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Evidence of habitat fragmentation affecting fish movement between the Patos and Mirim coastal lagoons in southern Brazil

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The communication between the Patos and Mirim lagoon systems occurs via a natural channel called São Gonçalo. In 1977, a dam was built in this channel to prevent entrance of saline waters from Patos Lagoon estuary into the Mirim Lagoon. Our results showed an abrupt discontinuity in salinity and fish species distribution along the study sites. Sites below the dam showed salinity values higher than zero, whereas sites above had zero salinity values across all sampling periods. Marine and estuarine fishes (*e.g.*, mullets *Mugil platanus*, *M. curema*, silversides *Odontesthes argentinensis*, *Atherinella brasiliensis*, sardine *Brevoortia pectinata*, and white croaker *Micropogonias furnieri*) were not captured above the dam. If these juvenile fishes could enter the Mirim lagoon in greater numbers, they probably would enhance catches in the artisanal fishery. We hypothesized that the São Gonçalo dam acts as a barrier hindering the entrance of salinity water and fishes inside the Mirim Lagoon.

A comunicação entre o sistema lagunar Patos-Mirim ocorre através de um canal natural denominado São Gonçalo. Em 1977, foi construída uma eclusa com o objetivo de evitar a entrada de água salgada, proveniente do estuário da Lagoa dos Patos, para o interior da Lagoa Mirim. Os resultados mostraram uma descontinuidade abrupta na distribuição da salinidade e dos peixes ao longo da área de estudo. Estações de coleta abaixo da barragem tiveram valores de salinidade acima de zero, enquanto os valores foram iguais a zero nas estações acima da barragem durante o período amostrado. Peixes marinhos e estuarinos (p.ex., tainhas *Mugil platanus*, *M. curema*, peixes-rei *Odontesthes argentinensis*, *Atherinella brasiliensis*, sardinha *Brevoortia pectinata*) não foram capturados acima da barragem. Caso entrassem em abundância na Mirim tais espécies poderiam contribuir positivamente para os desembarques da pesca artesanal nessa região. Dessa forma, é sugerida a hipótese de que a barragem do São Gonçalo atua como uma barreira impedindo a entrada de águas salobras e peixes marinhos e estuarinos para o interior da Lagoa Mirim.

Key words: dam, fish migration, artisanal fishery, estuary.

Introduction

The Patos-Mirim lagoon complex has a diverse flora and fauna and has long supported fisheries, agriculture, industry, and municipalities. These lagoons are located in the coastal plain of Rio Grande do Sul state (southern Brazil), although part of the Mirim lagoon is located in Uruguay (Fig. 1a). Starting in the 60's, the Brazilian and Uruguayan governments implemented policies to promote economic development around the Mirim lagoon. Dams were established to allow agricultural and industrial activities. The most important of these was a dam built in the São Gonçalo Channel in 1977 to prevent the entrance of salinity waters inside the Mirim Lagoon (Fig. 1b) where freshwater is extracted for rice irrigation. Prior to the dam, intrusion of salinity waters and occurrence of marine and estuarine fishes (*e.g.*, whitemouth croaker *Micropogonias furnieri*, mullet *Mugil platanus*, flounder *Paralichthys orbignyanus*), were common inside the Mirim Lagoon (Cunha, 1953; FAO, 1972; Machado, 1976).The effects of this salinity barrier on fish assemblages within Patos and Mirim lagoons have not been investigated.

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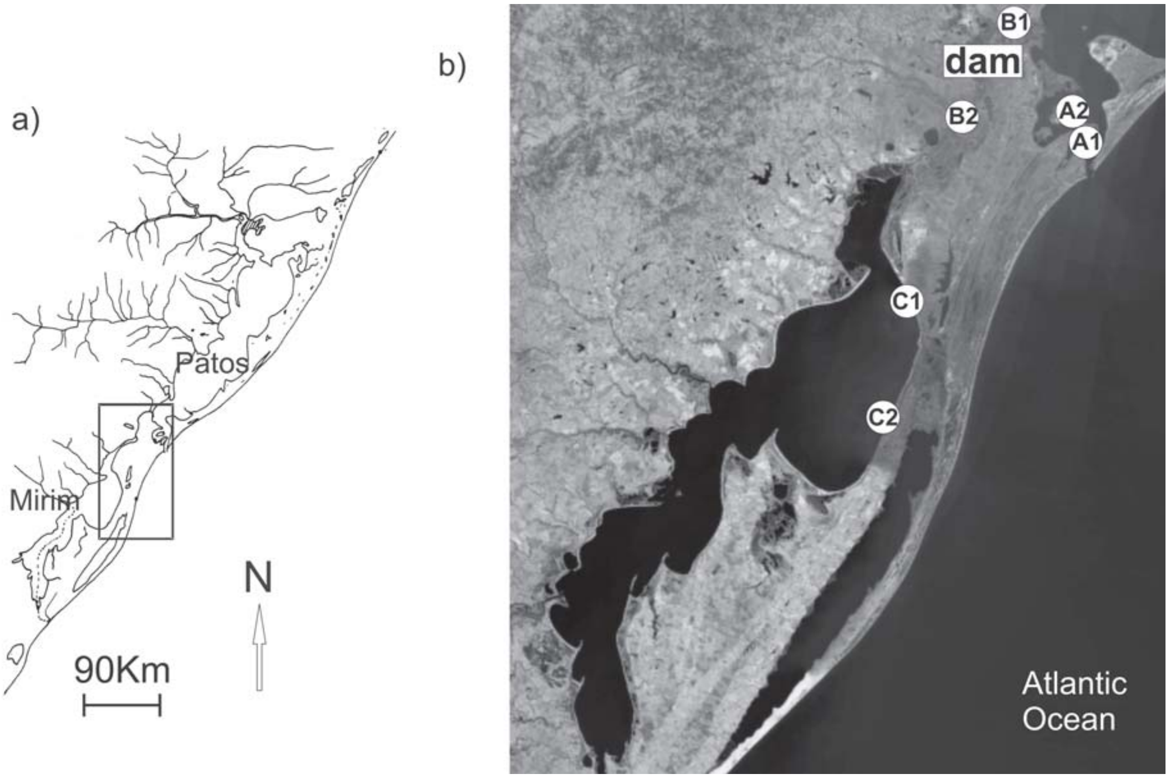

