

RESEARCH ARTICLE

# Can La Redonda lagoon (Cuba) be a suitable habitat for largemouth bass (*Micropterus salmoides*, Lacepède) recovery?

Roberto González-De Zayas<sup>1,2</sup>, Martín Merino-Ibarra<sup>3,\*</sup>, Julio A. Lestayo González<sup>4</sup>, Fermín S. Castillo-Sandoval<sup>3</sup> and Rosely Peraza-Escarrá<sup>4</sup>

<sup>1</sup> Departamento de Hidráulica, Facultad de Ciencias Técnicas, Universidad de Ciego de Ávila, Carretera a Morón, Km 9, Ciego de Ávila, Cuba: CP: 65100, Mexico

<sup>2</sup> Centro de Estudios Geomáticos, Ambientales y Marinos (GEOMAR), Avenida Ejército Nacional 404, Polanco V Sección, CP: 11560 CDMX, Mexico

<sup>3</sup> Unidad Académica de Ecología y Biodiversidad Acuática, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Ciudad Universitaria, Coyoacán, México, CDMX. 04510, Mexico

<sup>4</sup> Posgrado en Ciencias del Mar y Limnología, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Ciudad de México, Mexico, CP: 04510, Mexico

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**Abstract** – For decades, La Redonda lagoon was an excellent location for fishing the largemouth bass (*Micropterus salmoides*, Lacepède) in Cuba. There are indications that the species disappeared from the lagoon in 2009. Three water surveys were carried out in 2013 and 2014. Physicochemical parameters, including nutrients, were measured in all surveys. Chlorophyll *a* and water transparency were only measured in November 2013. Results showed that this lagoon is a fresh to brackish water system, with common salinization episodes. There were some hypoxic conditions, but mean dissolved oxygen value was above  $5.0 \pm 2.8 \text{ mg L}^{-1}$  for the entire survey period. The trophic state was evaluated as oligotrophic and Nitrogen and Phosphorus were limiting in most of the survey sites. The Habitat Suitability Index model (HSI) for largemouth bass had a mean value of  $0.63 \pm 0.02$  (moderate degree of suitability). All results showed that bass recovery could be possible in La Redonda lagoon, but management criteria are necessary. The largemouth bass recovery could help to increase visitations of American anglers to this place and a portion of the revenue could be used to conduct environmental monitoring and studies of the largemouth bass ecology in Cuba.

**Keywords:** Bass / habitat / suitability / lagoon / Cuba

## 1 Introduction

The largemouth bass (*Micropterus salmoides*, Lacepède) is rated as the most popular freshwater gamefish in North America. The species is native only to the United States (US), Canada and Mexico, but has been introduced in countries such as Russia, China, France and many others. Largemouth bass are capable invaders, strong competitors, and known predators on native fish species. In Canada, 3.2 million adults fished at least once in inland waters in 2005 (DFO, 2006) and in the United States, inland recreational anglers numbered over 25 million in 2006 (ASA, 2008). In Canada, the contribution to the economy in 2005 was estimated in \$7.5 billion, because of the direct and indirect expenditures on recreational fishing

(DFO, 2006). In the US, over 767,000 jobs are associated with inland recreational fisheries with a total economic value of \$95 billion (ASA, 2008).

The largemouth bass was introduced to Cuba in 1927 into freshwaters near of Havana region (Howell Rivero, 1937) and spread throughout the country rapidly. The species quickly adapted to habitats like reservoirs, natural freshwater lagoons and rivers. This species became a gamefish in 1969 and tournaments and fishing records showed the development of skills among national fishermen to target this new species of Cuban ichthyofauna (INDER, 1969).

La Redonda (Cuba) is a natural brackish lagoon, surrounded by dense mangrove forests and is connected to Los Perros Bay through a tidal channel that has been restricted by a road for 30 years (La Pesquera road). Los Perros Bay also connects to Le Redonda lagoon via pipelines that serve as floodgates. A popular fishery developed in the lagoon during

\*Corresponding author: [mmerino56.unam@gmail.com](mailto:mmerino56.unam@gmail.com)

1980s, primarily for tarpons (*Megalops atlanticus*) and largemouth bass. This fishery gained international notoriety and attracted many American anglers to La Redonda. Beyond fishing, the lagoon offered attractive scenery, with clear water, benthic vegetation (mainly dotleaf water lily, *Typha domingensis* and some algae species of the genus *Chara*). A largemouth bass fishing tournament was held in La Redonda every year from 1987 to 1997, during the month of March. However, by the end of the 1980s, the principal source of freshwater (La Yana watershed) to La Redonda lagoon was affected by the construction of the Puente Largo dam and salinity increased to levels over 3.0 PSU. As water flow was limited, water retention and sediment accumulation increased (more than 50 cm) inside the lagoon; aquatic vegetation began to disappear and water transparency, to decrease (González-De Zayas *et al.*, 2014). Fishing guides noted that largemouth bass number dramatically decreased by 2000 and the last recorded catch of a largemouth bass in La Redonda was in 2009 (González-De Zayas *et al.*, 2014). Eutrophication and harmful algal blooms (Moreira-González and Comas-González, 2014), salinization sedimentation, disease outbreak overfishing or some combination were identified by González-De Zayas *et al.* (2014) as probable causes of extinction of largemouth bass in La Redonda lagoon.

This study evaluates the physicochemical and trophic state of La Redonda lagoon and its conditions as suitable habitat for largemouth bass (*Micropterus salmoides*, Lacepède).

Our goals were (1) To compare the water quality and trophic state of the lagoon between seasonal surveys; (2) To relate observed water conditions with documented tolerance of those conditions by largemouth bass; and (3) To estimate habitat suitability for largemouth bass through the Habitat Suitability Index (HSI).

The results of this index will be compared with the tolerance ranges reported for largemouth bass, and the potential recovery of the species will be addressed.

