Fish diversity in the Río de la Plata and adjacent waters, environment influence on its spatial and temporal structure

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1) Introduction

The aim of this chapter is to show how and why the environment affects the fish community and the life history stage and how these changes can impact on the fisheries management. We begin by describing of physical characteristic and processes that mainly affect the fish diversity. We give a description of main species that inhabit the estuary considering its biology, followed by a description of influence of the environment on the spatial and seasonal pattern of fish community structure, and on the trophic structure, and the influence throughout life history of species in spatial and seasonal habitat use considering age and mature state. Throughout the chapter we emphasize the effect of environment on the fish distribution that determines the fish vulnerability to fishing.

2) Río de la Plata physical characteristic and processes

The Río de la Plata is an extensive microtidal shallow coastal-plain estuary (Balay 1961) on the western South Atlantic coast (36ºS-56ºW; Fig. 1A). The freshwater input, mainly coming from the Paraná and Uruguay rivers, averages 24,000 m^3s^{-1} with maximum values as high as 70,000 m^3s^{-1} under extreme wet conditions (Jaime *et al*., 2002). A salt wedge system in the estuary is a quasi permanent feature as a result of the interaction between the freshwater discharge and shelf waters. This mixohaline region is characterized by strong vertical and horizontal gradients (Guerrero *et al*., 1997a; Framiñan *et al*., 1999). The combination of the bathymetry and coastline with the prevailing wind variability is highly favorable to the maintenance of this salt wedge structure in the Río de la Plata (Guerrero *et al*., 1997a; Simionato *et al*., 2007).

The estuarine system, covers an area of roughly 35.000 km^2 (Mianzan *et al*., 2001) with depths ranging from 5 to 15-25 m, which is bounded by two border front and constitutes an extensive surface area for properties exchange between adjacent waters (Guerrero *et al*. 1997a; Framiñan *et al*., 1999). The upper estuarine water boundary (riverine–mixohaline front) is where the halocline intersects the bottom (Fig. 1 C), that corresponds to the bottom salinity fronts defined by Guerrero *et al.* (1997a) and coincides with the estuarine turbidity maximum zone (ETM) (Framiñan *et al.*, 1999). Simionato *et al.* (2006) suggest that physical forcing may generate high particle retention within this front area, independently on the wind direction. The down estuarine waters boundary (mixohaline - coastal waters front) defined by the maximum horizontal gradient of surface salinity and is identified by the extension of the 27-30 ups isohaline (Guerrero et al., 1997a, b). Both frontal systems have annual persistence and the geographical location throughout the year depend on the dynamics of estuarine waters (forced mainly by winds). The surface salinity front displays higher spatial variability than the bottom salinity front in seasonal and inter-annual timescales (Framiñan and Brown, 1996; Guerrero *et al*., 1997a, Framiñan *et al.*, 1999, Simionato *et al.*, 2001, 2007; Bava, 2004). The bottom salinity front remains mostly locked to a submersed shoal known as Barra del Indio (Figure 1A) following the 10 m isobath as the shelf water intrusion along the bottom to the estuary is controlled by the bathymetry (Guerrero *et al.*, 1997a)

Because the Río de la Plata estuary is a shallow system (< 20 m) the structure of the entire water column is highly influenced by atmospheric conditions, which determine the spatial and temporal distribution of the temperature and salinity fields. Thermally, the estuarine waters show a warm (December – March, 21 to 22ºC) and a cold period (June – September, 10 to 12ºC). For both, the estuarine waters are nearly homogeneous in temperature, vertically and horizontally (Guerrero *et al.*, 1997a, b, Simionato *et al.*, 2010).

The upper layer waters in the estuary show a dominant bi-modal discharge as result of most frequent synoptic and intra-seasonal winds acting along those seasons, and constrained by the coast line orientation, which define two conditions understood as spring-summer and autumn-winter (Guerrero *et al.*, 1997a; Simionato *et al*. 2001, 2004, 2007). During autumn-winter months, a weak dominance of offshore winds and a weak maximum in the RDP discharge allow the extension of the RDP fresh water plume along the Uruguayan coast, resulting in penetration of shelf water from the south into the estuary along the Argentinean coast (Guerrero *et al.*, 1997a, Simionato *et al.*, 2004). During spring and summer, dominant NE sector winds (first quadrant) force the RDP estuarine waters to the south along the Argentine coast as far south as 37ºS, while shelf subtropical waters penetrate from the north up to Punta del Este (Uruguay), constraining the NNE drift. The southward overshooting of estuarine waters latter interact and mix with coastal shelf waters up to the shelf break limit (Guerrero *et al.*, 1997a, Lucas *et al.* 2005) (Fig. 1C). A particular surface intrusion of surface shelf water, far into the estuary, occurs under southeasterly winds (Simionato *et al*. 2007).

The wind has differential effect on the water masses vertical distribution in the Río de la Plata. Results based on observation (Guerrero *et al.*, 1997, Simionato *et al.*, 2007) show that wind stronger than 10 m s^{-1}, particularly from the SW, cause a breakage of the salt wedge which is a semi-permanent feature of the central and southern portions. However, recently numerical model (Meccia *et al.*, in press) shows that only southeasterly winds can weaken the stratification whereas the other wind directions are favorable to the maintenance of a salt wedge in this estuary. Also, the wind produces a recirculation between surface and bottom layer (Simionato *et al.*, 2007). When the wind blows from directions between NW (315°) and E (45°) produce an inflow (outflow) of bottom (surface) waters, while the outflow (inflow) of bottom (surface) waters occurs when the wind blow from directions between SE (135°) and W (270°) (Simionato *et al.*, 2007).

The Río de la Plata continental discharge variability, highly correlated to the ENSO cycles (Robertson and Mechoso, 1998), has been associated to produce large variations on the spatial distribution of environmental condition and frontal location (Framiñan and Brown, 1996; Bava, 2004). The freshwater discharge time series show large variations, reaching the extreme average values in 1983 (57346.91 m^3s^{-1}) and 1998 (47340.08 m^3s^{-1}) associated to El Niño phenomenon and minimum value associated to La Nina phenomenon (*e.g.* 1970-71, 1973-1975, 1988, 1995-1996, 2005). The variation in the discharge has strong effect on the inner part of estuarine zone, as it is observed in the location of estuarine turbidity maximum zone (ETM; Bava, 2004). During months with higher discharge than the average it is observed a down-river displacement of the ETM, while the up-river displacement increase related to decrease in the discharge (Fig. 2).

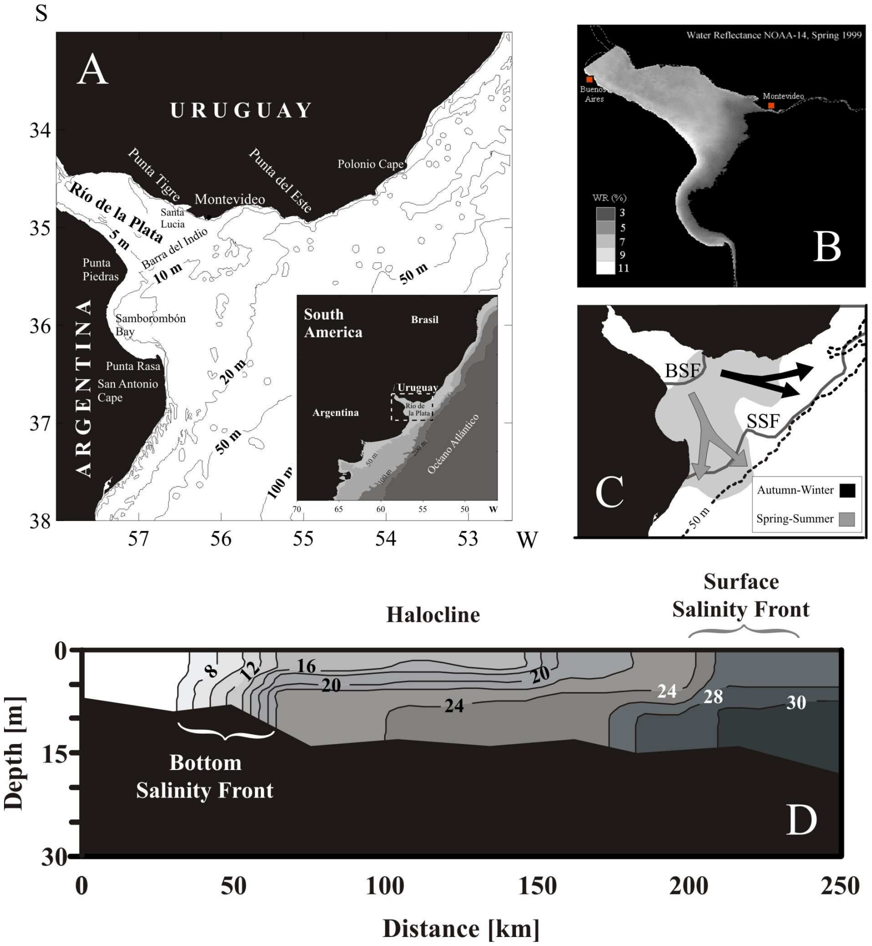


Figure 1 A) Location and bathymetry of the study area, B) spring distribution of turbidity, C) seasonal distribution of estuarine water indicating the inner (Bottom salinity front, BSF) and external boundary (Surface salinity front, SSF), D) high resolution salinity distribution along a central transaction of the estuary.

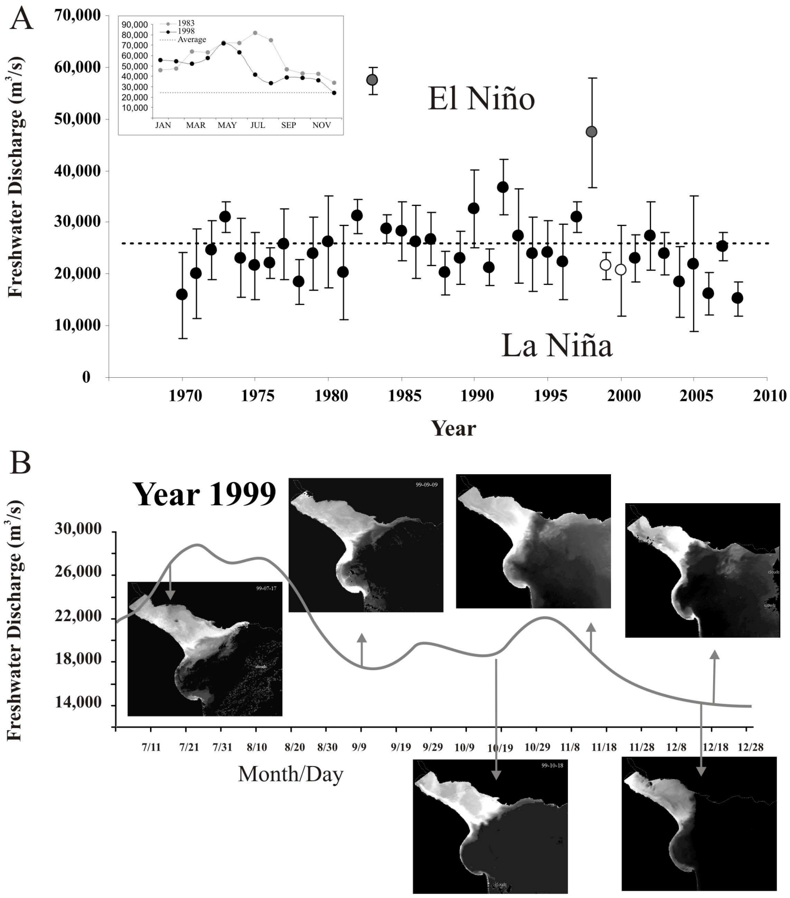


Figure 2 A) Time series of annual freshwater discharge of Río de la Plata (mean, standard deviation), indicating the averages (------- 24,000 m^3s^{-1}, Jaime *et al*., 2002), and the main El Niño (●) and La Niña (○) years, B) daily freshwater discharge between June and December of 1999 and the turbidity spatial distribution.

3.1) Fish diversity

A total of 119 fish species (24 Chondrichthyes and 95 Osteichthyes), belonging to 25 order and 64 families inhabit the Río de la Plata estuary (Boschi (1988) and Cousseau (1985). Within the Osteichthyes, *Acipenser baerii baerii*, *Cyprinus carpio* and *Oreochromis niloticus*, are invader species (Cousseau, 1985; Boschi, 1988; Jaureguizar *et al*., 2003; Jaureguizar, 2004; Solari, *et al*. 2009; García *et al.*, 2010, 2011). Along the main estuarine axis from deep water to freshwater, there is a decreasing in the number of species mainly related with the diminishing of salt water intrusion (Boschi, 1988; Cousseau 1985) and the inner and outer salinity boundary of estuarine waters coincide with minimum (among riverine and estuarine fish assemblages) and maximum (among the estuarine and coastal shelf fish assemblages) of species richness (Margalef index; Ludwig & Reynolds, 1998), respectively (Barletta *et al*., 2010).