Fig. 1. Patos-Mirim lagoon complex in southern Brazil (a) showing locations of the six beach seine stations (b) at the Patos Lagoon estuary (A1, A2), São Gonçalo Channel (B1, B2) and Mirim Lagoon (C1, C2). A dam is located between stations B1 and B2.

Material and Methods

Patos (10,227 km^2) and Mirim (3,750 km^2) lagoons have a drainage basin of 263,876 km^2 (Seeliger *et al.*, 1996). The lagoons are connected by a 75-km long, 200 to 500-m wide, 6-m deep natural channel (called São Gonçalo) that periodically changes flow direction (FAO, 1972) (Fig. 1a). Fishes were sampled at six stations (Fig. 1b) encompassing Patos Lagoon estuary (A1, A2), São Gonçalo Channel (B1, B2) and Mirim lagoon (C1, C2). From March 2004 to February 2005, five beach seine hauls were made monthly in each station. All captured fishes were preserved in 10% formalin and later identified, counted and measured to the nearest mm. Each month, water temperature, water transparency (*Secchi disc*), depth, salinity and dissolved oxygen were measured at each station.

Frequency of occurrence (FO%) was calculated as the ratio of the number of occurrences of a species divided by the total number of samples (x 100). Percent numerical abundance (PN%) was calculated as the total abundance (n) of a species, divided by the total abundance (N) of all species captured (x 100). Species showing FO% e” the average FO% in each site collection were considered frequent fishes, whereas those with FO% < the average FO% were considered rare fishes. A similar method was applied to the PN%, resulting in High Abundance (PN% e” average) and Low Abundance (PN% < average) categories. Finally, combining FO% and PN%, fishes were classified in terms of relative importance in four groups: 1. High abundance and Frequent (e”PN%, e”FO%), 2. High Abundance and Rare (e”PN%, <FO%), 3. Low abundance and Frequent (<PN%, e”FO%) and 4. Low abundance and Rare (<PN%, <FO%) (Garcia *et al*., 2004). Variations in abiotic factors (salinity, water temperature, water transparency, depth and dissolved oxygen) among sites were tested using one-way ANOVA (Zar, 1996).

Results and Discussion

There was an abrupt discontinuity in the fish species distribution along the study sites, especially between A1, A2, B1 and B2, C1, C2 (Table 1). Marine and estuarine fishes, such as mullets (*Mugil platanus*, *M. curema*), silversides (*Odontesthes argentinensis*, *Atherinella brasiliensis*), sardine (*Brevoortia pectinata*), and white croaker (*Micropogonias furnieri*), which regularly use or reside year-round at the estuarine area (A1, A2) (Chao *et al.* 1985) were not captured inside the Mirim Lagoon (C1, C2). Although these species occurred from the estuary (A1) to the São Gonçalo Channel below the dam (B1), they were absent from stations located above the dam. Mullets, silversides, sardine and white croaker have high commercial value and comprise important items of the artisanal fishery in the lower reaches of Patos Lagoon (Reis *et al.,* 1994). The most parsimonious explanation for this marked difference in spatial distributions seems to be the occurrence of a dam between B1 and B2.

Table 1. Relative importance based on frequency of occurrence (FO%) and percentual abundance (PN%) of the dominant fishes captured in the studt area (A: Patos lagoon estuary; B: São Gonçalo channel; C: Mirim lagoon). A total of 43 species, mainly freshwater fishes, showing only category 4 (Low Abundance and Rare) were not included. TL: average Total Length in mm. Min-Max: minimum and maximum total length. See legend below for categories' interpretation. Between B1 and B2 there is a dam (See Fig. 1b).