## 2 Material and methods

### 2.1 Study species

Largemouth bass are native to North America. They are capable invaders, strong competitors, and known predators on native fish species. Temperature requirements vary depending on the life stage and activity. The temperature for optimal growth of adult largemouth bass is 24.0–32.0 °C, but growth can occur from 15.0 °C to 36.0 °C (Stuber *et al.*, 1982). Spawning in temperate regions begins when temperature reaches 15.0 °C, particularly after spring and at the beginning of summer. For spawning and incubation, the optimal temperature is 20.0–21.0 °C (Clugston, 1964) with a range of 13.0–26.0 °C (Kelley, 1968). Nests are usually built in firm substrate covered with woody debris or aquatic vegetation in shallow water (<1.5 m). Recruitment of largemouth bass can be mediated by factors such as wind and wave action, water quality, cover, temperature (especially a rapid drop), predation, and human activities (Sammons *et al.*, 1999).

Largemouth bass are more tolerant of low dissolved oxygen and pH than smallmouth bass (*Micropterus dolomieu*) (Scott and Crossman, 1973; Lasenby and Kerr, 2000).

Largemouth bass avoid waters with dissolved oxygen below 3.0 mg L<sup>-1</sup>, but can survive at 1.5 mg L<sup>-1</sup> when temperatures are optimal (Scott and Crossman, 1973). Levels below 1.0 mg L<sup>-1</sup> are lethal (Stuber *et al.*, 1982). According to Stroud (1967), the optimal pH range for largemouth bass is 6.5–8.5. They will tolerate short-term exposure to a minimum pH of 3.9 and a maximum of 10.9; however, bass will not spawn when pH is less than 5.0, and eggs do not survive at pH above 9.6 (Stuber *et al.*, 1982).

Largemouth bass generally inhabit waters that range from fresh to oligohaline (0.5–5.0 PSU) (Meador and Kelso, 1989), although some individuals have been reported for tidal freshwater and estuaries with salinities up to 24.0 PSU (Moyle, 2002; Peer *et al.*, 2006). Klimah (2015) concluded that salinities between 0 and 12.0 PSU alone did not significantly stress or impact estuarine or inland largemouth bass swimming performance. Tebo and McCoy (1964) noted that abundance of largemouth bass declined when salinity was above 4.0 PSU. Embryonic development was impaired at 1.5, and survival was zero at salinities above 10.5 PSU. Some authors (Tebo and McCoy, 1964) suggested that fry growth could decline at 1.7 PSU and was zero at 6.0 PSU.

Spawning in temperate regions begins when temperature reaches 15.0 °C, particularly after spring and at the beginning of summer. Nests are built in the sand, gravel, debris and soft mud near reeds, bulrushes and water lilies. Nests are often built in shallow water (<1.5 m). Other factors such as wind and wave action, water quality, cover, temperature (especially a rapid drop), predation and human activities affect reproduction.

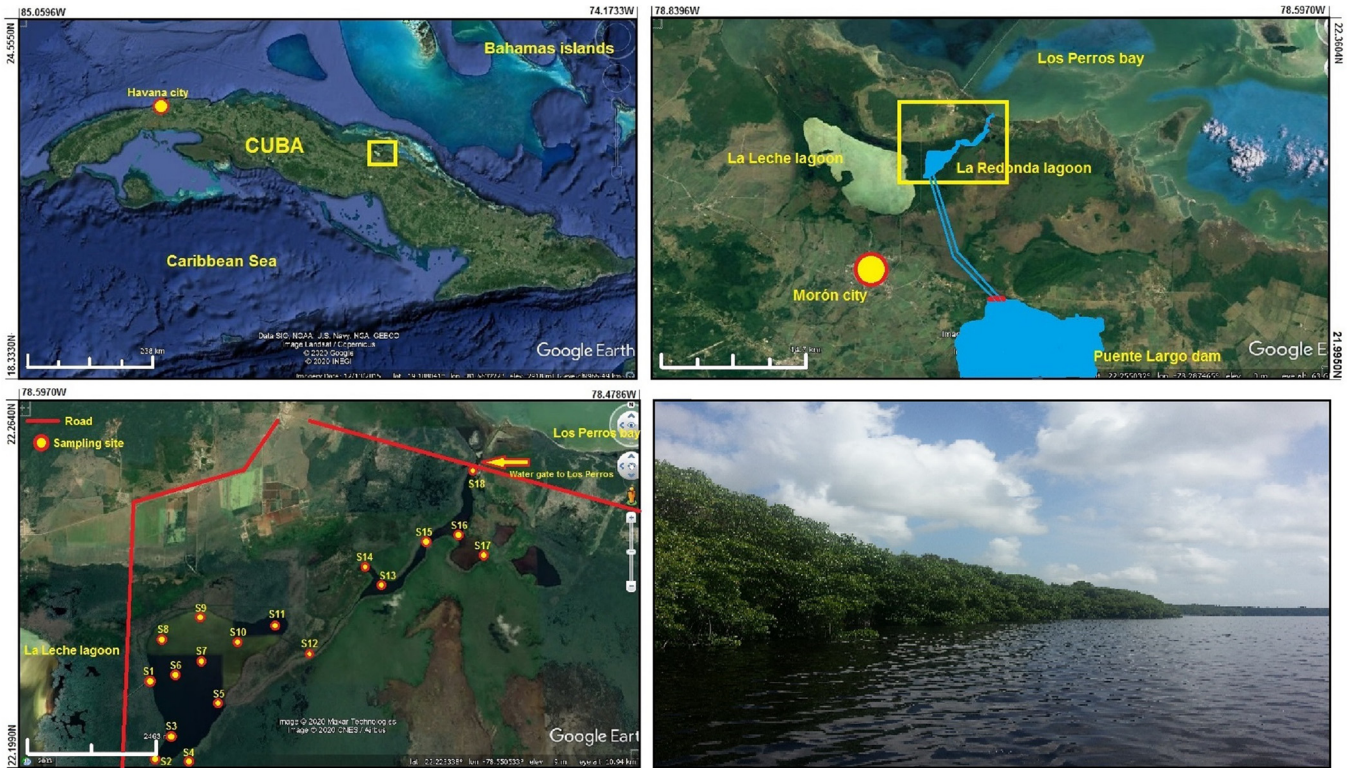
### 2.2 Study area

La Redonda is a natural lagoon formed by an open water body located (22.2154 N, 78.560 W) north of Moron City, in Ciego de Ávila province, Cuba (Fig. 1). It has an area of about 26.0 km<sup>2</sup> and a volume of 13.7 million m<sup>3</sup> (Fig. 1). La Redonda is the second most important lagoon (after La Leche lagoon, greatest natural freshwater lagoon in Cuba) in the Great Wetland of the North of Ciego de Ávila (Ramsar site). There are two well defined climate seasons at the study zone: the wet season (from May to October) and the dry season (from November to April). The wet season includes summer and the dry season includes winter.

