
   d. Information about the ecological behaviour of the Characidae species of the wetland is not complete understood yet. Thus, the time frame for changes in their reactions to variations in water depths and velocities cannot be defined with certainty. Therefore, a sensitivity analysis with different time steps for the 3 different calculations previously explained was developed (Table 1).

   e. Habitat index calculations for (VHI) and (Comb-HI) were also developed for each cell of the grid and the results were expressed in terms of percentages of suitable areas with an habitat index over 0,7 (PSA). More specifically, the analysis of the spatial and temporal variation was based on the spatial value of this selected habitat index in each one of the cells of the grid.

   f. The modelled time period was 20 weeks-150 days.



a) Water depth (m)



b) Velocity (m/s)

Figure 6: Fuzzy rules built in HABITAT software. Curves for water depth (a) and velocity (b). Variables values (X), Habitat index for the variable (Y)

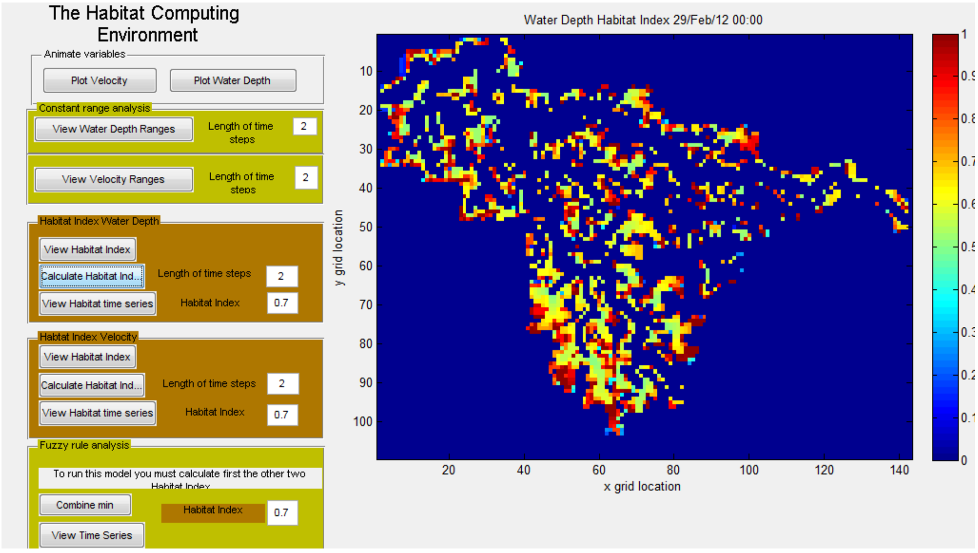


Figure 7: The dynamic habitat computing environment

3. RESULTS

3.1 Constant habitat index

Results from a constant habitat index for water depth showed that the wetland has a higher percentage of areas with a WD in the optimal range 2 (0.5-1.5 m), at the beginning (up to 20%) and at the end of the wet season (up to 35%) (Figure 8). While, during the peak of the wet season (from day 31 till day 84) the percentage of areas in this range were between 2 and 10%. The other two ranges 1 and 3 followed the same trend but were always lower than range 2.

Considering the 10% of the wetland area as a threshold, it can be shown that approximately 90 days (60% of the modelled period), the wetland has percentages of area over 10% for the optimal range 2 (one day time step). No changes in this result were observed when the time steps were two or four days (Figures 8b-8c). When the time steps were one week, this result decreased slightly to 57% of the modelled period (Table 1).