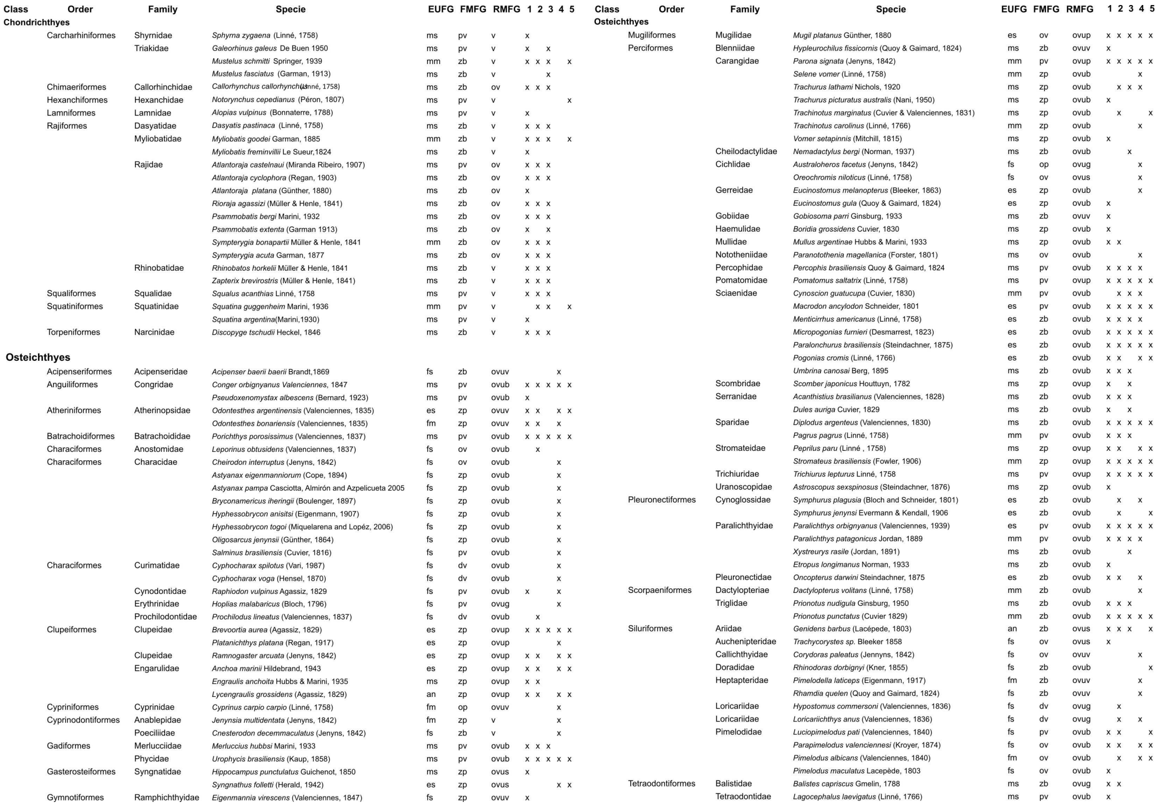
Following the functional group classification suggested by Elliot *et al.* (2007), based on Estuarine Use, Feeding Mode and Reproductive Mode, on the presence/absence species data (Cousseau, 1985; Jaureguizar *et al*., 2003, 2004, 2006) show that the Río de la Plata estuary is dominated for marine stragglers species (44.5%), followed by freshwater stragglers species (23.5%), estuarine species (15.1 %), marine migrants species (10.9%), and with lower percentage anadromous (1.7%) and freshwater migrants (4.2%). The first three groups represent more than 80% of fish species within the Río de la Plata, and the dominance of marine species is related to scale of estuarine area (38000 km^2) and the mouth length (~257 km) that allow the intrusion of marine species along the salinity penetration and even occurs, forced by the wind and low freshwater discharge condition, marine species associated to subtropical water masses as *Balistes capriscus* (García & Menni, 1982), *Dactylopterus volitans* (Devincenzi, 1920), *Eucinostomus melanopterus* (Solari *et al*., 2010), *Selene vomer* and *Lagocephalus laevigatus* (Cousseau, 1985) and *Trachinotus carolinus*. In general, the presence of freshwater stragglers species (n=28 species) is associated to shallow water or tributaries rivers (Río Salado, Río Samborombón, Río Santa Lucia, freshwater channels) and in deeper water its presences is sporadic and associated to low salinity spread forced high freshwater discharge or with natural processes of biology of species (*Prochilodus lineatus, Salminus brasiliensis*). The occurrence of anadromous species is related to use of it as nursery are during spring and summer (*Genidens barbus*) or spawning area during autumn (*Lycengraulis olidus*) (Fuster de Plaza & Boschi, 1961; Ringuelet *et al*., 1967).

At feeding mode functional group, the Río de la Plata is dominated by zoobenthivores (35.3%), followed by zooplanktivores (26.9%) and piscivores (23.5.8%). Most of the freshwater species are zooplanktivores (27%) or omnivores (24%), followed by detritivores (15%) mainly feeding on copepods, diatoms and organic detritus (*e.g*. Milessi, 2008). Wile the freshwater migrant species are mainly zooplanktivores (40%), the freshwater straggler species are zooplanktivores (25%) or omnivores (25%). Particularly the *Astyanax* genus has wide trophic spectrum, and they has been considered as carnivores (Ringuelet, 1975) insectivores (Gonzo *et al*., 1998; Barros *et al*., 2001), zooplanktivores (Grosman *et al*., 1996) or omnivores (Arcifa *et al*., 1991; Vales & Haro, 1998) indicating that the feeding mode change with the food availability. The estuarine species are dominated by zooplanktivores (44.4%) and zoobenthivores (38.4%) and in a lesser degree piscivores (11.1%), which the main preys are bivalves and gasteropds, mysids and small crustaceans such us shrimps. Within this functional group there is one omnivore (*Mugil platanus*) and one piscivore (*Macrodon ancylodon*) that feed on diatoms and copepods and small pelagic respectively (Ciechomski, 1981). The more abundant estuarine species (*Micropogonias furnieri*, *Macrodon ancylodon*, *Paralonchurus brasiliensis*) are mainly zoobenthivores at small size length (<10 mm LT) and change the feed habit with increasing size length, as *Micropogonias furnieri* where the individual shorter than 100 mm consumes mysids (*Neomysis americana*) and shrimps (*Peisos petrunkevitchi*, *Artemesialonginaris*) and the larger individual mainly prey upon bivalve mollusks (*Mactra isabelleana*) and secondarily upon shrimps, cephalopods and polychaetes (Sánchez *et al*., 1991; Giberto *et al.*, 2007), or *Macrodon ancylodon* that after 100 mm of length size progressively change from mysids (*Neomysis americana*) to epibenthic (*Peisos petrunkevitchi*, *Artemesia longinaris*) and nektonic organism (*Engraulis anchoita* and *Anchoa marinii*), or *P. brasiliensis* where the larger individual mainly prey upon polychaetes (*Onuphis* sp) (Giberto, 2008). The marine, just migrant or stragglers, species are mainly zoobenthivore (38.5 and 45.3% respectively) and piscivores (38.5% and 32.1% respectively). They consumes principally crustaceans, polychaetes (Goldstein & Cousseau, 1987) and small pelagics, small demersal fishes and others fishes (*e.g.* *Squatina guggenheim*: Vögler *et al*., 2003; *Percophis brasiliensis*: Milessi & Marí, in press; *Urophycis brasiliensis*: Acuña *et al*., 2007; *Atlantoraja castelnaui;* Paesch, 2000; *Zapterix brevirrostris:* Barbini *et al*., 2011, 2006; *Discopyge tschudii:* García, 1984). The Río de la Plata fish community is mainly sustained by organism related to bottom, and a transect from freshwater to marine water reflect a transition from a fish community influenced by muddy deposits originating from the river, where the community is dominated by bottom or detritus feeders indicating that main energy flow is coming from the detritus, to a fish community where energy flow originating from the bottom deposits is probably less import and the zooplankton production becomes more important (Garcia *et al*., 2010).

Since the reproductive mode, 78% of species in the Río de la Plata estuarine area are ovuliparous (ovu, species that produces ovules that are liberated into the surrounding waters), followed by species viviparous (14.3%) and oviparous (7.6%). The ovuliparous species present diverse modes, the mostly of species produce ovules, which when fertilized, produced eggs which settle on the substratum (65.4%, ovub), followed by species that produces ovules, which when fertilized, produced pelagic eggs (14%, ovup) or produces adhesive eggs that become attached to substrata and/or vegetation (10.8%). In the freshwater species, while the most straggler species (60,7%, ovub) produce ovules, which when fertilized, produced eggs which settle on the substratum, the freshwater migrant species (60%) produces adhesive eggs that become attached to substrata and/or vegetation (ovub) (as *Cyprinus carpio carpio*, *Odontesthes bonariensis*, *Pimelodella laticeps*). There are only two freshwater viviparous species, *Jenynsia multidentata* (migrant) and *Cnesterodon decemmaculatus* (straggler), only freshwater stragglers (21.5%) shows egg with parent protects, just one or the other parent guards their eggs externally (*Australoheros facetus, Hoplias malabaricus, Hypostomus commersoni, Loricariichthys anus*) or protects their eggs for a period in the mouth (*Oreochromis niloticus*, *Trachycorystes* sp.). The estuarine species mainly produces ovules, which when fertilized, produced eggs which settle on the substratum (61.1%) or produced pelagic eggs (27.8%) which spawning area within the estuary is related to salinity front (*e.g. Micropogonias furnieri*, *Macrodon ancylodon*, *Pogonias cromis*, *Brevoortia aurea*, *Ramnogaster arcuata*) or does not related to salinity front (*e.g. Paralonchurus* *brasiliensis* and *Menticirrhus americanus*) (see below). There are only one species that produce ovules, which when fertilized, the male protects their eggs for a peRíod in an incubation bag (*Syngnathus folletti*) and one species that produces adhesive eggs that become attached to substrata and/or vegetation (*Odontesthes argentinensis*), and in both cases mainly inhabit the inshore water of Bahía Samborombón (Lasta, 1995) that offer extensive flooding plain and vegetation that conferred protection to water current and abundant food. The male of *Syngnathus folletti* incubates egg produced by ovocites from different female, and the individual of Río de la Plata presents until three time of number of egg than the male form Brasil (Garcia *et al*., 2008). The marine species are mainly ovuliparus (47%) that produce ovules, which when fertilized, settle on the substratum (ovub), and viviparous (22.7%), and within the marine straggler there are tow species that show some kind of parent protection, *Balistes capriscus* (guards their eggs externally) and *Hippocampus punctulatus* (protects their eggs for a period in a part of their body). The marine migrant present the spawning or mating area just in the adjacent water to Río de la Plata, just in open coastal waters (*Cynoscion guatucupa*, *Paralichthys patagonicus*, *Prionotus punctatus*, *Parona signata*, see details below) or in the nearshore waters along Uruguay and Argentina coast (*Mustelus schmitti*, *Myliobatis goodei*, *Squatina guggenheim*, see below) and the juveniles of this species are mainly found in the Río de la Plata water.

Table 1; List of species indicating the Estuarine Use [estuarine (es), marine stragglers (ms), marine migrants (mm), freshwater stragglers (fs), freshwater migrants (fm), anadromous (an)] and Feeding Mode functional groups [detritivores (dv), Miscellaneous/ opportunist (OP), omnivores (OV), piscivores (pv), zoobenthivores (zv), zooplanktivore (zp)] classification suggested by Elliot *et al.* (2007), and Reproductive Mode functional groups [viviparous (v) species in which the female produces live progeny; oviparous (o) producing eggs that are liberated into the surrounding waters; ovuliparus (ovu) Species in which the female produces ovules that are liberated into the surrounding waters. The species in this group can be subdivided into the following five categories: Ovup Species producing ovules, which when fertilized, produced pelagic eggs; Ovub Species producing ovules, which when fertilized, produced eggs which settle on the substratum; Ovuv

Species producing ovules, which when fertilized, produced adhesive eggs that become attached to substrata and/or vegetation; Ovug Species producing ovules, which when fertilized, one or the other parent guards their eggs externally; Ovus Species producing ovules, which when fertilized, one or the other parent protects their eggs for a peRíod in a part of their body.