It is shallow (1–3 m, mean depth 1.5 m) without aquatic vegetation, but is rimmed almost entirely by well-developed mangroves, with prevalence of red mangroves (*Rhizophora mangle*). The bottom is almost completely covered with a layer of unstable sediment more than 50 cm deep that provides very little physical support. This sediment has a strong organic component that causes a deficit of dissolved oxygen through decomposition in the deeper areas (González-De Zayas *et al.*, 2014).

The sediment layer does not stretch into the mangroves, so there is a shallower broad strip around the entire lagoon where the substrate is firmer and is mainly covered by fallen leaves and mangrove branches. This type of substrate is also found in the channel bed. Salinity is low (<3.0 PSU), but the lagoon still supports salt water species, such as barnacles.

There are several species of microalgae and cyanobacteria, with greater diversity of diatoms. The diatoms present are



**Fig. 1.** Localization of La Redonda lagoon, Cuba.

typical of saline environments, organic matter and eutrophic waters. Desmidian algae also occur at this lagoon (Labaut *et al.*, 2014).

La Redonda lagoon is home to 11 freshwater fish species from eight genera and six families, but only two species are native to Cuba (*Nandopsis tetracanthus* and *Gambusia puncticulata*). Catfish (*Clarias gariepinus*) and blue tilapia (*Oreochromis aureus*) are the main commercial fisheries resources (González-De Zayas *et al.*, 2014). Today, the lagoon is one of the principal freshwater reservoirs of Ciego de Ávila province. The Puente Largo dam (located upstream of the watershed) receives runoff from the La Yana watershed and only small volume of this water reaches La Redonda through regulated floodgates.

### 2.3 Sampling and analysis

Water samples were collected at 18 sites: twice in 2013 (March and November, dry season) and once in 2014 (June, wet season) (Fig. 1). The sites were located in the central part and the main channels of the lagoon.

Temperature and salinity were determined in situ, using a digital thermo-salinometer (from WLW trade mark). Dissolved oxygen (DO) was determined in triplicate by the Winkler method. Samples for nutrients (dissolved inorganic nitrogen (DIN =  $\text{NH}_4^+ + \text{NO}_2^- + \text{NO}_3^-$ ), Soluble Reactive Silicate (SRSi) and soluble reactive phosphorus (SRP)) were immediately filtered through Millipore filters of 0.22  $\mu\text{m}$  and fixed with chloroform. Filtered samples were frozen until analysis, together with unfiltered samples for total nitrogen (TN) and phosphorus (TP). Dissolved nutrients were analyzed

with a Skalar San Plus segmented-flow auto analyzer using the standard methods adapted by Grasshoff *et al.* (1983) and the circuits suggested by Kirkwood (1994). Unfiltered samples for the analyses of TN and TP were held in polypropylene containers and analyzed as nitrate and SRP after high temperature (120 °C) oxidation with persulfate in an autoclave for 30 min, following Valderrama (1981). Organic nitrogen and organic phosphorus were calculated by subtraction (see González-De Zayas *et al.*, 2013 for details). For chlorophyll *a* (CHL *a*) samples were taken at 10 sites in November 2013 (Fig. 1) and were analyzed using the fluorometric method of extraction with methanol. Transparency was measured using a Secchi disk.

Water quality measurements noted above for November 2013 were used to generate a Trophic State Index for tropical zones (TSI; Carlson 1977, Toledo *et al.*, 1983) that classified the trophic state of La Redonda lagoon. The TSI was calculated using an index for each evaluated parameter (transparency from Secchi disk, TP, RSP and CHL *a*).

All equations to calculate TSI for La Redonda lagoon are listed below:

$$\text{TSI}_{\text{modified Secchi Disk}} = 10 * \left[ 6 - \left( \frac{0.64 + \ln(\text{Secchi Disk})}{\ln 2} \right) \right] \quad (1)$$

$$\text{TSI}_{\text{modified TP}} = 10 * \left[ 6 - \left( \frac{\ln\left(\frac{80.32}{\text{TP}}\right)}{\ln 2} \right) \right] \quad (2)$$

$$TSI_{\text{modified SRP}} = 10 * \left[ 6 - \left( \frac{\ln \frac{21.67}{SRP}}{\ln 2} \right) \right] \quad (3)$$

$$TSI_{\text{modified CHL } \alpha} = 10 * \left[ 6 - \left( \frac{2.04 - 0.695 * \ln CHL \alpha}{\ln 2} \right) \right] \quad (4)$$

$$TSI_{\text{modified (mean)}} = \frac{TSI(\text{Secchi Disk}) + 2 [TSI(TP) + TSI(SRP) + TSI(CHL \alpha)]}{7} \quad (5)$$

$TSI_{\text{modified (mean)}}$  was calculated using trophic classification of water taking into account the proposed interval: Oligotrophy  $\leq 44$ ; Mesotrophy  $44 < TSI < 54$  and Eutrophy  $\geq 54$  (Toledo *et al.*, 1983).

Additionally, we used the DIN:TP ratio as an indicator of limiting nutrients using the criteria outlined by Morris and Lewis (1988), where a DIN:TP ratio  $< 0.5$  indicates nitrogen limitation,  $5 < \text{DIN:TP ratio} < 4.0$  indicates both nitrogen and phosphorus limitation, and DIN:TP ratio  $> 4.0$  indicates phosphorus limitation.

#### 2.4 Habitat suitability index (HSI) model

To evaluate La Redonda lagoon as a suitable habitat for largemouth bass, we used the Habitat Suitability Index (HSI) proposed by Stuber *et al.* (1982) for largemouth bass in United States. We used this index, because there are no largemouth bass in the lagoon at this time and we cannot create a specific model for this lagoon. Also, the model was considered by Stuber *et al.* (1982) to apply to the species throughout its range in the United States, including southern Florida, which is only 166 km from Cuba. It is applicable across seasons and habitats, and does not establish a minimum habitat size for largemouth bass. We used the lacustrine model that is defined by variables related to several life requisites (Tab. 1).