	Estuary		Channel		Lagoon		TL (mm)	Min-Max
	A1	A2	B1	B2	C1	C2		
Cyanocharax alburnus		4	1	1	1	1	38.6	10-84
Jenynsia multidentata	3	4	4	4	4	4	34	10-97
Platanichthys platana	4	4	1	1	4	1	38.2	17-99
Hyphessobrycon luetkenii			1	3	4	4	44.1	19-76
Bryconamericus iheringii		4	4	3	4	4	43	19-91
Odontesthes mirinensis		4	4	4	1	3	68.3	11-223
Odontesthes ssp			4	4	2	3	39.1	14-94
Cheirodon ibicuhiensis			1	1	4	4	34.2	16-57
Cheirodon interruptus	4		4	4			37.1	21-60
Astyanax fasciatus			1	4	3	1	95.3	12-150
Cyphocharax voga			3	4	1	1	127	28-230
Corydoras paleatus			4	3	4	4	46.8	23-75
Astyanax eigenmanniorum	4		3	4	4	4	53.2	26-105
Oligosarcus jenynsii		4	3	3	4	4	74.3	24-246
Astyanax jacuhiensis			3	4	3	4	68.3	31-138
Geophagus brasiliensis		4	3	3			98.8	17-272
Gymnogeophagus gymnogenys			4	4	4		55.2	21-167
Oligosarcus robustus			3	4	4	4	113	35-252
Rineloricaria longicauda			4	3	4	4	83.1	32-161
Odontesthes humensis			4		3	4	62	19-190
Charax stenopterus			3	3			82.6	8-125
Ctenogobius shufeldti	4	3	3	4			40.2	12-108
Homodiaetus anisitsi			4	4	4		33.3	20-63
Hoplias malabaricus			4	3			256.8	23-485
Crenicichla punctata			4	3		4	136.2	44-351
Loricariichthys anus			4	4			142.4	23-386
Lycengraulis grossidens	4	3	3	3	4	4	42.5	17-201
Mugil platanus	1	1	2				38.3	21-336
Mugil curema	1	1	2				46.7	21-128
Odontesthes argentinensis	1	1					34.3	17-131
Brevoortia pectinata	1	1	4				36.4	20-105
Micropogonias furnieri	4	3	4				54.3	13-174
Atherinella brasiliensis	3	3					48.7	8-131
Eucinostomus melanopterus	3	3					32.8	15-72

Legend:
1 High abundance-Frequent
2 High Abundance-Rare
3 Low abundance-Frequent
4 Low abundance-Rare

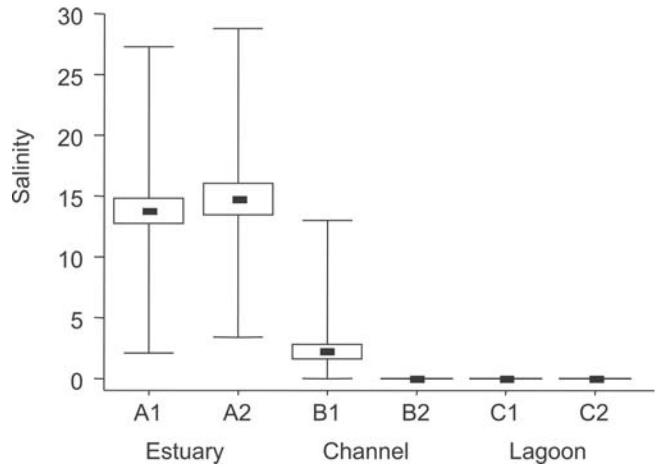

Fig. 2. Average, minimum and maximum salinity values along the Patos Lagoon estuary (A1, A2), São Gonçalo Channel (B1, B2) and Mirim Lagoon (C1, C2).

The dam acts as a barrier hindering the entrance of salinity water inside the Mirim Lagoon (Fig. 2). Among the physciochemical factors examined here, salinity had the greatest differences between sites above and below the dam ($F= 93.1$, $p < 0.0001$). Sites A1, A2, and B1 were the only locations showing values higher than zero, whereas B2, C1, C2 had zero salinity values across all sampling periods. In fact, salinity was the only abiotic factor showing a discontinuous spatial distribution that coincides with the one described for the fish fauna (Fig. 2).

To our knowledge, the present results provide the first concrete evidence of habitat fragmentation in the upper reaches of the Patos Lagoon estuary. This fragmentation did not allow that estuarine zone extends towards the Mirim Lagoon. If valuable commercial fishes were able to enter the Mirim lagoon in high numbers as juvenile and/or sub-adults, they could augment artisanal fishery catches in this area. In fact, before the dam construction, historical records show that marine and estuarine species were important components of fishery landings in Mirim lagoon (Machado, 1976).

Studies elsewhere (Holmquist *et al.*, 1998; Agostinho *et al*., 2002; Carolsfield *et al*., 2004) have shown that dams can alter habitat and fish assemblage structure and disrupt links among adjacent aquatic systems such as marine, estuarine and freshwater habitats. Future studies, with a higher sampling effort along the São Gonçalo Channel, should evaluate the degree to which loss of connectivity between the two lagoon systems affects not only the fisheries, but also ecological processes in this region.

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