Class	Order	Family	Specie	EUFG	FMFG	RMFG	1	2	3	4	5
Chondrichthyes											
	Carcharhiniformes	Shyrnidae	*Sphyrna zygaena* (Linné, 1758)	ms	pv	v	x				
		Triakidae	*Galeorhinus galeus* De Buen 1950	ms	pv	v	x		x		
			Mustelus schmitti Springer, 1939	mm	zb	v	x	x	x		x
			Mustelus fasciatus (Garman, 1913)	ms	zb	v			x		
	Chimaeriformes	Callorhinchidae	*Callorhynchus callorhynchus* (Linné, 1758)	ms	zb	ov	x	x	x		
	Hexanchiformes	Hexanchidae	*Notorynchus cepedianus* (Péron, 1807)	ms	pv	v					x
	Lamniformes	Lamnidae	*Alopias vulpinus* (Bonnaterre, 1788)	ms	pv	v	x				
	Rajiformes	Dasyatidae	*Dasyatis pastinaca* (Linné, 1758)	ms	zb	v	x	x	x		
		Myliobatidae	*Myliobatis goodei* Garman, 1885	mm	zb	v	x	x	x		x
			Myliobatis freminvillii Le Sueur,1824	ms	zb	v	x				
		Rajidae	*Atlantoraja castelnaui* (Miranda Ribeiro, 1907)	ms	pv	ov	x	x	x		
			Atlantoraja cyclophora (Regan, 1903)	ms	zb	ov	x	x	x		
			Atlantoraja platana (Günther, 1880)	ms	zb	ov	x				
			Rioraja agassizi (Müller & Henle, 1841)	ms	zb	ov	x	x	x		
			Psammobatis bergi Marini, 1932	ms	zb	ov	x	x	x		
			Psammobatis extenta (Garman 1913)	ms	zb	ov	x		x		
			Sympterygia bonapartii Müller & Henle, 1841	mm	zb	ov	x	x	x		
			Sympterygia acuta Garman, 1877	ms	zb	ov	x	x	x		
		Rhinobatidae	*Rhinobatos horkelii* Müller & Henle, 1841	ms	zb	v	x	x	x		
			Zapterix brevirostris (Müller & Henle, 1841)	ms	zb	v	x	x	x		
	Squaliformes	Squalidae	*Squalus acanthias* Linné, 1758	ms	pv	v	x	x	x		
	Squatiniformes	Squatinidae	*Squatina guggenheim* Marini, 1936	mm	pv	v		x	x		x
			Squatina argentina(Marini,1930)	ms	pv	v	x				
	Torpeniformes	Narcinidae	*Discopyge tschudii* Heckel, 1846	ms	zb	v	x	x	x		
Osteichthyes											
	Acipenseriformes	Acipenseridae	*Acipenser baerii baerii* Brandt,1869	fs	zb	ovuv				x	
	Anguiliformes	Congridae	*Conger orbignyanus Valenciennes*, 1847	ms	pv	ovub	x	x	x	x	x
			Pseudoxenomystax albescens (Bernard, 1923)	ms	pv	ovub	x				
	Atheriniformes	Atherinopsidae	*Odontesthes argentinensis* (Valenciennes, 1835)	es	zp	ovuv	x	x		x	x
			Odontesthes bonariensis (Valenciennes, 1835)	fm	zp	ovuv	x	x		x	
	Batrachoidiformes	Batrachoididae	*Porichthys porosissimus* (Valenciennes, 1837)	ms	pv	ovub	x	x	x	x	x
	Characiformes	Anostomidae	*Leporinus obtusidens* (Valenciennes, 1837)	fs	ov	ovub		x			
	Characiformes	Characidae	*Cheirodon interruptus* (Jenyns, 1842)	fs	ov	ovub				x	
			Astyanax eigenmanniorum (Cope, 1894)	fs	zp	ovub				x	
			Astyanax pampa Casciotta, Almirón and Azpelicueta 2005	fs	zp	ovub				x	
			Bryconamericus iheringii (Boulenger, 1897)	fs	zp	ovub				x	
			Hyphessobrycon anisitsi (Eigenmann, 1907)	fs	zp	ovub				x	
			Hyphessobrycon togoi (Miquelarena and Lopéz, 2006)	fs	zp	ovub				x	
			Oligosarcus jenynsii (Günther, 1864)	fs	zp	ovub				x	
			Salminus brasiliensis (Cuvier, 1816)	fs	pv	ovub				x	
	Characiformes	Curimatidae	*Cyphocharax spilotus* (Vari, 1987)	fs	dv	ovub				x	
			Cyphocharax voga (Hensel, 1870)	fs	dv	ovub				x	
		Cynodontidae	*Raphiodon vulpinus* Agassiz, 1829	fs	pv	ovub	x			x	
		Erythrinidae	*Hoplias malabaricus* (Bloch, 1796)	fs	pv	ovug				x	
		Prochilodontidae	*Prochilodus lineatus* (Valenciennes, 1837)	fs	dv	ovub		x			
	Clupeiformes	Clupeidae	*Brevoortia aurea* (Agassiz, 1829)	es	zp	ovup	x	x	x	x	x
			Platanichthys platana (Regan, 1917)	es	zp	ovup				x	
		Clupeidae	*Ramnogaster arcuata* (Jenyns, 1842)	es	zp	ovup	x	x		x	x
		Engarulidae	*Anchoa marinii* Hildebrand, 1943	es	zp	ovup	x	x		x	x
			Engraulis anchoita Hubbs & Marini, 1935	ms	zp	ovup	x	x			
			Lycengraulis grossidens (Agassiz, 1829)	an	zp	ovup	x	x		x	x
	Cypriniformes	Cyprinidae	*Cyprinus carpio carpio* (Linné, 1758)	fm	op	ovuv				x	
	Cyprinodontiformes	Anablepidae	*Jenynsia multidentata* (Jenyns, 1842)	fm	zp	v				x	
		Poeciliidae	*Cnesterodon decemmaculatus* (Jenyns, 1842)	fs	zb	v				x	
	Gadiformes	Merlucciidae	*Merluccius hubbsi* Marini, 1933	ms	pv	ovub	x	x	x		
		Phycidae	*Urophycis brasiliensis* (Kaup, 1858)	ms	pv	ovub	x	x	x	x	x
	Gasterosteiformes	Syngnatidae	*Hippocampus punctulatus* Guichenot, 1850	ms	zp	ovus	x				
			Syngnathus folletti (Herald, 1942)	es	zp	ovus				x	x
	Gymnotiformes	Ramphichthyidae	*Eigenmannia virescens* (Valenciennes, 1847)	fs	zp	ovuv	x				
Osteichthyes											
	Mugiliformes	Mugilidae	*Mugil platanus* Günther, 1880	es	ov	ovup	x	x	x	x	x
	Perciformes	Blenniidae	*Hypleurochilus fissicornis* (Quoy & Gaimard, 1824)	ms	zb	ovuv	x				
		Carangidae	*Parona signata* (Jenyns, 1842)	mm	pv	ovup	x	x	x	x	x
			Selene vomer (Linné, 1758)	mm	zp	ovub				x	
			Trachurus lathami Nichols, 1920	ms	zp	ovub		x	x	x	
			Trachurus picturatus australis (Nani, 1950)	ms	zp	ovub	x				
			Trachinotus marginatus (Cuvier & Valenciennes, 1831)	ms	zp	ovub		x			x
			Trachinotus carolinus (Linné, 1766)	mm	zp	ovub				x	
			Vomer setapinnis (Mitchill, 1815)	ms	zp	ovub	x				
		Cheilodactylidae	*Nemadactylus bergi* (Norman, 1937)	ms	zb	ovub			x		
		Cichlidae	*Australoheros facetus* (Jenyns, 1842)	fs	op	ovug				x	
			Oreochromis niloticus (Linné, 1758)	fs	ov	ovus				x	
		Gerreidae	*Eucinostomus melanopterus* (Bleeker, 1863)	es	zp	ovub				x	
			Eucinostomus gula (Quoy & Gaimard, 1824)	es	zp	ovub	x				
		Gobiidae	*Gobiosoma parri* Ginsburg, 1933	ms	zb	ovuv	x				
		Haemulidae	*Boridia grossidens* Cuvier, 1830	ms	zp	ovub	x				
		Mullidae	*Mullus argentinae* Hubbs & Marini, 1933	ms	zp	ovub	x	x			
		Nototheniidae	*Paranotothenia magellanica* (Forster, 1801)	ms	ov	ovub				x	
		Percophidae	*Percophis brasiliensis* Quoy & Gaimard, 1824	ms	pv	ovub	x	x	x	x	
		Pomatomidae	*Pomatomus saltatrix* (Linné, 1758)	ms	pv	ovup	x	x	x	x	x
		Sciaenidae	*Cynoscion guatucupa* (Cuvier, 1830)	mm	pv	ovub		x	x	x	
			Macrodon ancylodon Schneider, 1801	es	pv	ovub	x	x	x	x	x
			Menticirrhus americanus (Linné, 1758)	es	zb	ovub	x	x	x	x	
			Micropogonias furnieri (Desmarrest, 1823)	es	zb	ovub	x	x	x	x	x
			Paralonchurus brasiliensis (Steindachner, 1875)	es	zb	ovub	x	x	x	x	x
			Pogonias cromis (Linné, 1766)	es	zb	ovub	x	x		x	x
			Umbrina canosai Berg, 1895	ms	zb	ovub	x	x	x		
		Scombridae	*Scomber japonicus* Houttuyn, 1782	ms	zp	ovup	x		x		
		Serranidae	*Acanthistius brasilianus* (Valenciennes, 1828)	ms	zb	ovub	x	x	x		
			Dules auriga Cuvier, 1829	ms	zb	ovub	x		x		
		Sparidae	*Diplodus argenteus* (Valenciennes, 1830)	ms	zb	ovub	x	x	x	x	x
			Pagrus pagrus (Linné, 1758)	mm	pv	ovub	x	x	x		
		Stromateidae	*Peprilus paru* (Linné , 1758)	ms	zp	ovup	x	x		x	x
			Stromateus brasiliensis (Fowler, 1906)	mm	zp	ovup	x	x	x	x	x
		Trichiuridae	*Trichiurus lepturus* Linné, 1758	ms	pv	ovup	x	x	x	x	x
		Uranoscopidae	*Astroscopus sexspinosus* (Steindachner, 1876)	ms	zp	ovub	x				
	Pleuronectiformes	Cynoglossidae	*Symphurus plagusia* (Bloch and Schneider, 1801)	es	zb	ovub		x		x	
			Symphurus jenynsi Evermann & Kendall, 1906	es	zb	ovub		x			x
		Paralichthyidae	*Paralichthys orbignyanus* (Valenciennes, 1939)	es	pv	ovub	x	x	x	x	x
			Paralichthys patagonicus Jordan, 1889	mm	pv	ovub	x	x	x	x	
			Xystreurys rasile (Jordan, 1891)	ms	zb	ovub			x		
			Etropus longimanus Norman, 1933	ms	zb	ovub	x				
		Pleuronectidae	*Oncopterus darwini* Steindachner, 1875	es	zb	ovub	x	x		x	
	Scorpaeniformes	Dactylopteriae	*Dactylopterus volitans* (Linné, 1758)	mm	zb	ovub				x	
		Triglidae	*Prionotus nudigula* Ginsburg, 1950	ms	zb	ovub	x	x	x		
			Prionotus punctatus (Cuvier 1829)	mm	zb	ovub	x	x	x	x	x
	Siluriformes	Ariidae	*Genidens barbus* (Lacépede, 1803)	an	zb	ovus	x	x	x		x
		Auchenipteridae	*Trachycorystes sp.* Bleeker 1858	fs	ov	ovus	x				
		Callichthyidae	*Corydoras paleatus* (Jennyns, 1842)	fs	ov	ovuv				x	
		Doradidae	*Rhinodoras dorbignyi* (Kner, 1855)	fs	zb	ovub					x
		Heptapteridae	*Pimelodella laticeps* (Eigenmann, 1917)	fm	zb	ovuv				x	
			Rhamdia quelen (Quoy and Gaimard, 1824)	fs	zb	ovuv				x	
		Loricariidae	*Hypostomus commersoni* (Valenciennes, 1836)	fs	dv	ovug		x			
		Loricariidae	*Loricariichthys anus* (Valenciennes, 1836)	fs	dv	ovug		x		x	
		Pimelodidae	*Luciopimelodus pati* (Valenciennes, 1840)	fs	pv	ovub	x	x			x
			Parapimelodus valenciennesi (Kroyer, 1874)	fs	ov	ovub	x	x		x	x
			Pimelodus albicans (Valenciennes, 1840)	fm	ov	ovub		x		x	x
			Pimelodus maculatus Lacepède, 1803	fs	ov	ovub	x				
	Tetraodontiformes	Balistidae	*Balistes capriscus* Gmelin, 1788	ms	zb	ovug	x	x			
		Tetraodontidae	*Lagocephalus laevigatus* (Linné, 1766)	ms	pv	ovub	x				

3.2) Fish community structure

The environmental gradient from deep marine water to shallow freshwater is very strong (Fig. 1) with some bottom fishes species restricted to a particular section of it, demonstrating particular distribution pattern of the ichthyofaunal composition (Barletta *et al*., 2010; García *et al*., 2010; Jaureguizar *et al*., 2003a; 2004; 2006b; Lorenzo Pereiro, 2007). Three fish assemblage areas (Inner, Central, Outer), with persistent specific composition and mainly linked to particular salinity habitats have been defined along the main axis of the estuary throughout the year (Jaureguizar *et al*., 2003a, 2004; García *et al*., 2010). Their spatial differences in the species composition reflect the recruitment of marine species toward the head of the estuary, allowed by the shelf water intrusion along the bottom, where the fish assemblage is dominated mostly by freshwater species (Fig. 3).