A Suitability Index (SI) was calculated for each habitat variable using SI graphs provided in Stuber *et al.* (1982). These indices were used to calculate the components (C) of the HSI equation (6)

$$HSI = (C_F * C_C * C_{WQ} * C_R)^{\frac{1}{4}} \quad (6)$$

where  $C_F$ : Food;  $C_C$ : Cover;  $C_{WQ}$ : Water quality;  $C_R$ : Reproduction;  $C_F$  was calculated using level data in summer (from 1990 to 2014) and percent bottom cover 1.0 (*e.g.*, aquatic vegetation, logs, and debris) from González-De Zayas *et al.* (2014). The bottom cover at La Redonda lagoon is practically zero.

For  $C_C$ , we used the same level data in summer (from 1990 to 2014) and percent bottom cover (*e.g.*, aquatic vegetation, logs, and debris) data, average water level fluctuation (from historic data) during growing season (for fry, juvenile and adults) and depth of the lagoon ( $< 6$  m).

$C_{WQ}$  was calculated using some results of our own surveys.

**Table 1.** Principal life requisites and habitat variables used for lacustrine model for largemouth bass proposed by Stuber *et al.* (1982).

Life requisite	Habitat variable
Food ( $C_F$ )	Total dissolved solids ( $V_5$ ) % Area $\leq 6.0$ m deep ( $V_2$ )
Cover ( $C_C$ )	% bottom cover ( $V_3, V_4$ ) Water level fluctuation ( $V_{16}, V_{18}$ ) Dissolved oxygen ( $V_6$ ) pH range ( $V_7$ )
Water quality ( $C_{WQ}$ )	Temperature ( $V_8, V_{10}$ ) Turbidity ( $V_{11}$ ) Salinity ( $V_{12}, V_{13}$ ) % Area $\leq 6.0$ m deep ( $V_2$ ) Temperature ( $V_9$ )
Reproduction ( $C_R$ )	Salinity ( $V_{14}$ ) Substrate ( $V_{15}$ ) Water level fluctuation ( $V_{17}$ )

The reproduction component ( $C_R$ ) was calculated using average weekly mean temperature (from our temperature data) in pools or littoral areas during spawning and incubation, the substrate composition (silt and clay) and depth of the lagoon ( $\leq 6$  m).

#### 2.5 Statistical analysis

To determine data normality, a Shapiro-Wilk's  $W$  test was performed for all parameters surveyed. Because most data were normalized, we used an ANOVA test and a post-hoc Tukey test to find significant differences among surveys, with season (wet or dry) as an independent effect in the model. The Pearson correlation was used to determine significant correlation among measured physicochemical parameters. Using principal components analysis (PCA), was analyzed total variability of water quality (using measured parameter) and were associated these parameters with spatial distribution. Principal components analysis (PCA) was used to analyze total variability in measured water quality variables. The first (PC1) and second (PC2) principal components from the analysis were plotted to infer spatial differences in water quality. Also, with PCA we identified general tendencies and relationship among water quality variables by examining factor loadings of each variable on PC1 and PC2. STATISTICAL Software (version 10.1) as used to perform the analyses.

### 3 Results

#### 3.1 Water quality

All results of measured physicochemical parameters are shown in Table 2. Mean temperature for all surveys was  $26.1 \pm 2.4$  °C (22.0–28.8 °C). Temperature showed a seasonal behavior with the lowest mean temperature (significantly different,  $F = 94.08, p < 0.05$ ) in March 2013 (dry season) and the highest in November 2013 (beginning of winter) and June 2014 (wet season).

**Table 2.** Mean values  $\pm$  STD and range of physicochemical parameters (for each samplings and mean of all samplings) for three sampled lagoons. Minor letters denoted significant differences between samplings ( $p < 0.05$ ).

Lagoon	Sampling	Salinity (PSU)	Temperature (°C)	pH	DO (mg/L)	DIN ( $\mu\text{M}$ )	TN ( $\mu\text{M}$ )	SRP ( $\mu\text{M}$ )	TP ( $\mu\text{M}$ )	SRSi ( $\mu\text{M}$ )
La Redonda	March 2013	1.7 $\pm$ 0.5 <sup>a</sup> (1.0–3.0)	23.2 $\pm$ 0.8 <sup>a</sup> (22.0–25.3)	8.08 $\pm$ 0.62 <sup>a,b</sup> (6.62–8.79)	6.3 $\pm$ 3.0 <sup>a</sup> (0.9–9.0)	6.1 $\pm$ 3.9 <sup>a</sup> (2.5–14.8)	109.5 $\pm$ 33.5 <sup>a</sup> (66.2–208.6)	1.3 $\pm$ 0.2 <sup>a</sup> (1.1–1.8)	3.1 $\pm$ 1.8 <sup>a</sup> (1.6–8.4)	236.9 $\pm$ 26.8 <sup>a</sup> (173.8–292.4)
	November 2013	1.6 $\pm$ 0.6 <sup>a,b</sup> (1.0–3.0)	27.4 $\pm$ 1.1 <sup>b</sup> (25.0–28.6)	7.96 $\pm$ 0.41 <sup>a</sup> (7.09–8.46)	4.5 $\pm$ 2.4 <sup>b</sup> (0.0–7.1)	2.9 $\pm$ 2.2 <sup>b</sup> (0.5–8.5)	96.1 $\pm$ 16.4 <sup>b</sup> (70.7–136.4)	0.8 $\pm$ 0.1 <sup>b</sup> (0.5–1.0)	2.5 $\pm$ 0.7 <sup>a</sup> (1.5–4.0)	316.8 $\pm$ 58.9 <sup>b</sup> (187.3–401.5)
	June 2014	1.1 $\pm$ 0.6 <sup>b</sup> (0.0–3.0)	27.8 $\pm$ 1.3 <sup>b</sup> (24.3–28.8)	8.38 $\pm$ 0.60 <sup>b</sup> (7.10–9.00)	5.5 $\pm$ 2.6 <sup>a,b</sup> (0.3–8.5)	5.3 $\pm$ 5.7 <sup>a</sup> (1.6–27.1)	91.1 $\pm$ 22.1 <sup>c</sup> (68.7–165.6)	0.8 $\pm$ 0.2 <sup>b</sup> (0.5–1.4)	6.7 $\pm$ 8.1 <sup>b</sup> (2.0–9.5)	224.6 $\pm$ 58.9 <sup>a</sup> (150.2–448.3)
	Mean	1.5 $\pm$ 0.6 (0.0–3.0)	26.1 $\pm$ 2.4 (22.0–28.8)	8.15 $\pm$ 0.6 (6.62–9.00)	5.4 $\pm$ 2.8 (0.0–9.0)	4.8 $\pm$ 4.3 (0.5–27.1)	98.5 $\pm$ 25.9 (66.2–208.6)	1.0 $\pm$ 0.3 (0.5–1.8)	3.4 $\pm$ 0.2 (1.5–9.5)	258.4 $\pm$ 66.8 (150.2–448.3)

