Composition and spatial distribution of ichthyoplankton in intermittently-open coastal lagoons of Uruguay

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Abstract. We analyzed the composition, abundance and distribution of the ichthyoplankton community in two coastal lagoons of Uruguay, Laguna de Rocha and Laguna de Castillos, during a summer season.

Key words: *Brevoortia aurea*, *Lycengraulis grossidens*, Laguna de Rocha, Laguna de Castillos

Resumen. Composición y patrones de distribución espacial del ictioplancton en lagunas costeras intermitentemente abiertas de Uruguay. Se analizó la composición, abundancia y distribución del ictioplancton en dos lagunas costeras de Uruguay, Laguna de Rocha y Laguna de Castillos, durante un período estival.

Palabras clave: *Brevoortia aurea*, *Lycengraulis grossidens*, Laguna de Rocha, Laguna de Castillos

Coastal lagoons connected to the sea are particular estuaries that play an important role in the life cycle of marine, estuarine and anadromous fishes (Potter & Hyndes 1999). The relevance of these ecosystems for fish recruitment is based on characteristics such as high productivity and rich food supply, refuge against predators, and optimal temperature conditions for larval and juvenile growth (Able 2005). Movements of fish larvae between lagoons and adjacent seas are critical events influencing the survival and subsequent recruitment of species that inhabit these environments. Laguna de Rocha (LR) and Laguna de Castillos (LC) are coastal lagoons located on the southeastern coast of Uruguay (Fig. 1a) and are intermittently connected to the Atlantic Ocean. Attention has been focused mainly on the use of these systems by adult fishes, mostly species of economic relevance (Santana & Fabiano 1999, Saona *et al.* 2003). And few studies have been performed regarding their potential use as spawning sites (Vizziano *et al.* 2002), or as nurseries. In an effort to fill that gap and provide further insight into the role of coastal lagoons for fish recruitment, we present here the first description of the structure of the ichthyoplankton community (composition, abundance and distribution) in LR and LC during a summer season. We explored its distribution with the dominant environmental conditions.

Laguna de Rocha (34° 38' S - 54° 17' W; Fig. 1b) and Laguna de Castillos (34º 18' S, 53º 56' W; Fig. 1c) are microtidal shallow brackish lagoons (LR: 0.5 m mean depth, 72 km^2 surface area; LC: 1.0 m mean depth, 92 km^2 surface area). LR is separated from the sea by a narrow sand bar that opens intermittently by the combined effect of water level inside the lagoon and wave action on the seaward side (Conde *et al.* 2000). LC connects to the ocean through a stream that in turn connects with the ocean by a similar process than in LR (Valizas Stream; 12 km long; Fig. 1c). In both lagoons fresh and marine waters mix and a spatial salinity gradient is formed. This gradient can be weak or very pronounced depending on wind and rain patterns. However, in both systems marine conditions tend to dominate the south area while brackish-limnic conditions dominate the north area and the inner embayments close to the main affluents (Conde *et al.* 2000, 2003; Rodríguez-Graña *et al.* 2008).

Submerged plants and sediment properties also follow a spatial pattern with high vegetation cover and sediment organic content in the north area