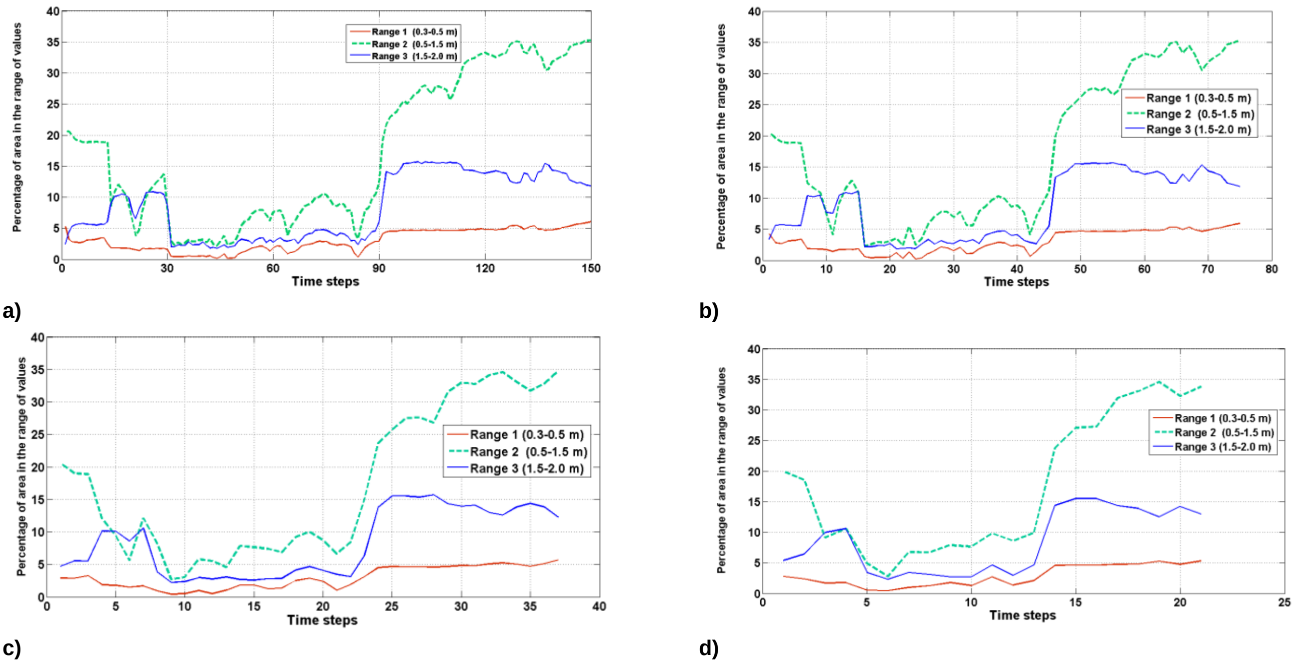


Figure 8: Percentage of the wetland area for the 3 water depth ranges (WD). Time steps a) per day, b) 2 days; c) 4 days; d) per week. Range 2 (selected as most suitable condition). Modelled period January-May 2012.

For water velocity, the behaviour was more constant through the whole period. Wetland areas with the optimal range 2 (0,02-0,2 m/s) varied between 2-24% throughout the modelled period. However, during the peak of the wet season (from day 42 till day 90) the percentage of areas in this range increased and were always over 10%.

The other two ranges 1 and 3 followed the same trend but were always lower than range 2. Lower velocities (Range 1: up to 0,02 m/s), were especially dominant during the peak of the wet season (day 44 to 90). During this period, 40-58% of the wetland area had velocities in this range. The percentage of wetland areas with higher velocities (up to 1,0 m/s), was very small throughout the whole modelled period, with a maximum of 4% when time step was one day, and 2% with the rest of time steps (Figure 9).

Considering the 10% of the wetland area as a threshold, it can be seen that approximately 40 days (27% of the modelled period), the wetland has percentages of area over 10% for the optimal range 2 (one day time step). No changes in this result were observed when the time steps were two or four days (Figure 9b-9c). When the time steps were one week, this result increased to 38% of the modelled period (Table 1).