Mean salinity for all surveys showed that La Redonda has fresh to brackish water (0.0–3.0) (Tab. 2). Like temperature, salinity followed a seasonal behavior; it was higher in the dry season (March and November 2013) and lower in the wet season (June 2014). Salinity only reached zero during June 2014 and varied spatially in all surveys.

The pH varied widely during the survey period (Tab. 2), without a clear seasonal pattern. The lowest pH was in November 2013 and the highest value ( $F=6.09$ ,  $p < 0.05$ ) was in June 2014. This parameter (pH) showed a spatial pattern; the lowest pH values ( $<7.50$ ) were recorded on the southern side of the lagoon and the highest ( $<8.27$ ) in the central portion of the lagoon, which is exposed to winds and light. The pH had a significant correlation with salinity, temperature, DO, SRSi and DIN (Tab. 3).

Dissolved oxygen (DO) varied widely and had lower mean concentration ( $F=4.30$ ,  $p < 0.05$ ) in November of 2013. For all surveys, DO concentrations were above 3.1 mg L<sup>-1</sup>, except at site 12, where there were hypoxic conditions ( $<2.0$  mg L<sup>-1</sup>) in March and November 2013. Dissolved oxygen had a significant correlation with temperature, pH and SRSi (Tab. 3).

Ammonium was the principal fraction of DIN (75%). Mean DIN was 4.8  $\pm$  4.3  $\mu\text{mol L}^{-1}$  for all the survey period. This parameter did not show a clear seasonal pattern. The lowest mean DIN concentration was in November 2013 (dry season), significantly different from those of March 2013 (dry season) and June 2014 (wet season).

Most of TN in La Redonda lagoon was in organic form (90%). Mean TN concentrations varied widely during the survey period (Tab. 2), with significant differences among surveys. The highest mean TN concentration was in March 2013 and the lowest in June 2014. Spatial distribution of TN showed higher concentrations at the northern sites of the lagoon, while lower concentrations were at the center of the lagoon. Total nitrogen only had significant correlation with temperature (Tab. 3).

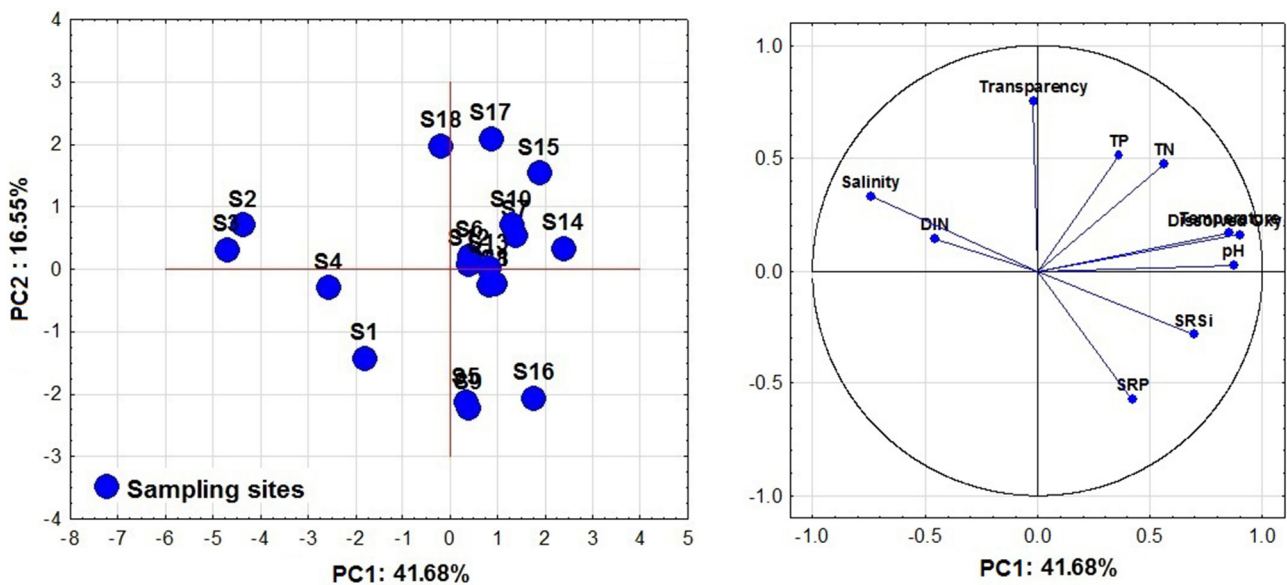
The SRP concentrations were between 0.5 and 1.8  $\mu\text{mol L}^{-1}$  for all surveys, with a mean value of 1.0  $\pm$  0.3  $\mu\text{mol L}^{-1}$  (Tab. 2). The mean SRP was higher in March 2013 than in November 2013 and June 2014. The mean TP concentration was 3.4  $\pm$  0.2  $\mu\text{mol L}^{-1}$ , with a greater fraction (more than 50%) of organic phosphorus. The highest TP mean was in June 2014 and the lowest concentration was in November 2013. The spatial distribution was different in each survey. TP did not show significant correlation with any parameter. Chlorophyll a concentrations were between 0.26 and 3.183  $\mu\text{g L}^{-1}$  with a mean value of 1.38  $\mu\text{g L}^{-1}$  in November 2013.