The Inner area includes the stations from the inner Río de la Plata estuarine zone, has the shallowest depth range, the minimum bottom salinities ranging from 0.5 to 15, and has the maximum bottom salinity horizontal gradient and partial vertical salinity stratification for all seasons (Fig. 3). The heterogeneity of their ichthyofaunal is shown by the affinity of freshwater stragglers (*Luciopimelodus pati* and *Parapimelodus valenciennesi*), anadromous species (*Genidens barbus*), together with estuarine species (*Micropogonias furnieri*, *Macrodon ancylodon* and *Brevoortia aurea*). Fishes associated with the Central Area, with intermediate depth range (means from 9.9 to 10.76 m), intermediate salinities (between 14 and 29) and highest vertical saline stratification, were mainly estuarine species (*Micropogonias furnieri*, *Brevoortia aurea, Macrodon ancylodon*, *Paralonchurus brasiliensis*, *Paralichthys orbignyanus, Mugil sp*., *Menticirrhus americanus*). It shows great overlap of its fish composition, in particular, with marine species of the Outer Area. The Outer Area cover the deepest zone in the estuary (means from 12.63 to 16 m), with salinities (between 25 and 34), and maximum surface salinity horizontal gradient and partial salinity stratification. The fishes associated with the Outer Area were marine species, either migrant (*Cynoscion guatucupa*, *Paralichthys patagonicus*, *Mustelus schmitti*, *Sympterygia bonapartii*, *Stromateus brasiliensis*, *Squatina guggenheim*, *Myliobatis goodei* and *Prionotus punctatus*) or stragglers (*Conger orbignyanus*, *Discopyge tschudii*, *Percophys brasiliensis*, *Atlantoraja castelnaui*) (Jaureguizar *et al*., 2003a, 2004, 2006).

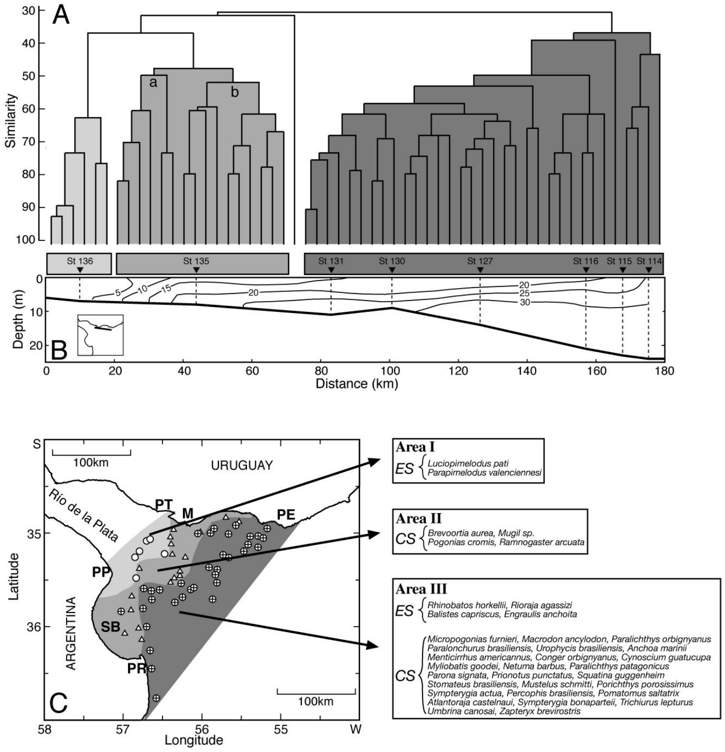


Figure 3. (A) Dendrogram of the cluster analysis results corresponding to summer, (B) location of the groups on the distribution of the salinity along of Sampling Station (St) on the north transect of high resolution. (C) Area of distribution of the groups [Inner (I) Central (II) and Outer (III) Areas] and species affinity [(ES) Exclusive species, (CS) Common species] corresponding to each group (Jaureguizar *et al*., 2004).

The fish assemblages show consistent seasonal and temporal boundaries, which occur near the location of the frontal zone (García *et al.*, 2003; Barletta *et al.*, 2010; Jaureguizar, 2004; Jaureguizar *et al*., 2003b, 2004, 2006b). The border among the Inner and Central area is near the location where the halocline intersects the bottom (Figs. 1 and 3), and corresponds to the bottom salinity front (Guerrero *et al*., 1997a). This represents the boundary for intrusions of freshwater species into the estuary (*Pimelodus maculatus*, *L. pati*, *P. valenciennis*, *L. obtusidens*, *P. lineatus* and species of Loricariidae) and the incursion of marine species toward the head of the estuary through the shelf water intrusion along the bottom (Boschi, 1988; Jaureguizar, 2004; Jaureguizar *et al*., 2003b, 2004, 2006b). The intrusions degree of freshwater and marine species to estuary is determined by the vertical stratification of water column (DCCA, Figure 4). When the Río de la Plata shows strong stratification (Transect I, Fig. 4), it allows a maximum intrusion of freshwater (*e.g. Pimelodus maculatus*, Loricariidae spp) and marine species (*Cynoscion guatucupa*) to estuary. As the vertical stratification are broken, and the water column begin to be homogenous (the isohaline are more vertical, from transect I to transect III), the Río de la Plata show lesser incursion of freshwater and marine species and the inner zone is more dominated by estuarine species (*Micropogonias furnieri*, *Brevoortia aurea*, *Macrodon ancylodon*, *Paralonchurus brasiliensis, Mugil sp*.) (Figure 4). The border zone between the central and outer area (Fig. 3) coincides with the location of the maximum horizontal gradient of surface salinity (Guerrero *et al*., 1997a), indicating the boundary between the estuary and the continental coastal waters (Jaureguizar *et al*., 2007). This zone is the limit for the presence in the estuary of marine species (*Balistes capriscus, Engraulis anchoita,Ríoraja agassizi, Rhinobatos horkelii, Oncopterus darwini, Mullus argentinus, Psammobatis bergi, Sparus pagrus, Trachinotus marginatus, Merluccius hubbsi, Trachurus lathami, Callorhynchus callorhynchus* and *Dasyaatis spp*.) (Jaureguizar *et al*., 2003).

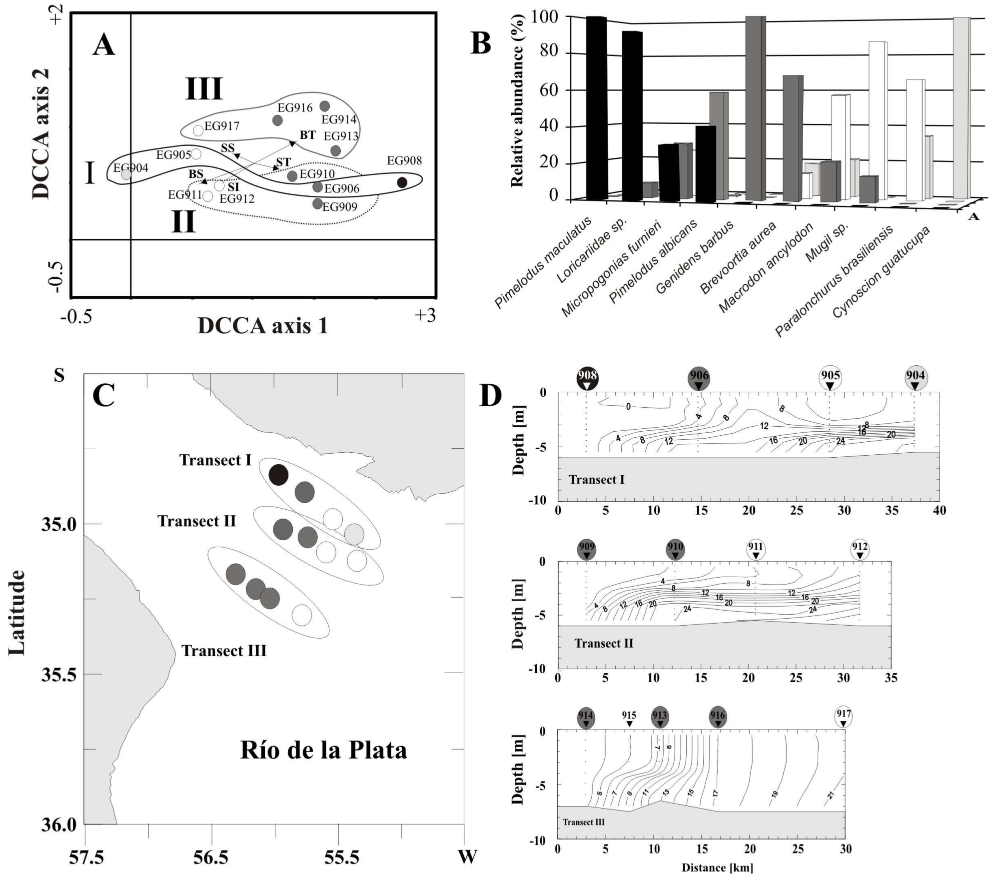


Figure 4. (A) Detrended Canonical Analysis ordination diagram of the sampling stations corresponding to spring, showing the station groups (color) defined for axis 1 of DCCA and its correspondent transect, (B) their average composition, (C) area of distribution and (D) location of the groups on the distribution of the salinity along of sampling station

At seasonal and temporal scale the fish assemblages are persistent in specific composition, and the geographic variations of the boundaries indicate contraction or expansion of fish assemblage areas associated with water masses dynamics, as a consequence of river flow and winds (Jaureguizar *et al.*, 2003a, 2004, 2006). The seasonal changes observed in the fish assemblages composition suggest that these are caused mainly by seasonal migrations, as a result of salinity and temperature variations (*e.g.*, *Trichiurus lepturus* and *Discopyge tschudii*) and reproductive movements (*Micropogonias furnieri*, *Mustelus schmitti* and *Cynoscion guatucupa*) to spawning and mating areas (Jaureguizar *et al*., 2004). *Trichiurus lepturus* is a benthopelagic teleost abundant in the continental shelf of southern Brazil (Haimovici *et al*., 1989), and its higher densities in the Río de la Plata estuarine water is associated with the penetration of subtropical continental water masses during warm peRíods forced by the southward flow of southern Brazil water (Jaureguizar *et al*., 2004). While, decreasing temperature in the outer estuarine zone as consequence of cold (<16°C) shelf water intrusion from the south are associated with relatively large densities of *Discopyge tschudii* (Jaureguizar *et al*., 2004; Cortés *et al*., 2011). The seasonal variation in the spatial coverage of fish assemblage areas (Jaureguizar *et al*., 2003a, 2004) reflects the seasonal discharge pattern of the Río de la Plata (Fig. 5, Guerrero *et al*., 1997b). During autumn and winter, river discharge is highest and continental winds almost neutralize marine winds. Without wind stress the continental runoff is affected only by the Coriolis force, and the river turns north along the Uruguayan coast. During these seasons the Central Area is mainly extended along the Uruguayan coast, reaching Punta del Este during winter, and there is an intrusion of Outer Area on the Argentine coast. During spring and summer, the marine winds overcome continental winds and Ekman drift forces waters southward generating a flow of freshwater along the Argentine coast, passing Punta Médanos (Guerrero *et al*., 1997a). In this season, the Central Area show a retraction along the Uruguayan coast, and the Outer Area can get the location near to Montevideo (Fig. 5).