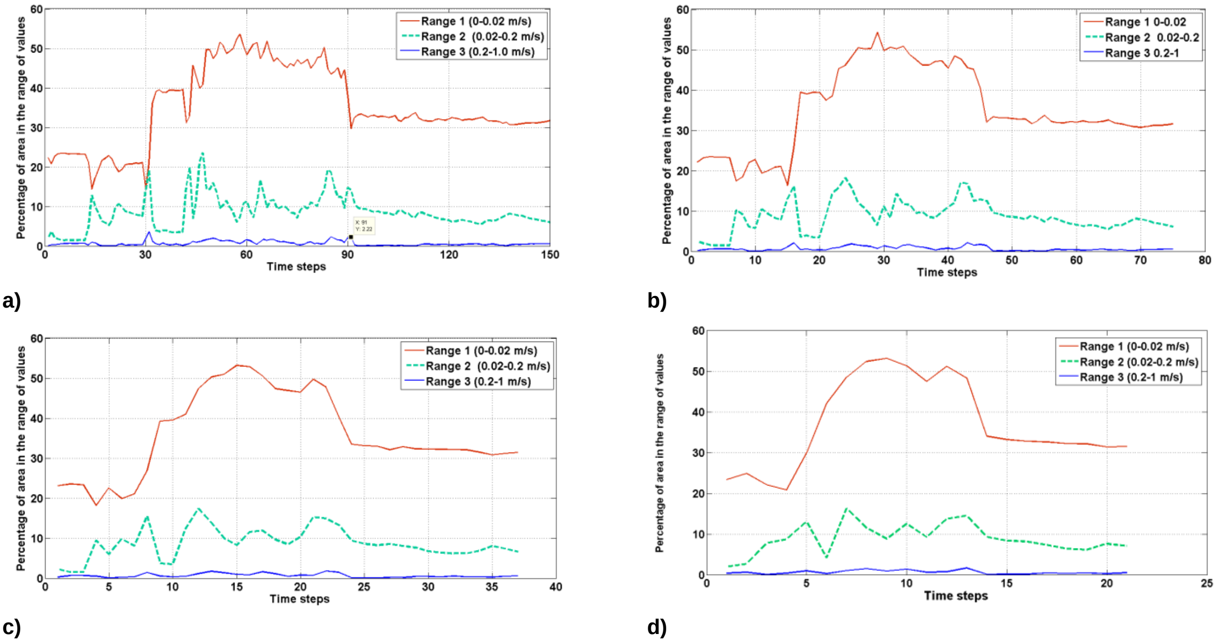
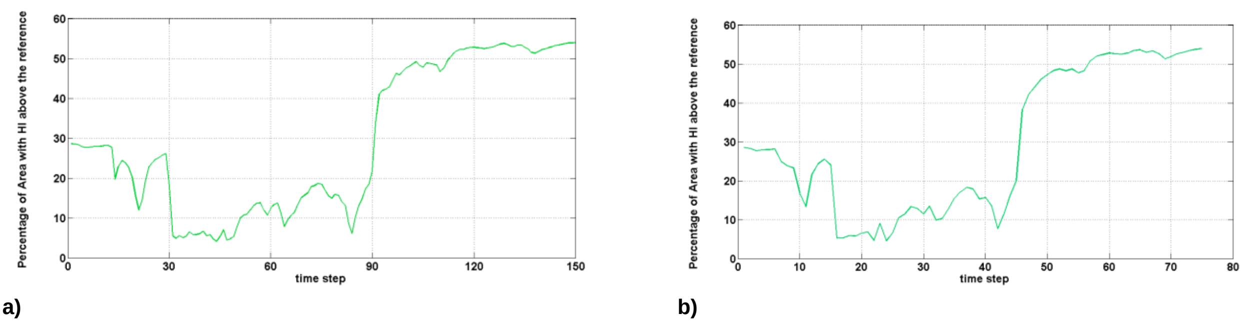


Figure 9: Percentage of the wetland area for the 3 velocity ranges (Vel). Time steps a) per day, b) 2 days; c) 4 days; d) per week. Range 2 (selected as most suitable condition). Modeled period January-May 2012.

3.2 Variable Habitat Index

Higher percentage of suitable areas (PSA) for water depth habitat index (V_WD-HI over 0,7) were observed at the beginning and end of the wet season. From day 85 until day 100 the wetland experienced a sudden increase in the suitable areas (from 10 to 50%), and is maintained over 50% until the end of the modelled period (Figure 10).

Considering the 10% of the wetland area as a threshold, it can be seen that during 123 days (82% of the modelled period), the wetland has areas with a HI > 0,7 for WD (Table 1). Sensitivity analysis showed a slightly increase to 86% when time step was one week (Table 1).



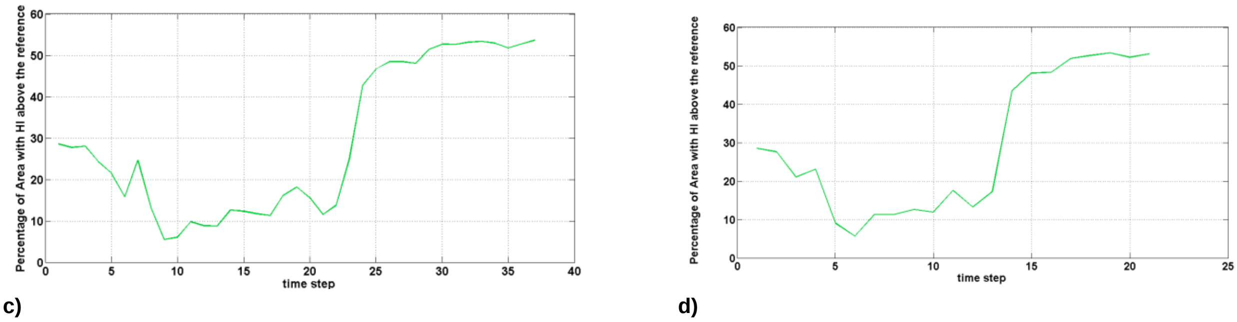


Figure 10: Water depth Habitat index (WD-HI). Percentage of the wetland area with habitat index (HI) above (>0,7). Time steps a) per day, b) 2 days; c) 4 days; d) per week. Modeled period January-May 2012.