The PCA analysis identified general tendencies and relationships among measured parameters and sampling sites. The two principal components (PC1 and PC2) explained the 56.34% of data variability (Fig. 2). For PC1 ( $\lambda=4.01$ ; 40.10%), salinity (factor loading=0.75) and DIN (0.48) had the more positive values and pH (−0.88), temperature (−0.84), DO (−0.82) and SRSi (−0.70) had more negative values. For PC2 ( $\lambda=1.62$ ; 16.24%) other measured parameters (with less importance in PC1) had high values: transparency (0.73), TN (0.549), TP (0.53) and SRP (−0.53). The sites located at south of lagoons (inside channels) and at center of lagoons were highly correlated with measured parameters along PC1 axis. Sampling sites located at north of lagoon were highly correlated with parameters along PC2 axis (Fig. 2).

**Table 3.** Pearson correlation between all measured parameters in La Redonda lagoon for all samplings.

Parameter	Salinity	Temperature	pH	Dissolved oxygen	SRP	SRSi	DIN	TN	TP
Salinity	1.000	-0.456	-0.609*	-0.438	-0.501*	-0.496*	0.391	-0.243	-0.280
Temperature	-0.456	1.000	0.734*	0.781*	0.414	0.472*	-0.186	0.504*	0.225
pH	-0.609*	0.734*	1.000	0.810*	0.234	0.482*	-0.473*	0.318	0.251
Dissolved oxygen	-0.438	0.781*	0.810*	1.000	0.200	0.497*	-0.375	0.205	0.134
SRP	-0.501*	0.414	0.234	0.200	1.000	0.317	-0.007	-0.018	-0.092
SRSi	-0.496*	0.472*	0.482*	0.497*	0.317	1.000	-0.281	0.333	0.152
DIN	0.391	-0.186	-0.473*	-0.375	-0.007	-0.281	1.000	-0.185	0.085
TN	-0.243	0.504*	0.318	0.205	-0.018	0.333	-0.185	1.000	0.433
TP	-0.280	0.225	0.251	0.134	-0.092	0.152	0.085	0.433	1.000

\*\*Denote significant correlation.



**Fig. 2.** Principal component Analysis (PCA) of the first (a) and second (b) factors (PC1 and PC2) for survey sites and water physicochemical parameters in La Redonda lagoon.

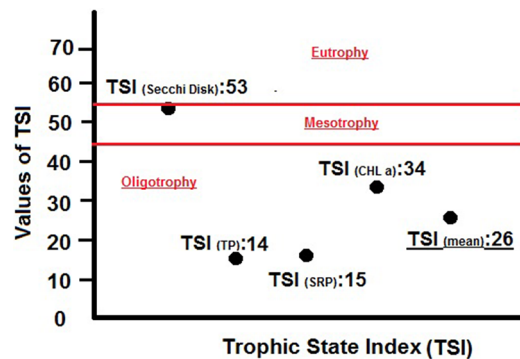
### 3.2 Trophic state index (TSI)

Using equations (1)–(5), we calculated each TSI and  $TSI_{mean}$  (Fig. 3). La Redonda lagoon was characterized as a mesotrophic system when including Secchi Disk in the TSI and  $TSI_{mean}$  (26.0) (Fig. 3), but oligotrophic otherwise.

Considering the criterion of Morris and Lewis (1988), 80% of the samples showed that both (nitrogen and phosphorus) are limiting in La Redonda lagoon, while only 12% showed nitrogen limiting and 8% phosphorus limiting.

### 3.3 Habitat suitability index (HSI) model

The HSI calculated for all surveys was  $0.63 \pm 0.02$  (Tab. 4). This result showed that La Redonda has a moderate degree of suitability for largemouth bass habitat, according to the calculated components. The food component had a low value ( $0.40 \pm 0.02$ ) and the reproduction component was moderate ( $0.69 \pm 0.01$ ).



**Fig. 3.** Mean calculated values of Trophic State Index (TSI) for La Redonda lagoon.

**Table 4.** Values of suitability components and mean Habitat Suitability Index (HSI) for La Redonda lagoon.

Suitability Index	Value	Grade of suitability
C <sub>F</sub> : Food	0.40 ± 0.02	Low
C <sub>C</sub> : Cover	0.74 ± 0.01	High
C <sub>WQ</sub> : Water quality	0.83 ± 0.02	High
C <sub>R</sub> : Reproduction	0.69 ± 0.01	Moderate
HSI	0.63 ± 0.02	Moderate

**Table 5.** Nutrients concentration at La Redonda lagoon and at some others freshwater systems in Cuba and the world.

Site	DIN ( $\mu\text{mol L}^{-1}$ )	SRP ( $\mu\text{mol L}^{-1}$ )	TN ( $\mu\text{mol L}^{-1}$ )	TP ( $\mu\text{mol L}^{-1}$ )	Classification by authors	References
Recreativa dam (Cuba)	92.1–105.7	0.6	–	–	Oligotrophic	Arpajón <i>et al.</i> (2012)
Comunidad dam (Cuba)	173.6–191.4	2.6	–	–	Oligotrophic	Arpajón <i>et al.</i> (2012)
Chalons dam (Cuba)	6.1–35.7	1.0–6.5	–	–	Eutrophic	Rodríguez-Tito <i>et al.</i> (2017)
Parada dam (Cuba)	10.7–55.7	1.0–3.9	–	–	Eutrophic	Rodríguez-Tito <i>et al.</i> (2017)
Paso bonito dam (Cuba)	0.5–100.4	–	–	0.2–7.5	Eutrophic	Betancourt <i>et al.</i> (2009)
La Leche lagoon (Cuba)	1.98–107.1	0.20–12.2	–	1.3–18.1	Eutrophic	Popowski <i>et al.</i> (1994)
Higuanojo dam (Cuba)	200.0	0.0	650.0	39.0	–	Laiz <i>et al.</i> (1994)
Tuinicú dam (Cuba)	65.0	10.0	720.0	51.0	–	Laiz <i>et al.</i> (1994)
Lebrije dam (Cuba)	85.0	30.0	940.0	73.0	–	Laiz <i>et al.</i> (1994)
Zaza dam (Cuba)	110.0	19.0	780.0	92.0	–	Laiz <i>et al.</i> (1994)
Valle de Bravo dam (México)	26.5	0.6	75.2	2.9	Eutrophic	Ramírez Zierold <i>et al.</i> (2010)
Okeechobee lake (USA)	–	–	105.7	3.0	Eutrophic	Bachmann <i>et al.</i> (1996)
George (USA)	–	–	100.0	1.8	Eutrophic	Bachmann <i>et al.</i> (1996)
Istokpoga (USA)	–	–	50.0	6.8	Eutrophic	Bachmann <i>et al.</i> (1996)
<b>La Redonda lagoon</b>	<b>4.8 ± 4.3</b>	<b>1.0 ± 0.3</b>	<b>98.5 ± 25.9</b>	<b>3.4 ± 0.2</b>	<b>Oligotrophic</b>	<b>This study</b>