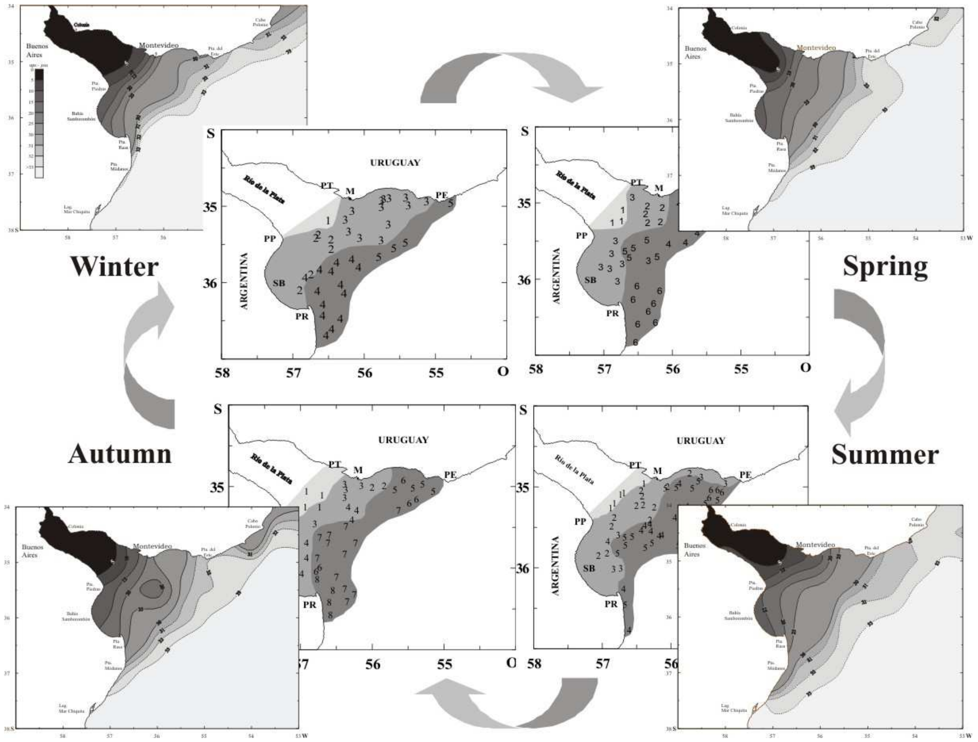


Figure 5 Seasonal spatial distribution of bottom salinity (Guerrero *et al*., 1997b) and fish assemblage areas (Jaureguizar *et al*., 2004).

The changes in the environmental conditions on the coastal system, in particular, the influence of high freshwater discharge (flow) of the Río de la Plata during El Niño years, associated with high precipitation (Robertson and Mechoso, 1998; Camilloni and Barros, 2000), produced a movement of the estuarine assemblage areas to the coastal shelf (years 1983 and 1998, Fig. 6). Depending of the spring dominant wind pattern, their expansion is along the main axis of the estuary (1998) or along the Argentine coast (1983). Also, decreases in the freshwater discharge of the Río de la Plata estuary during La Niña years produced upriver movement of the estuarine assemblage areas (years 1981 and 1999, Fig. 6) and the marine fish assemblages areas cover a greater portion of the estuary. Under normal freshwater discharge, the boundaries of the fish assemblages were relatively more stable (Jaureguizar *et al*., 2006).

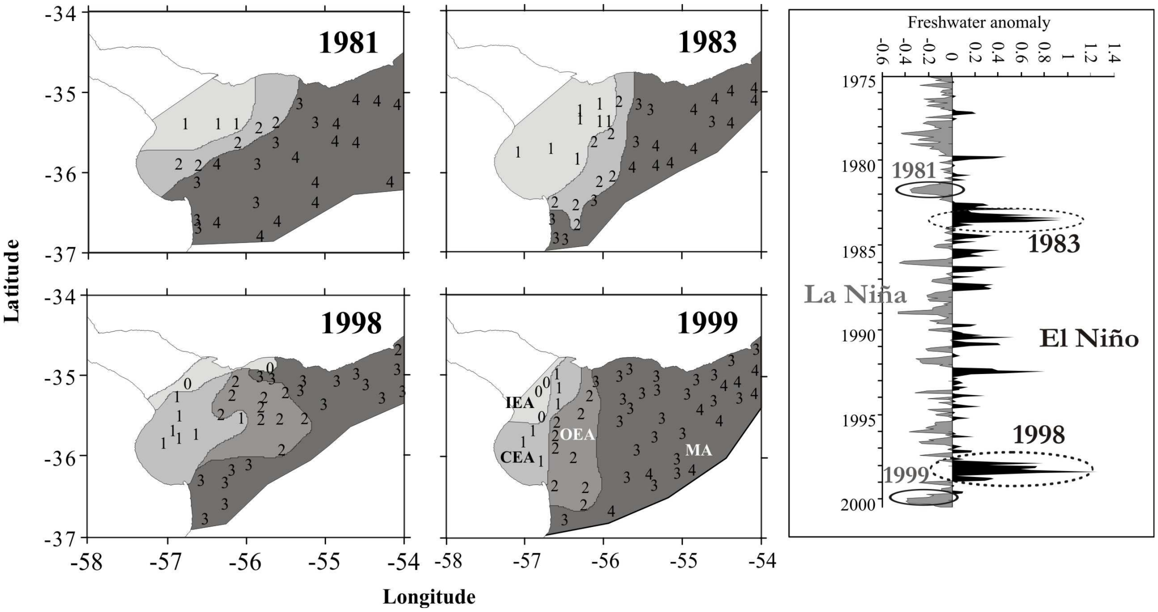


Figure 6 Spring spatial distribution of the fish assemblage areas [Inner (IEA), Central (CEA), Outer (OEA) Estuarine Areas, Marine Area (MA) from Jaureguizar *et al*., 2006) and freshwater anomaly of Río de la Plata

Spring ECOPATH models for Río de la Plata estuarine system (considering 25 groups of species, Fig. 7) during the expansion (1998 year, 0.651 pedigree index) and contraction (1999 year, 0.658 pedigree index) time indicates that the differences in the spatial coverage of the fish assemblage do not have impact in the trophic structure of estuarine ecosystem (Table 1). Total biomass, TST, total primary production, ascendancy and others ecosystems indicators do not changes significantly among models. However, annual consumption by each species-group decreased for instance total consumption marginally decreased (~7%), perhaps because to the presence of lower sea temperatures. Consumption by demersal fish significantly decreased in 1999. When aggregated by trophic level, consumption significantly decreased in all trophic levels. Increases in the sum of consumption and exports are counterbalanced by a significant decrease in the sum of all flows to detritus (and a decrease in the sum of respiratory flows), resulting in no net difference in the size of these systems.

There are also not differences in the sum of all production, net system production, or calculated primary production, but Trophic Transfer Efficiency (TTE) show that the ecosystem is more efficient during contraction (1999, 14.0%) than expansion (1998, 16.5%) situation (Table 1). The high PP/R ratio (1.807 and 1.994) and low Ascendancy (A, 33.1 and 35.4%) indicate a rather underdeveloped state of the Río de la Plata estuarine system. These metrics likely result from the disturbance of high frequency resulting from the intermittent extension of intermediate zone in which the community of organisms are involved. This could preclude the system to reach a developed state; or alternatively, affects attributes in a way that they do not fit into the ecosystem classification scheme proposed by Odum (1969). Estimated TTE and the high overhead (~65%) also point in the same direction, further suggesting that the Río de la Plata estuarine system has high potential for adaptation and resilience capacity.

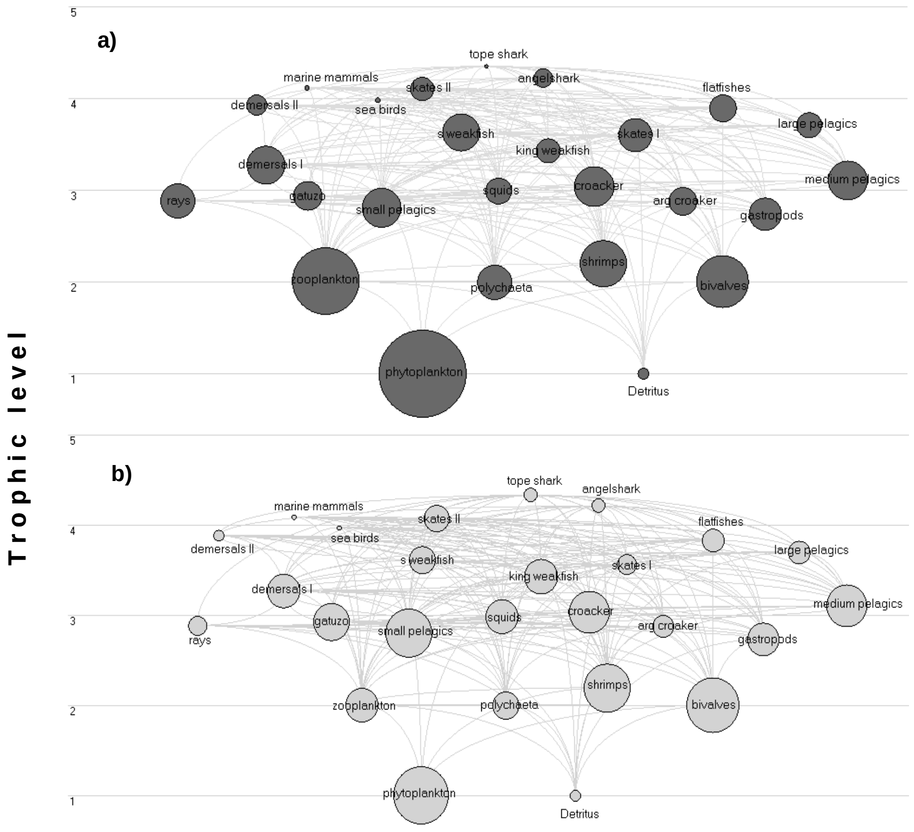


Figure 7. Trophic interactions and wet mass fluxes within the trophic web of Río de la Plata estuarine system. Its position in the axis y is given by its trophic level and the

compartment area is a function of the biomass. Flows are given in t km^{-2} year^{-1} a) 1998 and b) 1999.

Table 2. Summary statistics after mass balancing and network flow indices for Río de la Plata models years 1998 and 1999.

Ecosystem Statistics	**1998**	**1999**	**units**
Sum of all consumption	1058,27	988,37	t/km^2/year
Sum of all exports	293,24	363,17	t/km^2/year
Sum of all respiratory flows	768,42	697,64	t/km^2/year
Sum of all flows into detritus	451,56	457,51	t/km^2/year
Total system throughput	2572	2507	t/km^2/year
Sum of all production	1581	1594	t/km^2/year
Mean trophic level of the catch	3,34	3,23	
Gross efficiency (catch/net p.p.)	0,000146	0,000126	
Calculated total net primary production	1388,58	1391,09	t/km^2/year
Total primary production/total respiration	1,807	1,994	
Net system production	620,16	693,45	t/km^2/year
Total primary production/total biomass	16,41	16,67	
Total biomass/total throughput	0,033	0,033	
Total biomass (excluding detritus)	84,60	83,45	t/km^2
Total catches	0,202	0,175	t/km^2/year
Connectance Index	0,355	0,36	
System Omnivory Index	0,293	0,263	
Pedigree	0,651	0,658	
Transfer efficiencies	16,50%	14,00%	
PPR (%)	2,44	1,33	
Ascendency	3478,5 (33,1)	3395 (35,4)	
Overhead	7018,6 (66,9)	6194,9 (64,6)	

3.3) Fish population structure

The seasonal and inter-annual spatial distribution of fish species, at different stage of its life history, reflect the combined influence of distribution of coastal shelf water masses along the Southwestern Atlantic Coastal System (SWACS) and the discharge pattern of Río de la Plata, which dynamic is coupled to the wind seasonality and regulated by the bathymetry and the Coriolis force (Guerrero *et al*., 1997a; Lucas *et al*., 2005).

During winter, when cool and high salinity water covers a greater area of the SWACS, allows a wider northern distribution of marine species associated to shelf water (e.g. *Discopyge tschudii*, *Prionotus nudigula*) forcing their intrusion into the southbound of the Río de la Plata (Jaureguizar *et al*., 2004; Jaureguizar *et al*., 2007; Cortés *et al*., 2011). Due physiological constraint, the spatial distribution of *D. tschudii* is restricted to water with salinities higher than 32.2 (Cortés *et al*., 2011). During spring, the low salinity conditions in the adjacent waters of Río de la Plata along the Argentine coast produces a reduction in the northern flow of cool and high salinity waters, thus restricting the northern distribution of *D. tschudii* and *P. nudigula* and its intrusion into the Río de la Plata estuary (Cortés *et al*., 2011) and produce a offshore extended distribution of species associated to estuarine waters (*Prionotus punctatus*, Jaureguizar *et al*., 2007).