(Rodríguez-Gallego *et al.* 2010). Environmental variables were recorded and ichthyoplankton collected in January 2004 at eight stations in LR
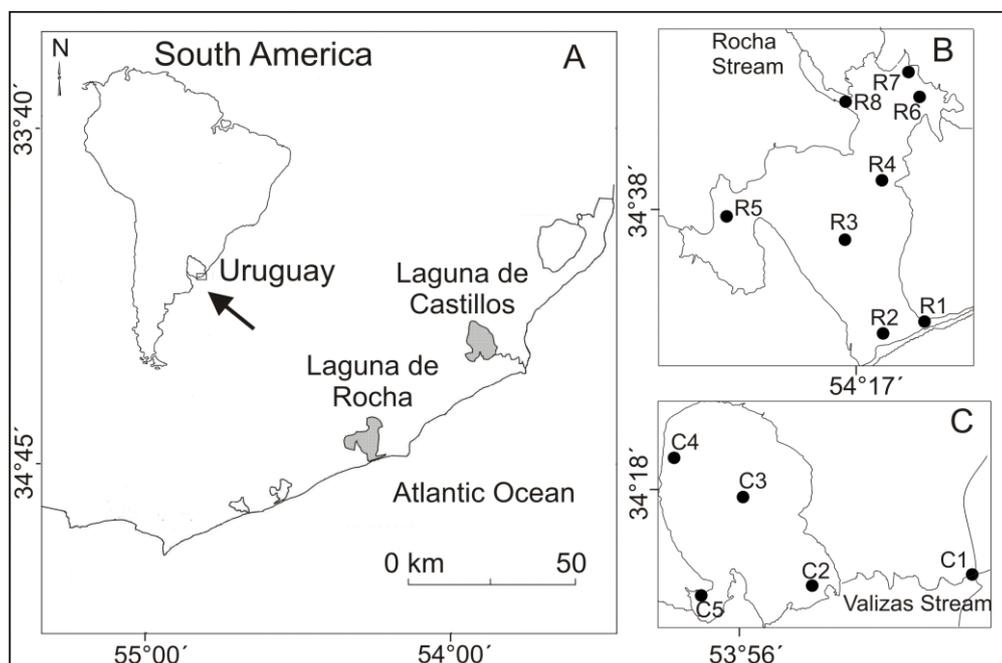

Figure 1. Location of coastal lagoons of Uruguay (A), sampling stations in Laguna de Rocha (B) and in Laguna de Castillos-Valizas Stream system (C).

(January 12th and 13th) and at five stations in LC-Valizas Stream system (February 23rd) (Figs. 1b- 1c). Depth, temperature, dissolved oxygen (Horiba OM-14), pH and conductivity (Horiba D-24) were recorded at each lagoon and sampling station. Salinity was estimated from conductivity and temperature measurements (Bodelón *et al.* 1994). Chlorophyll-*a* was determined spectrophoto-metrically (Beckman DU 650). Ichthyoplankton was collected with a tow net sled (65 cm width x 80 cm high, 500 μm net mesh; Neira 1994) specifically designed for shallow systems (effectively collecting plankton from ca. 10 cm to 90 cm above the bottom). Samples were preserved in 4% buffered formaldehyde. Fish eggs and larvae were sorted and identified to the lowest taxon based on taxonomic keys (e.g. Weiss 1981, Cassia & García de la Rosa 1993, Nakatani *et al.* 2001). For genus *Brevoortia*, we classified the species as *B. aurea* according to Cassia & García de la Rosa (1993) and García *et al.* (2008). Fish larvae were classified based on their stage of development (yolk-sac, preflexion or postflexion stages), and notochordal (NL) or total length (TL) was measured (0.1 mm resolution). Species were categorized according to the use of the estuary during their life cycle: marine, marine

opportunist, estuarine, freshwater or anadromous (Elliot *et al.* 2007). Species assemblages were defined by dendograms using Bray-Curtis measure of similarity and group average sorting. The relationship between larval distribution patterns and environmental conditions (standardized as log [x+1]; temperature, salinity, dissolved oxygen and chlorophyll-*a*) were explored by weighted rank correlations using the BIO-ENV procedure and Spearman coefficient correlation (ρ) (Clarke & Ainsworth 1993). Spatial ordination of the stations based on larval distribution and the variable with highest correlation (BIO-ENV results) was analyzed graphically by non-metric multidimensional scaling (MDS). Body size spatial distribution of dominant species between north or inner embayments and south areas was analyzed by one-way Kruskal-Wallis test.