## 4 Discussion

### 4.1 Water quality and trophic state

La Redonda lagoon can be classified as a fresh to brackish system, with possible episodes of salinization, due to the input of euhaline waters (Batista Tamayo *et al.*, 2006) from Los Perros Bay. These episodes may occur in extreme dry seasons, when water managers restrict supply of freshwater from the Puente Largo dam and the water flow from La Redonda to Los Perros Bay is reversed. Apparently, these salinization episodes could be common due to the presence of species of phytoplankton with a wide variety of environments (fresh, brackish and haline) in the lagoon (Labaut *et al.*, 2014). Another lagoon of the Great Wetland of the North of Ciego de Ávila (GHNCA), Laguna de la Leche, had similar salinity levels (mean salinity of 1.0 PSU), with episodes of salinization due to the input of marine waters through floodgates (Batista Tamayo *et al.*, 2006). However, all salinity values measured in this survey were under 3.0 PSU and at least for this period 2013–2014, the haline conditions of La Redonda lagoon were within the range reported by some authors as normal habitats for the largemouth bass (Moyle, 2002; Peer *et al.*, 2006).

Although there was one site with low DO concentrations, other sites maintained suitable and high levels of DO. It is not uncommon for DO to vary among Cuban reservoirs

(Seisdedos *et al.*, 2017; Domínguez-Hurtado *et al.*, 2019) or within the range natural range of largemouth bass. Therefore the observed levels of dissolved oxygen should not impair the habitat suitability for largemouth bass.

Nutrient (dissolved and totals) concentrations in La Redonda were lower than in other studied Cuban freshwater reservoirs (Tab. 5). Most Cuban dams receive great volumes of polluted waters from populated and industrial areas, or high quantities of N and P from agricultural runoff, dominated by sugar cane fields and pasture grasses (Laiz *et al.*, 1994; Betancourt *et al.*, 2010; Rodríguez-Tito *et al.*, 2017). However, contributions of N and P to the lagoon are probably related to the opening of floodgates in Puente Largo dam, which receives all N and P from catchment and acts as a nutrient trap. Dams increase water retention and rates of degradation and sedimentation of particulate organic matter. The new impoundment and reservoirs become effective nutrient sinks (Stockner *et al.*, 2000). When compared with other tropical reservoirs (in United States and Mexico), nutrient concentrations in the lagoon are similar or even lower than at these sites (Tab. 5).

La Redonda lagoon was characterized as an oligotrophic lagoon, with very limited nutrients (N and P) and low levels of chlorophyll a. The lagoon has no direct human or natural water supplies, and the Puente Largo dam controls most nutrient and organic matter from catchment. Since the end of the 1980s,

nutrients and organic matter have probably come from internal processes and recycling. Mean concentration of chlorophyll *a* ( $1.4 \mu\text{g L}^{-1}$ ) showed oligotrophic conditions (according to Straškraba *et al.*, 1979) in the lagoon (Labaut *et al.*, 2014). While, using the limits proposed by OECD (1982) for chlorophyll *a* and for TP La Redonda lagoon can be classified as oligotrophic.

Most of other Cuban reservoirs (Tab. 5) are classified as eutrophic; some of these studies used the index of our study (Betancourt *et al.*, 2010; 2012). These reservoirs were influenced by important discharges of nutrients and organic matter from populated and industrial areas and from agriculture. Similar results, eutrophic conditions and anoxia, were found by Ramírez Zierold *et al.* (2010) for the Valle de Bravo dam (México) and Ledesma *et al.* (2013) at the Río Tercero dam (Argentina), due to nutrient contribution from rivers and sewage from populated areas located in the catchment.

#### 4.2 Suitable habitability for largemouth bass

Previous studies of the Cuban largemouth bass populations are scarce (Guerra *et al.*, 1980; Prokes *et al.*, 1981). However, it is known that largemouth bass adapted very well to Cuban water conditions and is present in most reservoirs and rivers of the country. It was so in La Redonda, but the causes of the largemouth bass extinction in this lagoon are not known.

The results of our work show that all studied parameters are within the ranges found in many studies of this freshwater species. Temperature range of our study was suitable for all life cycles of the species, including spawning. The existence of large areas of the lagoon covered by mangroves prevents a significant increase of temperature during daytime. Boucek *et al.* (2017) found that micro-refuges and vegetation helped maintain suitable water temperature of 23 Florida lakes for largemouth bass. French (2016) found that a temperature range between 20.0 and 27.0 °C was good for the largemouth bass at Lake Ridge in Illinois. Such values are similar to those of our work.

Salinity range at La Redonda was 0–3.0 PSU, which has been reported as suitable for largemouth bass by some authors (Meador and Kelso, 1989; Peer *et al.*, 2006; Klimah, 2015). However, there is evidence that some salinization episodes at La Redonda could increase salinity up to values not tolerated by largemouth bass juveniles, which can experience osmoregulation and growth problems (Lowe *et al.*, 2009). The frequency of these episodes has not been thoroughly studied at La Redonda, so there is no available data to support how much salinity increases during the episodes or describe salinity distribution in the lagoon. Drought events have been common since the 1980s (Vidal Olivera *et al.*, 2015) and salinity in La Redonda may have increased when salinity rose in a connected lagoon, Laguna de la Leche. In 1988, the mean salinity of Laguna de la Leche was 20.0 PSU with an extreme increase up to 50.0 PSU, which were much greater than that measured between 2004 and 2006 when salinity was 25.0 PSU or in 2010 when salinity was 15.0 PSU.