The inter-annual variation in the spatial distribution of fish species (*P. nudigula, D. tschudii*) is higher in spring than winter (Jaureguizar *et al*., 2007; Cortés *et al*., 2011). In *D. tschudii*, inter-annual spring spatial distribution demonstrates variations at regional scale (200 km, ~35%) in the coastal system distribution, been important in the area influenced by the Río de la Plata (north of 39ºS). Northward extension, that forces the *D. tschudii* intrusion in the Río de la Plata along bottom layer (spring 1994, 1999, and 2005), is forced by the advection of cold waters over coastal area which may be modulated by the strength and location of the Malvinas Current and predominant synoptic wind conditions. When spring dominant wind direction is from N-NE-E (1994, 1999, and 2005), warm and low saline (<28) surface waters (up to 10m) are pushed downstream from the upper part of estuary, and the mass transport is compensated by a net inflow of cold and saline (>30) bottom waters upstream the estuary. This forcing of *D. tschudii* bottom intrusion in the Río de la Plata is stopped by the progression of adverse wind conditions as it was observed during 1998 and 2003. In these springs, the dominance of S and SW winds pushed surface waters (up to 10m) upstream towards the upper part of the Río de la Plata, and the net outflow of warm and fresh bottom water downstream the estuary restricted the progression of *D. tschudii* intrusion or even forced them back into the coastal system (Cortés *et al.*, 2011).

Atlantic searobin species have a persistent spatial distribution pattern in the coastal ecosystem. *Prionotus punctatus* inhabits the environment influenced by estuarine waters of the Río de la Plata, while *P. nudigula* inhabits the coastal shelf system, with wider depth ranges, lower bottom temperatures and higher bottom salinity. Although both species show a persistent spatial distribution, the patterns change seasonally in an onshore/offshore direction, as well as in a north/south direction. Bottom salinity has the greatest influence on spatial distribution of both Atlantic searobins, with the variation of both distribution areas being mainly associated with the wind driven discharge of estuarine water from the Río de la Plata. The minimum winter intrusion of *P. nudigula* into the Río de la Plata estuary along the Argentine coast (year 1993) occurred when the offshore wind stress was weak (6.5 m s^{-1}) and freshwater discharge was maximum. When alongshore and offshore wind stress was the strongest (11.3 m s^{-1}) and the freshwater discharge was minimum, *P. nudigula* shows a maximum intrusion along the Argentine coast (year 2000). Under similar freshwater discharge (year 1996 with 19 800 m^3 s^{-1} and year 2000 with 21 227 m^3 s^{-1}), a lower intensity of offshore wind stress (7.2 m s^{-1}, 1996) produced an intermediate intrusion of *P. nudigula* along the Argentine coast (1996). Interannual variation in spring showed an opposite pattern to that of early winter. The minimum *P. punctatus* intrusion into the coastal system (1995) occurred when weak onshore wind stress was dominant (4.8 m s^{-1}), and the freshwater discharge was low. When alongshore wind stress dominated the area, and freshwater discharge was highest, the *P. punctatus* intrusion into the coastal system was maximum (1994). Under similar freshwater discharge (1999 with 18780 m^3 s^{-1} and 1995 with 19725 m^3 s^{-1}), the alongshore wind stress (5.8 m s^{-1}, year 1999) following an opposed wind condition drove an intermediate intrusion of *P. punctatus* into the coastal system (Jaureguizar *et al.*, 2007)

Although the entire life cycle of some estuarine (*i.e. M. furnieri*) and marine species (*e.g. Mustelus schmitti*, *Squatina guggenheim*, *Cynoscion guatucupa*, *Percophis brasiliensis, Paralichthys patagonicus*) seems to occur within the SWACS, life history stages show difference in habitat preferences that have been associated with ontogenetic movements from the nursery area to deeper waters through the development. Environmental variables have a significant influence on the life stage spatial pattern, been salinity more influent than temperature (Barreto, 2007; Jaureguizar *et al*., 2003a; 2006a; Vögler *et al*., 2008; Riestra, 2010; Cortés *et al*., 2011a). As observed in other costal system, including estuaries and bays, the selection of inshore water by neonates and juveniles [Río de la Plata: *M. furnieri*, Lasta 1995*;* Jaureguizar *et al*., 2003b; 2008a; Coastal shelf ecosystem: *M. schmitti*, Cortés *et al*., 2011a; *S. guggenheim*, Colonello *et al*., 2007, Vögler *et al*., 2008; *C. guatucupa*, Jaureguizar *et al*., 2006b; *P. brasilienesis*, Barreto, 2007; *P. patagonicus*, Riestra 2010] have been related to predator protection, food availability or environmental conditions which promote faster growth. Neonates and juveniles has show a persistent preference for inshore habitat through the seasons, while adults, during the reproductive seasons (austral spring-summer), show a penetration toward the inner area of estuarine ecosystem (*M. furnieri*) or inshore area of coastal ecosystem (*C. guatucupa*, *P. brasilienesis, P. patagonicus*, *M. schmitti, S. guggenheim*) from the offshore area to the spawning or mating area respectively.

The spatial distribution of *M. furnieri* stage (Fig. 8) shows that the juveniles occupy the inner and shallow waters of the RDP estuarine area and the adults been common toward the offshore regions (Cousseau *et al*., 1986; Díaz de Astarloa *et al*., 1997; Lasta, 1995; Jaureguizar *et al*., 2003b). This pattern is mainly influenced by bottom salinity spatial distribution (Jaureguizar *et al*., 2003b, 2008b). The juveniles persistently inhabit waters with low bottom salinity and depth coinciding with the estuarine turbidity maximum zone (ETM) (Jaureguizar *et al.*, 2003b). The relation of immature individuals to ETM could be associated to feeding benefits produced by an increase of abundance or the visual contrast of prey items (Chesney, 1989). The ETM (Fig. 8), a region of high *M. furnieri* larval abundance (Braverman *et al*., 2009), high plankton concentration (Mianzan *et al*., 2001; Kogan, 2005; Berasategui *et al*., 2006) and prey abundance (Giberto, 2001; Schiariti *et al.*, 2006), that offers juveniles protection from avian predation (Favero *et al*., 2000, 2001; Mauco *et al*., 2001), could link the two main nursery areas of the estuary, Samborombón Bay and Santa Lucia River (beside Punta Tigre) (Lasta, 1995; Jaureguizar *et al*., 2003b). During spring, there is adult stage penetration toward the inner area of RDP associated with reproductive movements from the outer zone to the spawning area (Machi *et al*, 1996; Jaureguizar *et al*., 2003b), whereas increase the size of individuals captured by the artisanal fishery of Pajas Blancas (near Montevideo, Uruguay) (Norbis *et al*., 1992). Spawning, which takes place between November and April, occurs in the inner zone (Macchi & Christiansen, 1996) and coincides geographically with the bottom salinity front (Macchi & Christiansen, 1996; Macchi, 1997; Acha *et al*., 1999; Militelli 2007; Jaureguizar *et al*., 2008a). Although juveniles and spawning individuals inhabit similar bottom salinity and depth (Fig. 8), the spawning individuals are more links to habitats with high Bottom Salinity Horizontal Gradient (BSHG) and moderate vertical stratification of the water column (SI) supporting that BSHG determines the spawning ground (Macchi, 1997; Jaureguizar *et al*., 2008a).

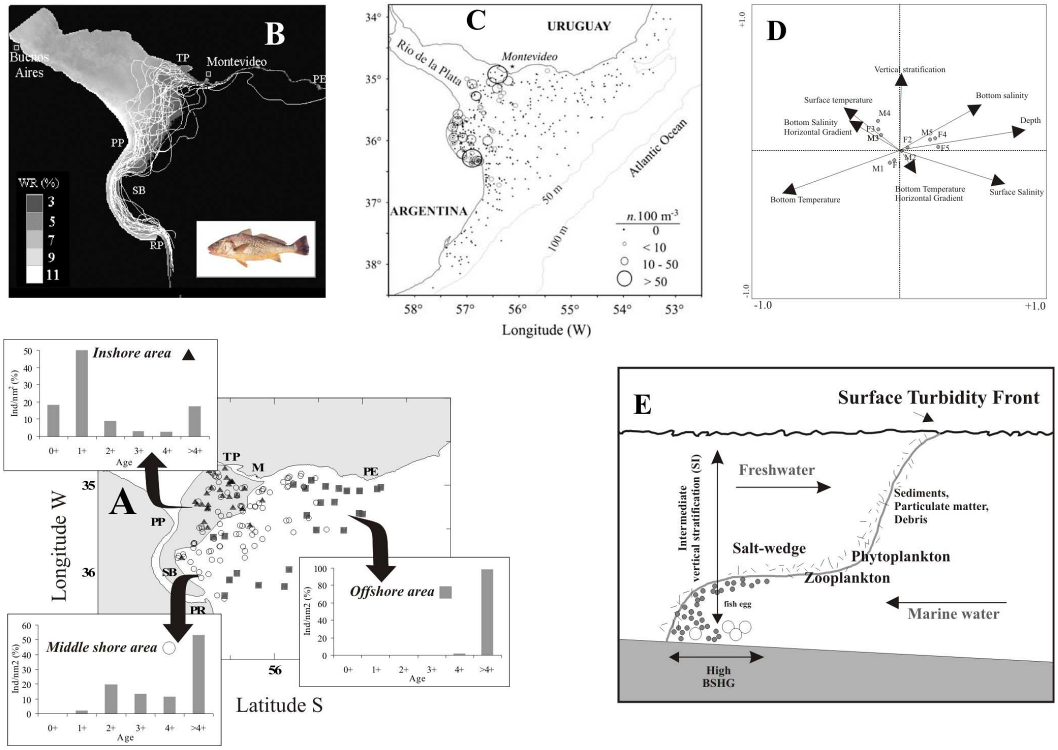


Figure 8 (A) Spring distribution areas of *Micropogonais furnieri* age-classes groups and (B) turbidity (%WR= percentage of water reflectance (Jaureguizar *et al*., 2003b), (C) larval distribution (Braverman *et al*., 2009), (D) environmental preference per sex [Male (M), Female (F)] and maturity stages [immature,1; developing and partially pent, 2; gravid (with hydrated oocytes) or running, 3; spent, 4; resting, 5)] (Jaureguizar *et al*., 2008a) , and (E) the schematic representation (Bava *et al*., 1996).

Micropogonias furnieri spawning strategy in the Río de la Plata is different from Brazilian coast (e.g. Patos Lagoon, Castello, 1986; Vieira & Castello, 1997; Sinque & Muelbert, 1997) which coincides with the general pattern that characterizes temperate marine fishes with estuarine dependence, spawning in marine areas and use of estuaries as nursery habitats (Day *et al.*, 1989; Potter & Hyndes, 1999; Nordlie, 2003). The spatial scale (38000 km^2) and stable environmental gradients of the Río de la Plata allow for a favorable combination of properties that guarantees a reproductive success (enrichment, concentration, transport and retention processes, Bakun, 1996). Within the Río de la Plata estuary, nutrients enrichment is associated to freshwater discharge (24000 m^3 s^{-1}, Jaime *et al*., 2002). When discharge is high, inorganic nutrients (silicate, nitrite, nitrate and phosphate) exceed the threshold of phytoplankton cellular growth. Vertical fluxes of nutrients produce a high Chlorophyll-a (Chl-a) concentration and, presumably, a high phytoplankton standing-stock (Carreto *et al*., 1986; Calliari *et al*., 2009). Nutrients enrichment leads to a high production of food items for larvae and prey abundance for fish. Therefore, retention within the zone with high BSHG whatever the wind direction (Simionato *et al*., 2008), provides both hydrological (preventing drift or advection to the adjacent marine coastal water) sand nutritional stability during and immediately after spawning events, which favors planktonic eggs and larvae development of *M. furnieri.* Militelli (2007) classified this species as estuarine spawning associated to bottom salinity front (Fig. 9). Within this group would find other sciaenids like king weakfish (*Macrodon ancylodon*) and black drum (*Pogonias cromis*) and other species like brazilian menhaden (*Brevoortia aurea*) (Acha & Macchi, 2000) (Fig. 9); and Jenyns's sprat (*Ramnogaster arcuata*) (Rodrigues *et al*., 2008). There are other sciaenid species, banded croaker (*Paralonchurus brasiliensis*) and southern kingcroaker (*Menticirrhus americanus*), that spawn within the estuary but where no relationship was observed with some oceanographic structure and were classified by Militelli (2007) as estuarine spawning not associated with bottom salinity front.