During the study, sand bars were open and both lagoons were connected to the ocean. Water column was shallow and similar in both lagoons (LR 0.7 ± 0.4 m; LC 0.9 ± 0.3 m). There was no clear salinity gradient in any of the systems but LR was dominated by brackish water (salinity 11.4 ± 3.7) while LC presented freshwater in the main water body (0.6 ± 0.5) and brackish water in the Valizas

stream (22.0 ± 0.1) (Figs. 2a- 2b). Water temperature was typical of summer (Conde *et al.* 2000) (LR 26.1 ± 1.5 °C; LC 25.0 ±0.6 °C) and dissolved oxygen was near or above saturation levels (LR 8.2 ± 0.7 mg ml^{-1}; LC 7.6 ± 0.8 mg ml^{-1}) (Fig. 2a). Chlorophyll-*a*

was lower in LR (12.4 ± 3.1 µg l^{-1}) than in LC (20.7 ± 28.7 µg l^{-1}) (Fig. 2b). Moderate winds dominated during the five days before sampling (Southeastward in LR and Northeastward in LC) and it did not promote seawater intrusion into the systems.
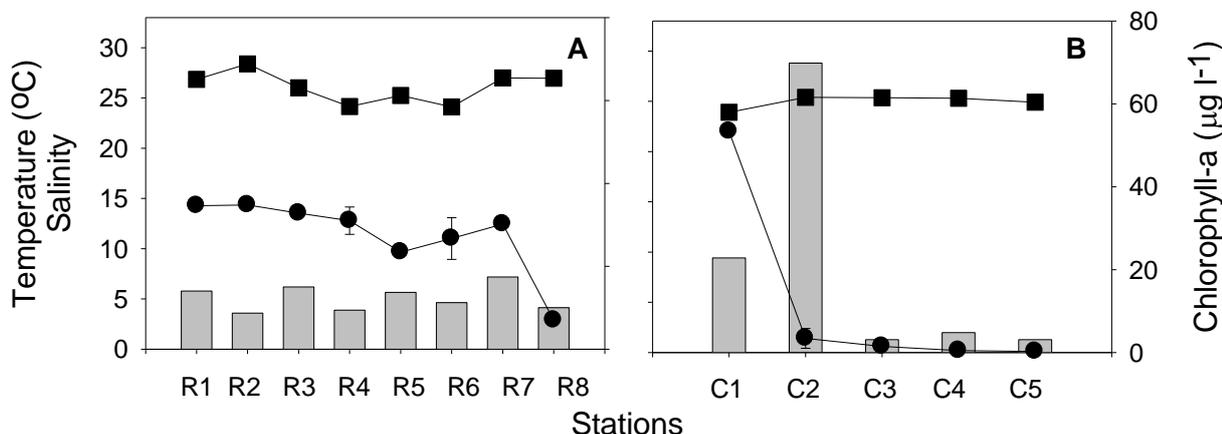