Before 1988, La Redonda could have strongly impacted its trophic state due to large contributions of nutrients and organic matter from La Yana watershed, but after the construction of the Puente Largo dam, water inputs from the said watershed

were restricted to very low volumes (Vidal Olivera *et al.*, 2015). This process could have produced an important impact (possible reduction) on the trophic state of La Redonda (there are no previous studies). Studies on the largemouth bass habitat requirements (Stuber *et al.*, 1982; Brown *et al.*, 2009) do not address water nutrient contents and trophic state. Zachary *et al.* (2010) found a direct relationship between common carp abundance and increasing nutrient concentrations, while abundance of the largemouth bass decreased under such conditions in 129 lakes of Iowa (USA). However, Maceina and Bayne (2001) suggested that the largemouth bass recruitment decreased due to oligotrophication in one Georgia reservoir; growth rates of age-4 and older largemouth bass and the relative weight of preferred-memorable (38–51 cm) fish also declined. Bachmann *et al.* (1996) and Boucek *et al.* (2017) found that the total fish biomass per unit area (including largemouth bass) was positively correlated with total phosphorus, total nitrogen and chlorophyll *a*, while temperature did not have a significant influence on the individual performance of the largemouth bass in some Florida lakes (USA). Therefore, the oligotrophic or mesotrophic status of La Redonda Lagoon should support this species.

The HSI is a tool for assessing relative habitat availability, and has been widely used by many authors for some freshwater species like the largemouth bass (Brown *et al.*, 2009; Love, 2011; Oyugi, 2014). However, these studies combined some published models with field data (Love, 2011; Hijuelos *et al.*, 2016) or developed new models and indexes (Bain and Jia, 2012). In Cuba, there are no studies on habitat suitability criteria for freshwater species, and in the case of La Redonda, largemouth bass is no longer present. For this reason, we used the HSI proposed by Stuber *et al.* (1982) as a better approach to evaluate habitat of this lagoon, including components as food, cover and reproduction.

Mean calculated HSI for La Redonda showed that the water quality component had a high degree of suitability, *i.e.* good water conditions. However, it is not so particularly for the food component and for the reproduction component (moderate). During the early life stages, the diet of fry and juveniles of largemouth consists mainly of micro crustaceans and small insects, juveniles consume mostly insects and small fish, and adults feed primarily on fish and crayfish (Stuber *et al.*, 1982), which are relatively abundant in La Redonda lagoon (González-De Zayas *et al.*, 2014). Stuber *et al.* (1982) used only one variable for this component in lacustrine habitats: total dissolved solids (TDS). This could be a limitation in the case of La Redonda, where high organic matter in sediments due to mangrove litter deposition, stable margin vegetation and channels are ideal habitats for insects (principally of the family Chironomidae), fry and juveniles of other fish species (of the genus *Oreochromis* and *Cyprinus*) and small fishes as *Gambusia puncticulata* (González-De Zayas *et al.*, 2014).

The reproduction component ( $C_R$ ) in the HSI model has a moderate value. The absence of submerged aquatic vegetation, gravel and high abundance of exotic species as *Clarias gariepinus* (omnivorous and strong predator) could be factors that affect the largemouth bass reproduction, which have not been studied. Some authors documented important relation among abundance of submerged and emergent aquatic vegetation with nesting black bass (Kramer and Smith, 1960; Chew, 1974), as refuge from predation for juvenile bass

(Miranda and Hubbard, 1994; Miranda and Pugh, 1997; Paukert and Willis, 2004) and abundance of largemouth bass (Iguchi *et al.*, 2004; Love, 2011; Hijuelos *et al.*, 2016). Oyugi *et al.* (2014) found that largemouth bass population in an African lake displayed a niche-restricted spatial distribution, where its stocks were only pronounced in areas with sandy/rocky substrates. For these reasons, we recommend dredging of the lagoon areas to reduce sediment volumes, building of a wooden structure and placement of gravel and rocks in some areas of La Redonda to create spawning sites for the species (Houser, 2007). Also, these artificial structures could enhance the protection of largemouth bass in earlier stages from predators such as *Clarias gariepinus*.

### 4.3 Some considerations on the largemouth bass recovery

Cuba has a long experience in aquaculture of freshwater species. In 2001, approximately 200 million of fry of different species (particularly carp and tilapia) were produced (Coto and Acuña, 2007). There are approximately 400 ha of nursery ponds throughout the country, one on them near La Redonda lagoon.

The production of largemouth bass fry at a nursery pond in the outskirts of the town of Morón city can be possible using local or imported breeders, previously certified by the corresponding authorities. Every year, a certain number of fry should be introduced and specialists must study fry survival. With these results, tourism, fishing and water management authorities of the province must work to re-introduce the largemouth bass in the lagoon. For a complete recovery of the largemouth bass fishing in La Redonda, some actions must be taken, namely: a complete ban of largemouth bass harvest; enforcement to prevent illegal fishing, regardless species; use of selective fishing gear for commercial species (catfish and tilapia); avoid the reversal of fluxes from Los Perros Bay building new floodgates in La Pesquera road; establish an ecological water supply from the Puente Largo dam, particularly during the dry season; as well as other management actions (Lowe *et al.*, 2009). Monitoring is also necessary, not only in La Redonda lagoon, but also in other dams such as Hanabanilla, Leonera, Muñoz, where largemouth bass fishing is still a local resource. Revenues from largemouth bass fishing are one of the Cuban government strategies to diversify and increase tourist options, which can draw anglers particularly from the United States.

## 5 Conclusions

La Redonda lagoon is a fresh to brackish water body that became famous as an exclusive largemouth bass fishing place during the last decades of the 20th Century. There are no studies about the causes of the largemouth bass extinction in the lagoon. In this study, we found environmental conditions that could favor the potential recovery of the largemouth bass, in spite of salinization episodes that could affect largemouth bass populations (particularly fry and juvenile). The calculated value of the HSI for the largemouth bass and the good water conditions of the lagoon support the idea that recovery of this species in La Redonda is possible. This is the first study about

the water quality and trophic state of La Redonda lagoon, so it is critical to implement an efficient environmental monitoring program at this reservoir.

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