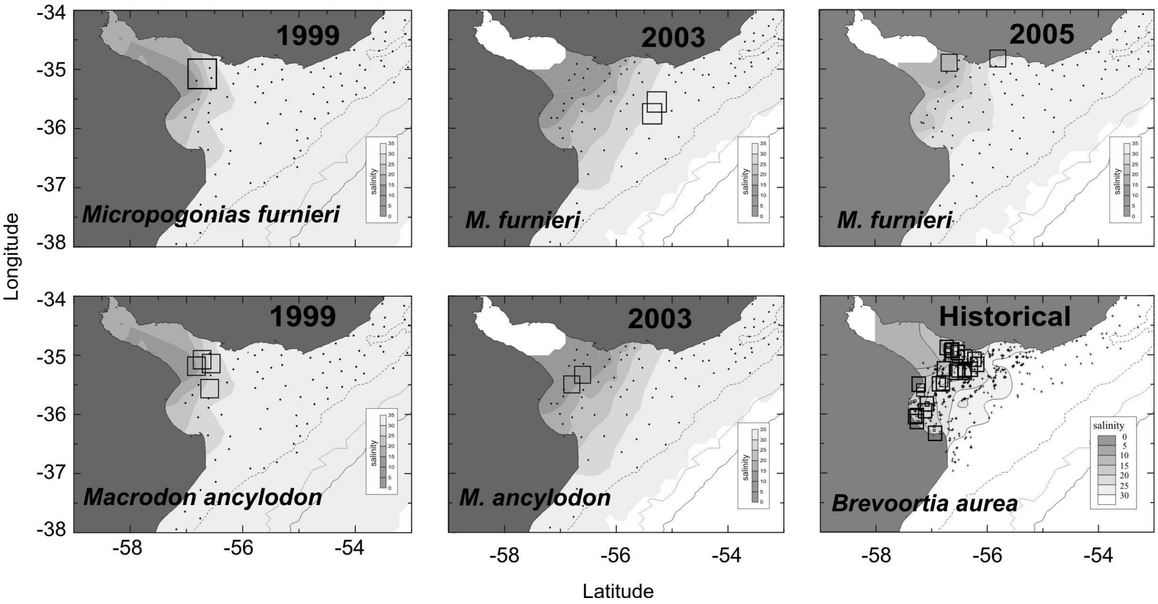


Figure 9 Spatial distribution of estuarine spawning associated to bottom salinity front during springs and its relationship with the bottom salinity. The sizes of the symbols are proportional to the percentages of gravid females. (*Micropogonias furnieri* and *Macrodon ancylodon* taken and modified from Militelli, 2007, and *Brevoortia aurea* from Acha & Macchi 2000)

Even though *Cynoscion guatucupa* is a marine migrant species along the Río de la Plata, but permanent in the adjacent water where has stage-specific environment conditions association (Jaureguizar *et al*., 2006b), and the synoptic environment conditions (at short time scale) along the coast determine the population age-class structure available in the region (Jaureguizar *et al*., 2009). Neonates and juveniles inhabit brackish, warmer and shallowest water (outer RDP estuarine area) while adults are more abundant in waters with high bottom salinities and depth, and low temperature. Although the area persistently dominated by neonates and juveniles, they show seasonal variations. The abundance of neonates (age-class 0+) is highest following the spawning peRíod, with intermediate values at the beginning of the spawning seasons (spring). Juveniles (from age-class 1+ to 3+) showed the same pattern in estuarine and marine area, being more abundant during spring, while the highest abundance of mature individuals (> 4+) occurs during autumn in the estuarine area, and during winter in the coastal marine area. The lower abundance of mature individuals during spring in the coastal marine area seems to be associated with reproductive movements from this area to the spawning areas.

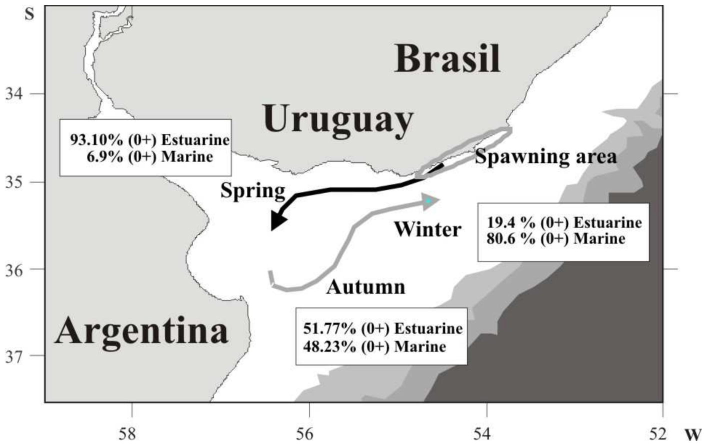


Figure 10 Conceptual model of *C. guatucupa* spawning area location and migration neonates. It is indicated the seasonal neonates proportion for estuarine and marine environment. (Draw from Jaureguizar *et al*., 2006b)

Considering the coastal circulation (Simionato *et al*., 2004; Palma *et al*., 2004) and the spatial distribution and age-class frequency in the estuarine and marine coastal area, Jaureguizar *et al*. (2006b) suggested that *C. guatucupa* spawning took place in inshore coastal waters at very shallow depths (Fig. 10). In spring the percentages of mature individual increase from offshore to inshore waters and the marine nearshore areas is dominated by neonates. As the spawning season progressed, neonates (age-class 0+) could be transported to the RDP estuary by the southward coastal water flow along the Uruguayan coast, where they represent 93.10% of total neonates individuals, the marine coastal area only has 6.9% of the total individuals. From autumn to winter, as southward coastal water flow decreases and the northward water flow increases, age-class 0+ abundance increases in the marine coastal waters where they represent 80.6% of the total age-class 0+ individuals observed during winter (Jaureguizar *et al.*, 2006b). The nearshore area represents an essential ecological habitat for this species, constitute a spawning area in the region and the pathway for the connection with the outer estuary for youngest individuals, where they will pass the critical period. Also, the main spawning area is not well defined within the Río de la Plata region; Militelli and Macchi (2006) found that during March 2000 and 2001, spawning of striped weakfish took place mainly in a reduced area in front of Punta del Este shore (Uruguay). These results agree with previous observations of Macchi and Acha (1998), who analyzed samples collected in November 1994. Nevertheless, in December of 2003 the highest concentrations of spawning females in the Río de la Plata estuary were located in the external sector in coincidence with a temperature bottom front (Militelli and Macchi, 2006). *C. guatucupa* as *Umbrina canosai* were classified by Militelli (2007) as marine spawner, where the spawning occurs always in marine waters (higher than 30 ups). Within this group may include other species such as *Perocophis brasiliensis*, *Paralichthys patagonicus* and *Parona signata* that also show higher reproductive activity (Fig. 11) in the outer estuarine area (Macchi and Acha, 1998; Rodrigues *et al*., 2007; Militelli, 2011).

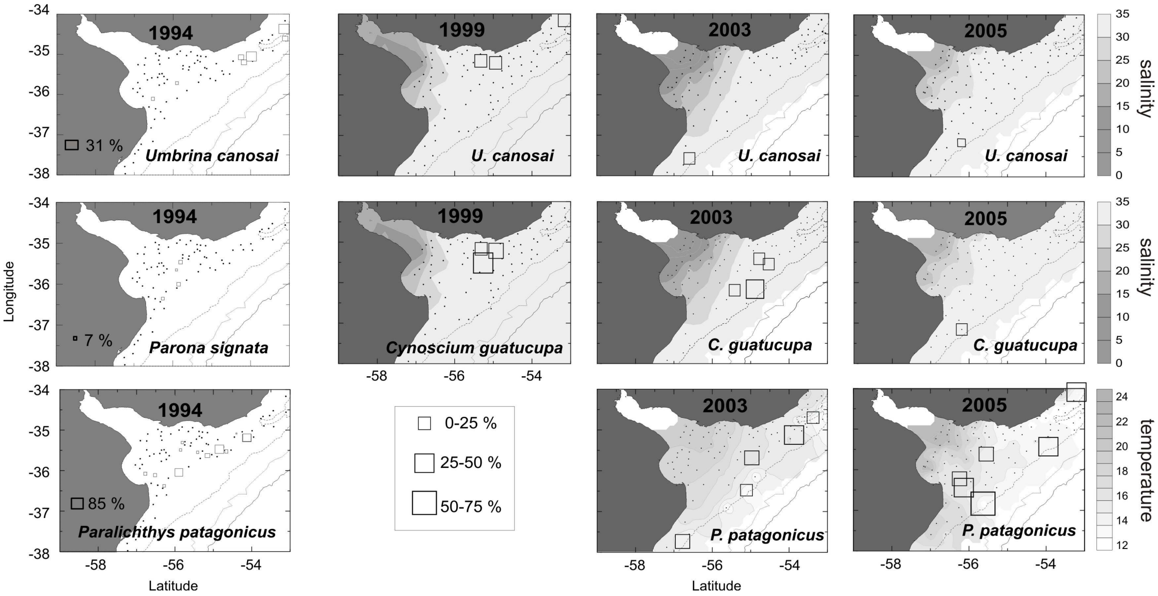


Figure 11 Spatial distributions of marine spawner and its relationship with bottom salinity and temperature in the area below influence of Río de la Plata estuary. The sizes of the symbols are proportional to the percentages of gravid females. (Year 1994 taken and modified from Macchi and Acha 2008 and the other year from Militelli, 2007)

Under classical conditions understood as spring and summer conditions (see WACS physical dynamics), where cool and high salinity water covers a greater area of the uruguayan coast (similar to 1998-Niño and 1999-Niña years) allows wider distribution of *C. guatucupa* adults individual forcing even an intrusion into the northern portion of the Río de la Plata estuary (Jaureguizar *et al*, 2009). However, when spring wind blows mainly from the west (1994 and 2003 years), like to autumn and winter classical conditions, the wind forces an outflow of brackish water from the estuary along the uruguayan coast (NNE drift) allowing a wider distribution of juveniles individual trough the coast and a dispersion of adults from de inshore uruguayan coast (Jaureguizar *et al*, 2009). Therefore, variations in the predominant synoptic environmental conditions could have strong effect on *C. guatucupa* population state, just on the age fishing mortality (affecting juvenile availability) or reproductive success through the use of nearshore as spawning area. Therefore, as the location of boundaries or extension of the juvenile area depends on the seasonal environmental conditions, the seasonal physical dynamics will need to be considered in refining seasonal and spatial fisheries management approaches and in delineating essential fish habitat.

The environment has also influence on the spatial distribution of sharks, skates and rays size-classes (*M. schmitti*: Menni, 1985, Massa, 1998, Cortés *et al*., 2011; *S. guggenheim*: Vögler *et al*., 2008; *Sympterygia bonapartii*: Mabragaña *et al*., 2002) and reproductive stages (*S. guggenheim*: Colonello *et al*., 2007; *Zapterix brevirostris*: Colonello, 2009) within the SWACS. The salinity has more influence than temperature during spring (Cortés *et al*., 2011; Vögler *et al*., 2008) due to SAWCS physical dynamics that force a freshwater tongue along the Argentine coast, allowing a greater influence of the southern Brazil waters and leaving a saltier system (Lima *et al*.,1996). The neonates and juveniles (< 50 cm TL) of *M. schmitti* have seasonal persistence to shallow and fresher habitats, these habitats are warm and have high abundance of its main preys (decapods crustaceans) during spring, allowing *M. schmitti* neonates and juveniles to maximize their growth rate. The adult has preference by deeper and warm waters in winter, while that in spring show segregation by sex with the females inhabit shallower water than male (Cortés *et al*., 2011). The spring environmental preference by sex is also observed in *S. guggenheim*, where the preference salinity range of adults males (27.8–35.5) and females (24.8–35.4 ups; gravid and non-gravid) show significant differences (Vögler *et al*., 2008). In both shark species, the adults are associated to the deepest coastal waters during winter, and coincide with the period (autumn - winter) of highest abundance in the outer shelf water (between 50 and 130 m depth, *M. schmitti*, Pereyra *et al*., 2008; *S. guggenheim*, Vögler *et al*., 2008). The observed predominance of neonates and juveniles in coastal water, and the larger individuals in outer shelf water, indicates that the winter size class distribution pattern seems to be associated with the ontogenetic movements from the nursery area to deeper waters through the development. During the reproductive season, the parturition of both species takes place in spring and early summer (Colonello *et al*., 2007; Cortés, 2007), the adult males and females display a differential migration towards nursery area (shallow coastal waters, <30 m). The female of *S. guggenheim* has a reproductive cycle of three year, at difference of *M. schmitti* who has annual reproductive cycle, which will determine that the migration movements related to mating and parturition does not affect all the reproductive population, and therefore the migration will be less intense than other species (Vooren & Klippel, 2005). Considering the similar behavior of these shark species females, and according to Vögler *et al*. (2008) hypothesis for *S. guggenheim*, the birth and nursery area should be located along the coastal zones of both Uruguay (~34–35°S) and northern Argentina (~35–38°S); adjacent to Río de la Plata discharge. The relative use of these areas as *M. schmitti* nursery and mating grounds shows inter annual variation affected by the environmental conditions (Fig. 12, Cortés *et al*., 2009) and the juveniles (37 to 56 cm TL) and medium-sized adults (57 to 75 cm TL) are the most influent stages in population growth rate (Cortés, 2007). Therefore, the environmental conditions could have a considerable impact in the *M. schmitti* population growth rate restricting the use of suitable habitats to growth and reproduce.