For water velocity, a higher percentage of suitable areas (PSA) with Velocity habitat index (V_Vel-HI over 0,7) were observed mainly in the middle of the modelled period. During this phase (day 44 until day 95), wetland areas with HI over 0,7 represented 10 to 30% of the total wetland area (Figure 11).

Considering the 10% of the wetland area as a threshold, it can be seen that during 76 days (51% of the modelled period), the wetland has areas with a HI > 0,7 for velocity (Table 1). Sensitivity analysis showed a slightly decrease to 48%, when time step was one week (Figure 11d - Table 1).

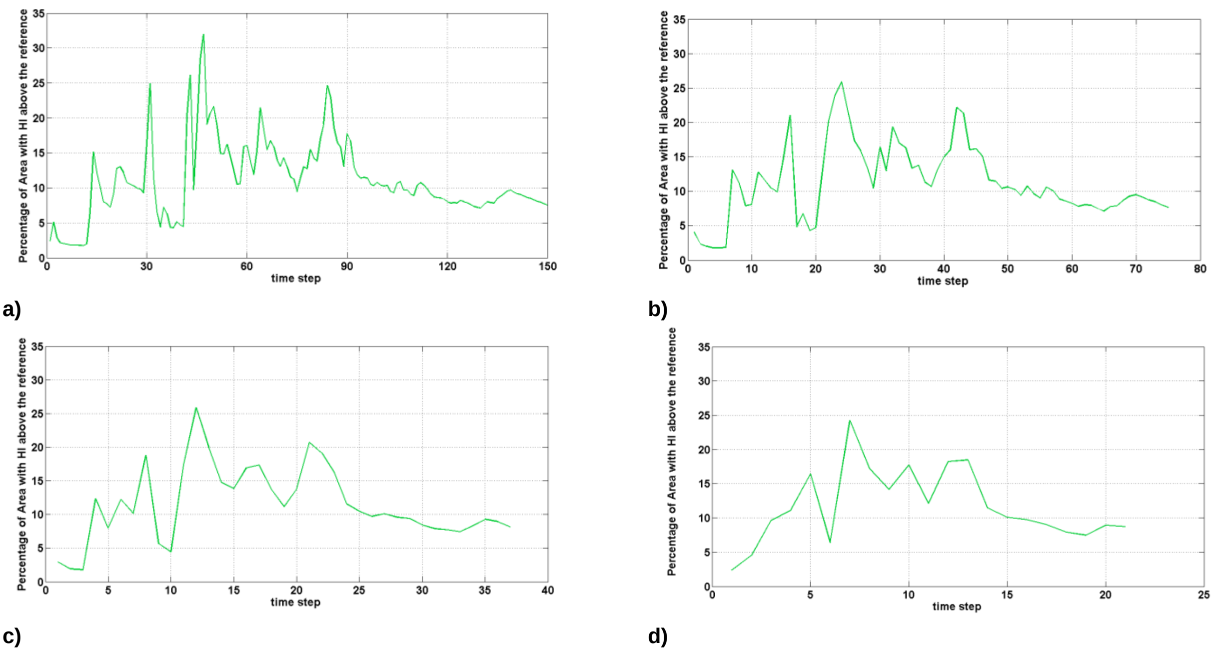
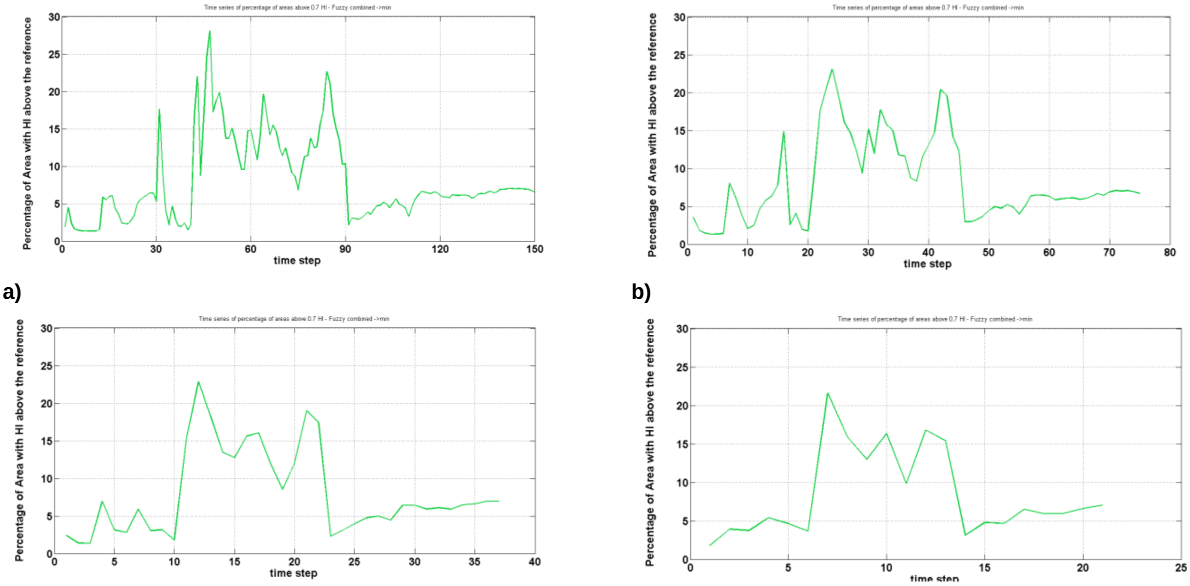