Figure 2. Temperature (squares), salinity (circles) and chlorophyll-*a* (bars) in Laguna de Rocha (A) and Laguna de Castillos-Valizas Stream system (B). Error bars indicate the standard deviation.
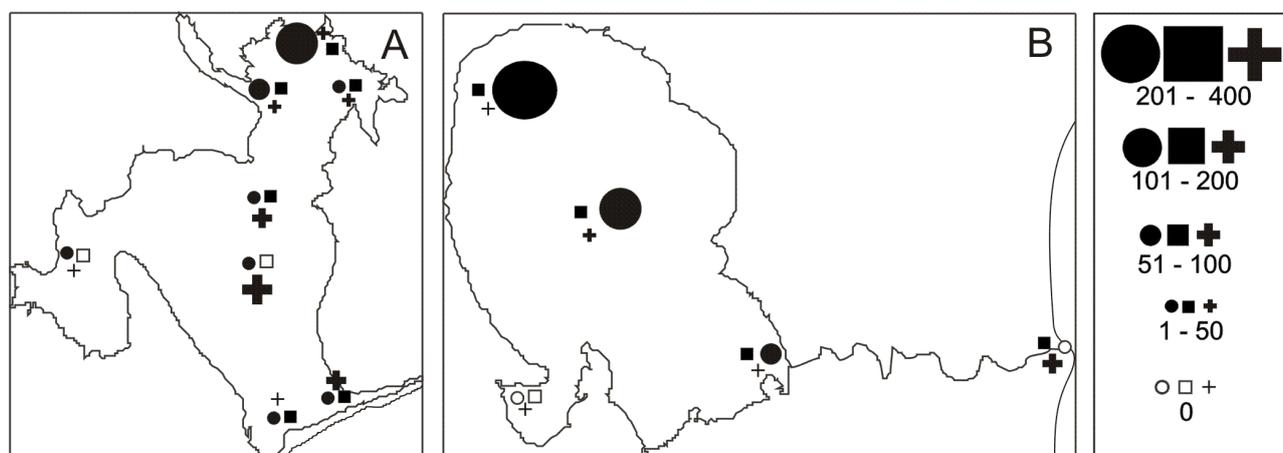
Figure 3. Eggs and larval abundance (ind. 100 m^{-3}) of A) *Brevoortia aurea* (circle) larvae, *Odonthestes* sp. larvae (square) and total eggs (cross) in Laguna de Rocha, and B) Clupeid-ni larvae (circle) and *Lycengraulis grossidens* larvae (square) and total eggs (cross) in Laguna de Castillos.

In LR total mean egg abundance was 66.3 ± 115.7 eggs 100 m^{-3}. Eggs were distributed in most of the sampled area. However, the highest abundance occurred at the center of this lagoon (station R3, Fig. 3a). In LC total mean egg abundance was lower than in LR (21.5 ± 42.8 eggs 100 m^{-3}) and eggs occurred only at two stations (C1 and C3, Fig. 3b) with the highest abundance in the Valizas stream. In both lagoons, only Atherinidae eggs were identified and

their total abundances were low and similar between lagoons (LR: 0.2 ± 0.6 eggs 100 m^{-3}; LC: 0.3 ± 0.6 eggs 100 m^{-3}). While Atherinidae eggs occurred only in the inner part of LR (station R6), in LC they occurred near the ocean (station C1). The presence of fish eggs and their spatial distribution depend mainly on the spawning areas selected by adults and their physiological requirements for reproduction and patterns of water circulation (Werner 2002,

Chiappa-Carrara *et al.* 2003). The occurrence of eggs within lagoons could be a consequence of two reproductive strategies: (1) eggs are spawned in adjacent waters and transported passively into the lagoon by tidal currents and/or wind, or (2) eggs are spawned directly inside the lagoon. LR and LC are microtidal systems and in consequence the transport of eggs into the lagoons by tidal action might be low. However, the entrance of marine eggs and larvae has been reported in some coastal lagoons by seawater overtopping events during the sandbar forming phase (Kemp & Froneman 2004). The environmental conditions (salinity, pH, temperature) in LR and Valizas stream matched the physiological requirements for spawning induction described for *Micropogonias furnieri* (Vizziano *et al.* 2002), *Brevoortia aurea* (Acha & Macchi 2000) and *Odontesthes argentinensis* (Phonlor & Cousin 1997). A previous study reported *B. aurea* eggs in high abundances in LR during a long period of isolation from the ocean in spring (Conde *et al.* 2003), further suggesting spawning events inside the lagoon. However, a higher sampling effort is needed in order to test that hypothesis for *B. aurea*.