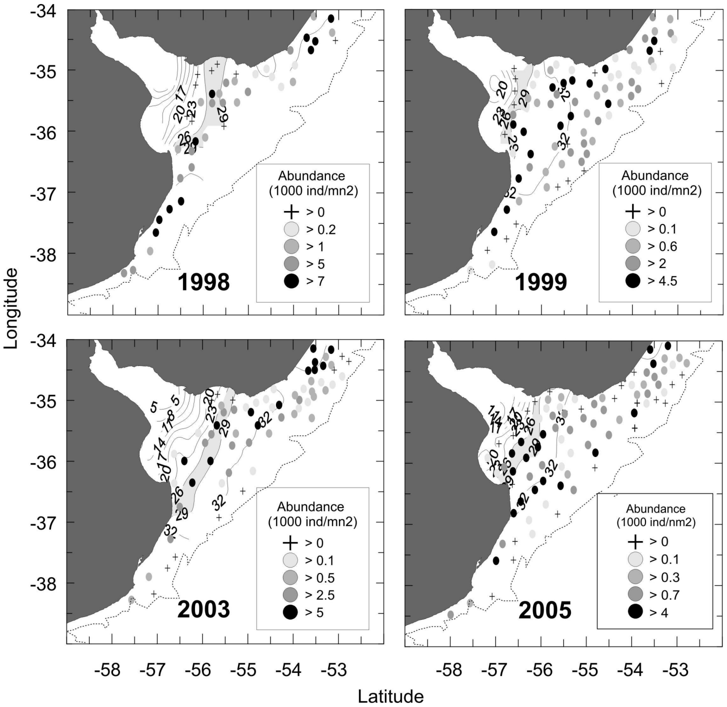


Figure 12. Variation in the spatial distribution of *Mustelus schmitti* during springs with different salinity conditions. Shadow area indicates the salinity range preferred by *M. schmitti* during spring. Points indicate the sampling stations and abundance (in thousand individuals per squared nautical miles) of *M. schmitti* during research surveys (Cortés *et al*., 2009).

The coastal area is also used by juveniles of *Zapterix brevirostris,* and by the pregnant females that inhabit this shallow area from the spring-summer until the parturition, that mainly occur during autumn-winter. The rest of adult females and adult males migrate to depth water after the reproductive season, although reproductive cycle of three year of the female (Colonello, 2009; Colonello *et al*., 2011) would determine that the migration movements related to mating and parturition does not affect all the reproductive population *Z. brevirostris* select sandy bottoms to feed on polychaetes and lancelets, where the fishing has the higher activity (Barbini *et al*., 2011).

The chondrichthyes ecological relationship is still little knowledge, but the available information evidence that many shark species use the SWACS as feeding [*M. schmitti* (Bellegia *et al.,* in press)*, S. guggenheim* (Vögler *et al.,* 2003, Colonello 2005, Vögler *et al.,* 2009), *Galeorhinus galeus* (Lucifora *et al*., 2006), *Carcharhinus brachyurus* (Lucifora, 2003)*; Notorynchus cepedianus* (Lucifora *et al.*, 2002, , Lucifora *et al.*, 2005a), Z. *brevirostris* (Barbini *et al.,* 2011)], mating [*M. schmitti* (Menni 1985, Cousseau 1998), *S. guggenheim* (Colonello *et al*., 2007), *G. galeus* (Lucifora *et al.*, 2004), *Carcharias taurus* (Lucifora, 2003, Lucifora *et al.*, 2002)*, Sympterygia bonapartii* (Mabragaña *et al*., 2002)], and nursery grounds [*M. schmitti* (Cousseau 1986, Menni 1986, Menni *et al.*, 1986), *S. guggenheim* (Colonello *et al*., 2007; Vögler *et al*., 2008), *G. galeus* (Lucifora *et al*., 2004), *Carcharhinus brachyurus* (Lucifora *et al*., 2005b), *N. cepedianus* (Menni & Garcia, 1985; Lucifora, 2003)], suggesting that the environment could have influence on spatial and temporal use of habitat.

4) Implication of environment variation on the coastal fishery and fisheries management to fish conservation.

It is clear that climatic variability (changes in salinity and temperature distribution, wind fields, hydrological cycles, etc. at annual to decadal time scales) have effects on the abundance and distribution of fish of the Río de la Plata and its adjacent coastal waters, which could have major effects on their population dynamics. The scarcity of long term biological observations (physiology, growth, reproductive capacity, mortality, prey abundance, etc) in the Río de la Plata has limited the knowledge of the variability in different time scales of this important variables as to determine the consequences of environment forcing.

The high spatial variation (200 km, ~35% of area) in the coastal water distribution affect the fish distribution at different level, from community level (fish assemblage) to single species (*P. nudigula, P. punctatus, D. tschudii, M. schmitti)* and its life history stage (*M. furnieri, C. guatucupa).* That environment variation affects the production of artisanal fishery settled at the inner (*Micropogonias furnieri*, Norbis 1995) and outer (*Mustelus schmitty*, Jaureguizar *et al*., in press) part of the Río de la Plata, due to short travel distance in order to access the resources, the available fish population in the area accessed is one of the most important factor that determine its production. *Mustelus schmitti* is available to artisanal fishery of Partido de la Costa (Argentina) during austral spring/summer season, associated to reproductive migration from depth to shallow water (Cortes et al., 2011a). The *M. schmitti* production (Ind/100m*24 Hs) during 2008/2009 fishing season was higher than the 2009/2010 production (Fig. 13) and the change was related to environment. The temporal series of Chlorophyll satellite (mg m^{-3}), related to salinity (Piola *et al*., 2008), and the habitat association of *M. schmitti* (Cortés *et al*., 2009), allow to determine that during the time where the salinity was higher than 28 there was an elevated fishery, while the declining in the production was associated to low salinity in the coast (Figure 13)

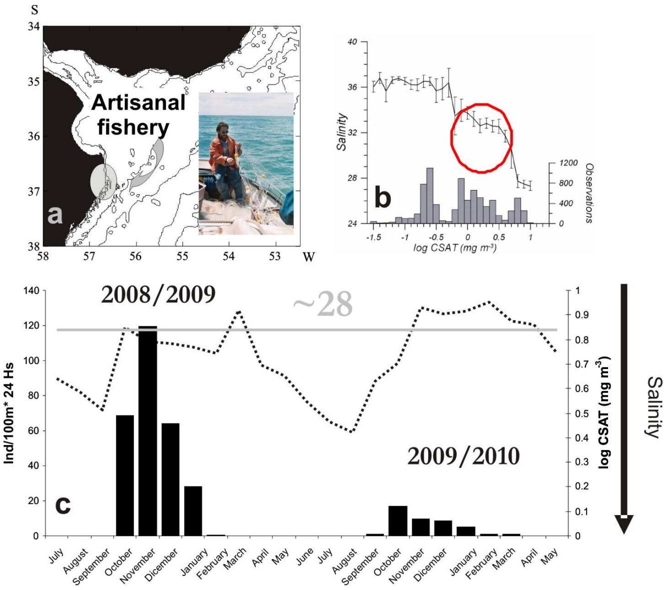


Figure 13. a) Location of the artisanal fishery of Partido de la Costa, b) relationship among chlorophyll satellite (CSAT, mg m^{-3}) and salinity in the Río de la Plata (Piola *et al*., 2008), and c) *Mustelus schmitti* production (Individual caught by 100 meter of net during 24 hours).

In the same way, the environment, across its differential influence in the habitat used by size composition, age and maturity stage, affects the basic information (numbers caught) obtained during the cruises evaluation for assessing fish stocks, and finally have implications on management regulation of fishing population. This is the case of *Cynoscion guatucupa* (Fig. 14), marine migrant specie whose population age-class structure available in the Río de la Plata and adjacent Uruguayan coast is determined by the synoptic environment conditions (see early) along the coast (Jaureguizar and Guerrero, 2009). The environment dynamic affects the availability of different length size class to commercial fishery and as to evaluation cruises affecting the CPUE and the total biomass estimated from cruises (Fig. 14). The CPUE commercial fishery does not follow a determined pattern, it will not be proportional to biomass and the CPUE could no explain the changes in the *Cynoscion guatucupa* abundance (Perrota and Ruarte, 2009). Therefore, as the estimation did not represent global index of total biomass, to describe the total biomass dynamic in reliable term it is impossible to use Schaeffer global model, and only can be estimated a partial abundance for a population fraction taking in account the environmental condition (Aubone and Ruarte, 2008)

Taking in account the high environment dynamics of the Río de la Plata and the strong habitat association of fish species/stage, the monitoring programmers need to be designed with all of these objectives in mind, as part of a dynamic and reflexive process which integrates science and management. Understanding how the habitat associations change along the time with species/stage will provide new knowledge which may be useful in refining spatial fisheries management approaches and in delineating essential fish habitat. Effective fisheries management relies on knowledge of the spatial-temporal distribution of fish populations, and the quality of these data have in some cases been deteriorating and continuing effort is needed to maintain adequate standards.

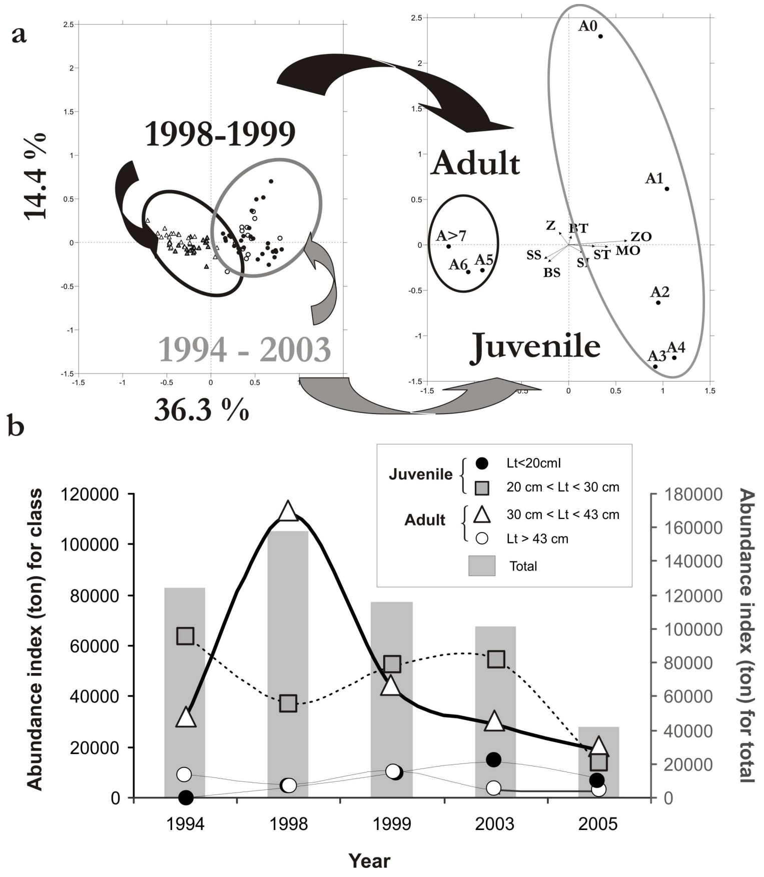


Fig. 14. a) CCA ordination diagram showing sampling station and *Cynoscion guatucupa* spatial distribution per age-class, and environmental variables (Bottom temperature, BT; Bottom Salinity, BS; Depth, Z; Simpson index, SI; MW, Meridional wind; ZW, Zonal wind) (Jaureguizar and Guerrero, 2009), b) spring abundance index by total and length size class (Aubone and Ruarte, 2008).

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