Figure 11: Velocity Habitat index (Vel-HI). Percentage of the wetland area with habitat index (HI) above (>0,7). Time steps a) per day, b) 2 days; c) 4 days; d) per week. Modelled period January-May 2012.

3.3 Fuzzy combination of Habitat Index

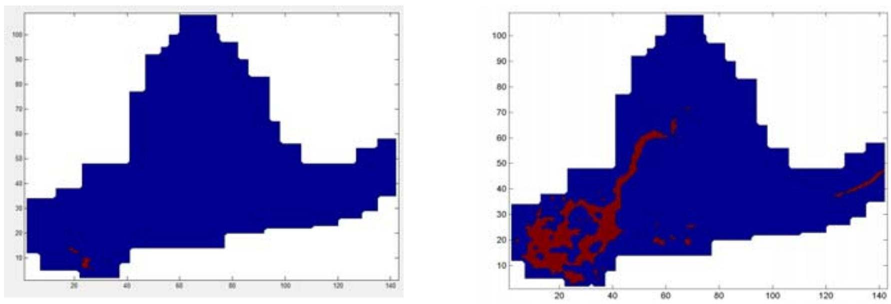
When both membership rules were combined (Comb-HI), results showed a similar trend to the velocity index, with a higher percentage of suitable areas (PSA) observed during the middle of the wet season. During this period (day 42 to 90), wetland areas with HI over 0,7 represented 10 to 28% of the total wetland area (Figure 12).

Overall, when 10% of the wetland area was set up as a threshold, it can be seen that during 45 days (30% of the modelled period), the wetland has areas with a HI above 0,7 (Table 1). Sensitivity analysis did not show an important change when the time step was one week (29%) (Figure 12d - Table 1). Figure 13 shows the results of the spatial distribution of minimum and maximum suitable areas calculated with the combined habitat index (Comb-HI). These snapshots show specific time steps during the flooding season. Thus, the location of these areas can change spatially during the modelling period and therefore it can be better appreciated in the dynamic video.



a) b) c) d)

Figure 12: Fuzzy combination of habitat index (Comb-HI). Percentage of the wetland area with habitat index (HI) above (>0,7). Time steps a) per day, b) 2 days; c) 4 days; d) per week. Modelled period January-May 2012.



a) Minimum suitable areas b) Maximum of suitable areas

Figure 13: Spatial representation of areas with a combined habitat index (Comb-HI) over 0,7 (red areas). a) time step with minimum suitable areas; b) time step with a maximum of suitable areas. Time step (daily)

Table 1: Sensitivity analysis for different time steps (1, 2, 4 days and 1 week) of the time (% of modelled period that the wetland has areas (above a threshold of 10%), for: a) areas in optimal range 2 for Constant Habitat index; and b) areas over 0,7 of HI for WD-HI; Vel-HI and Comb-HI. Ts: time step