Mean total larval abundance was lower in LR (55.4 ± 49.5 ind. 100 m^{-3}) than in LC (91.6 ± 90.7 ind. 100 m^{-3}). Larvae were discriminated in six families and six taxa in LR and in five families and eight taxa in LC. Larvae of Clupeidae were the most abundant in both lagoons (LR 91.5 %; LC 64.9 %) followed by Atherinidae in LR (3.2 %) and Engraulidae in LC (12.5 %). Estuaries tend to exhibit a low number of dominant species (Whitfield 1999), and our results were similar to those reported for other estuaries in the region (e.g. 3 dominant families at Lagoa dos Patos, Muelbert & Weiss 1991; 5 dominant families at Río de la Plata, Berasategui et al. 2004). However, total number of taxa registered was lower in LR and LC than in those systems. The small sampling effort applied in our study could explain partly this low diversity. However, Lagoa dos Patos and Río de la Plata are estuaries permanently open and with higher surface area than LR and LC increasing the chances for marine opportunistic species to ingress into these estuaries at any time. In our systems the presence of a sand bar restricts that possibility.

Brevoortia aurea occurred only in LR and it was the most abundant species (71.7 % of total abundance), while a non identified clupeid (clupeid-ni) occurred only in LC and it was the dominant species (64.9 % of total abundance) (Table I). This clupeid-ni could be *Platanichthys platana* since it is the only clupeid species recorded and captured in LC (Santana & Fabiano 1999, G. García pers.

comm.). LR was dominated by estuarine species (72 % of total abundance; e.g. *B. aurea;* Table I). A dominant life strategy was not determined in LC since the dominant species could not be identified. A preponderance of larvae from estuarine species is typical of systems under microtidal influence like LR, where transport into and out of the lagoon is reduced, diminishing the arrival of marine species (Neira & Potter 1992). In LR, *B. aurea* showed the broader spatial distribution and exhibited a tendency to occur in higher abundances northward (Fig. 3a). Other species occurring in LR such as *Sygnathus folletti, Anchoa marinii, Cynoscion guatucupa* and Characidae exhibited a restricted distribution and occurred mainly in the inner part of the lagoon (stations R6, R7 and R8) in low abundances. In LC the Clupeid-ni occurred only in the lagoon and exhibited a tendency to occur in higher abundances in the north (Fig. 3b). *Lycengraulis grossidens* was distributed in LC-Valizas Stream system. Loricariidae species occurred only at the northernmost station (C4), while *S. folletti, A. marinii, C. guatucupa* were restricted to Valizas Stream (station C1), all of them occurring in low abundances. *Micropogonias furnieri* occurred at Valizas Stream and south of the lagoon (stations C1 and C2).

Total larval body length ranged from 2.3 to 27.3 mm (average 11.1 ± 4.7 mm) in LR and 3.9 to 29.0 mm in LC (12.1 ± 4.4 mm). In both lagoons postflexion larvae dominated (LR 64 %; LC 79 %). A dominance of postflexion stages could be related to spawning events during spring within lagoons (e.g. Vizziano *et al.* 2002) or in adjacent waters with later transport and development inside these systems. *Brevoortia aurea* body length ranged from 2.3 (yolk-sac stage) to 27.3 mm (near metamorphosis) and size distribution differed between stations. Smaller larvae tend to occur at southern stations (7.6 ± 4.2 mm LN; stations R1 to R4), while bigger larvae dominated at northern stations (12.2 ± 4.2 mm LN and LS; stations R5 to R8) (Kruskal Wallis, $p < 0.001$). Larval distribution and habitat selection are related with larval behavior which in turn is influenced by the stage of development and physiological requirements (Werner 2002). The dominance of advanced stages of *B. aurea* in the north of LR could be related to the presence of dense macrophyte fields in this area, serving as larval refuge. A preference for coastal shores in Lagoa dos Patos (Brazil) was reported for *B. pectinata* (Weiss 1981). *Odontesthes* sp. body length ranged from 6.4 to 13.9 mm and preflexion stages (< 7.1 mm) occurred in north LR (stations R6 and R7). In LC, Clupeid-ni larvae body length ranged from 4.0 to 26.9 mm and preflexion

larvae (< 8.4 mm) tended to occur in the southern area but no spatial differences were found in its size distribution (Kruskal Wallis, p = 0.78). In the same lagoon, *L. grossidens* body length ranged from 8.6 to 23.9 mm and 95% of them were in postflexion stage (> 9.2 mm).

Table I. Ichthyoplankton taxa, total and mean (± sd) larval abundance (Abund.; ind 100 m^{-3}) and relative total abundance (%) in Laguna de Rocha (LR) and Laguna de Castillos-Valizas Stream system (LC). ni = unidentified or damaged larvae. E = estuarine, O = marine opportunist, F = freshwater, A = anadromous.

Family	Species	Life cycle	Abundance			
			Laguna de Rocha		Laguna de Castillos	
			Total (%)	Mean ± sd	Total (%)	Mean ± sd
Clupeidae	*Brevoortia aurea*	E	317.7 (71.7)	39.7 ± 35.6	-	-
	Clupeid-ni	-	-	-	296.6 (64.9)	59.3 ± 71.5
	n/i		87.8 (19.8)	11.0 ± 15.8	-	-
Engraulidae	*Anchoa marinii*	O	0.9 (0.2)	0.1 ± 0.3	1.4 (0.3)	0.3 ± 0.6
	Lycengraulis grossidens	A	-	-	57.2 (12.5)	
	n/i		1.7 (0.4)	0.2 ± 0.4	8.6 (1.9)	1.7 ± 3.8
Atherinidae	*Odontesthes* sp.	-	14.2 (3.2)	1.8 ± 2.3	-	-
Sciaenidae	*Cynoscion guatucupa*	O	0.5 (0.1)	0.1 ± 0.2	1.4 (0.3)	0.3 ± 0.6
	Micropogonias furnieri	E	-	-	3.7 (0.8)	0.7 ± 1.2
Syngnathidae	*Syngnathus folletti*	E	1.1 (0.3)	0.1 ± 0.4	1.4 (0.3)	0.3 ± 0.6
Characidae		F	0.8 (0.2)	0.1 ± 0.3	-	-
Loricariidae		F	-	-	0.1 (0.0)	0.01 ± 0.03
Ni			18 (4.1)	0.4 ± 0.7	86.5 (18.9)	4.1 ± 4.3

Three larval assemblages were defined for LR at a similarity level of 19 % (Fig. 4a, b). Group RI included euryhaline species with highest abundance and broad distribution (*B. aurea,* and *Odontesthes* sp*.)*. Group RII was constituted by estuarine and marine opportunistic species with low abundance collected in brackish areas (salinity ca. 13) and RIII was defined by freshwater species with low abundance collected in salinities below 2. In LC, two larval assemblages were defined at a similarity level of 36 % (Fig. 4c, d). Group CI included the estuarine and marine opportunistic species inhabiting Valizas stream (*A. marinii, C. guatucupa, M. furnieri)*. Group CII included dominant species under freshwater conditions (Clupeid-ni and *L. grossidens*). Among all variables tested, salinity showed the highest correlation with larval abundance and distribution (BIO-ENV procedure). Salinity is the main abiotic variable structuring the ichthyoplankton distribution in estuarine systems, including coastal lagoons (Potter & Hyndes 1999, Chiapa-Carrara *et al.* 2003, Berasategui *et al.* 2004). However, in LR larval abundances showed low but positive correlation with salinity (Spearman ρ=0.19). In this system, there was a mismatch between the spatial ordination of stations discriminated by abundance and the ordination discriminated by

salinity (Figs. 4a- 4b). This mismatch could be explained by a dominance of euryhaline species such as *B. aurea* and *Odontesthes* sp., more tolerant to salinity fluctuations (Muelbert & Weiss 1991, Berasategui *et al.* 2004), or by spatial homogeneity in the water conditions during the study. In LC the correlation between larval abundance and salinity was positive and high (Spearman ρ = 0.89). This high correlation was also evidenced in the MDS plots with similar spatial distribution patterns between larval abundance and salinity (Figs. 4c- 4d). In this lagoon, the presence of Valizas stream (located between the lagoon and the ocean) could act as a buffer for marine intrusions, creating a pronounced salinity gradient between both subsystems and structuring the ichthyoplankton community in different assemblages. Differences in fish assemblages inhabiting subsystems of coastal lagoons have been reported before (Chuwen *et al*. 2009).