		1d	**2d**	**4d**	**1 week**
Constant Habitat index [(a)]	**(C_WD)**	60% (90days)	60% (45 ts)	59% (22 ts)	57% (12 ts)
	(C_Vel)	27% (41 days)	29% (22 ts)	27% (10 ts)	38% (8 ts)
Variable Habitat index	**(V_WD-HI)**	82% (123 days)	84% (63 ts)	84% (31 ts)	86% (18 ts)
	(V_Vel-HI)	51% (76 days)	51% (38 ts)	49% (18 ts)	48% (10 ts)
Fuzzy combination of Habitat index	**(Comb_HI)**	30% (45 days)	29% (22 ts)	27% (10 ts)	29% (6 ts)

(a) :for optimal range 2

4. DISCUSSIONS

This study describes the temporal and spatial changes in habitat suitable areas in a tropical wetland. The results of this habitat assessment determined that during 45 days of the wet season, the wetland had a higher percentage of areas with a suitable Habitat index (> 0,7). These suitable areas in Abras de Mantequilla wetland represented up to 28% of the total modelled area and have specially two main characteristics: water depths up to 1 meter, and velocities up to 0,2 m/s. These hydrodynamic values are in agreement with the findings of other studies of neotropical Characids about their habitat, distribution and feeding ecology (Casatti et al., 2003; Ferreira et al., 2012; Maldonado-Ocampo et al., 2012; Teresa and Casatti, 2013) and suggest both variables as good predictors of community structure and species abundance (Teresa and Casatti, 2013).

During fish sampling, another important characteristic observed in the littoral areas of Abras de Mantequilla wetland was the presence of associations of aquatic macrophytes. Floating macrophytes from the species *Eichornia crassipes* (Pontederiaceae), commonly known as "water hyacinth", represented around 80% of the total macrophytes biomass in Abras de Mantequilla wetland. Thus, our sampling results confirm the findings of other authors (Agostinho et al., 2007; Meerhoff et al., 2007; Meschiatti et al., 2000), that recognized the association of small size species from Characidae family to macrophytes banks that colonize littoral shallow areas, and their essential role as shelter and food provider. Since, juvenile and adults stages of small size species and eventually juveniles of larger species are typical in macrophytes banks present in lentic shallow habitats (Meschiatti et al., 2000), their shelter role to protect small fish from higher predators plays an important role.

Based on the results of this study, management measurements can be recommended. An initial measure would be to maintain the timing and magnitude of the natural flows especially during the periods with higher percentage of suitable habitat areas (days 40 to 90) that correspond to February and March (peak of the wet season). These periods could be be crucial to foment the spawning of these species.

5. CONCLUSIONS

Regarding time steps and sensitivity analysis, our results showed that daily and week time steps gave overall similar results in terms of percentage of suitable areas (PSA) (when analyzed over a 10% threshold). However, a daily time step is recommended to account for flood pulses variations that can influence other physical and chemical variables that have not been considered in this study. In this study, wetland areas above 0,7 Comb (HI) were described as optimal habitat for this fish community. However, areas below this HI (<0,7) cannot be considered necessarily as uninhabitable.

Regarding fuzzy rules development, in the present study, fuzzy rules were developed for a littoral fish assemblage at a higher taxonomic level (Characidae family). The criterion for the development of these rules was based on field sampling and literature on this group, previously explained. Although, different species from this family were collected, an overall rule for the whole family was assumed. This assumption was based on the fact that higher densities of the different species were always collected when the sampling sites had water depths not higher than one meter, and in combination with velocities not higher than 0,2 m/s.

Nevertheless, a parallel study on biotic communities structure (Alvarez-Mieles et al., 2015) determined that although the different areas of the wetland shared similar fish species from Characidae family, there were also Characidae species that typified middle areas where lower velocities and higher residence times take place. Other species typified the lower area, which is more influenced by the river inflow and where intermediate velocities occurred, while other species typified the river inflow. Therefore, these findings at species level can provide with the basis for future research on the construction of new fuzzy rules and habitat assessment at a lower taxonomic level for this fish community in this tropical wetland.

The combination of hydrodynamic variables for the analysis of temporal and spatial variation in the habitat of Characids proved to be useful for an initial habitat assessment in Abras de Mantequilla wetland. The present study is the first attempt in providing an assessment of the temporal and spatial distribution of suitable habitat areas for a littoral fish community in this tropical wetland. Hydrodynamic features have been analyzed for this initial assessment. The peak of the wet season was recognized as the period with a higher percentage of suitable areas for this fish assemblage, given the hydrodynamic variables selected. However, we acknowledged that other physical, chemical and biotic variables play an important role in the presence of this community and therefore should be gradually included for an integrated ecological habitat assessment.

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