This study revealed the presence of fish eggs and larval stages in two coastal lagoons of Uruguay during summer. Laguna de Rocha, with direct connection with the Atlantic Ocean, seems to be a suitable habitat for larvae of estuarine species, e.g *B. aurea*. Laguna de Castillos seems to be a more proper habitat for larvae of freshwater species or for

species tolerant to low salinity conditions, e.g. Clupeid-ni and *L. grossidens,* meanwhile the end of Valizas Stream could be used by estuarine or marine opportunistic species such as *A. marinii* and *C. guatucupa.* Further research including annual and interannual temporal series are necessary to evaluate the persistence of these species in both lagoons under a wider range of environmental conditions in order to contribute with knowledge about their life cycle and the role of these systems as nursery areas.
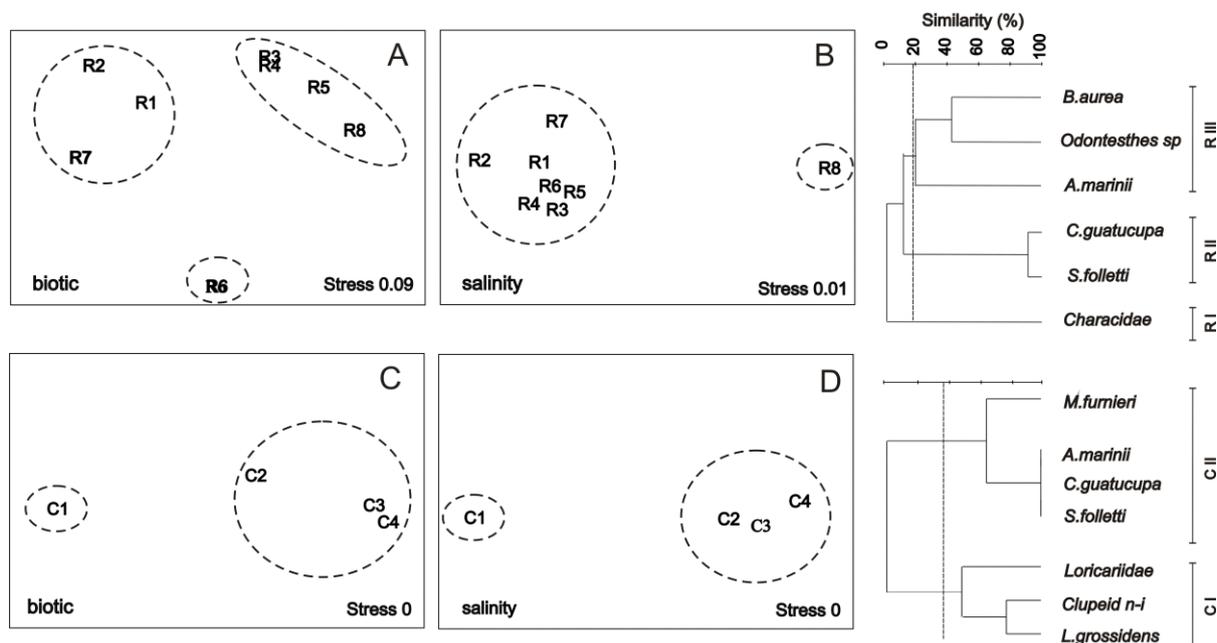

Figure 4. Multidimentional scaling ordination plots based on Bray-Curtis similarity matrix of species abundance and Euclidian distance similarity matrix of salinity in Laguna de Rocha (A and B) and Laguna de Castillos (C and D). On the right side: Clusters based on abundance similarity matrix, using Bray-Curtis for each lagoon.

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