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An essay on the potential effects of climate change on fisheries in Patos Lagoon, Brazil

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Abstract. Important artisanal fisheries depend on the Patos Lagoon estuarine resources (southern Brazil). About 3,500 fishermen work in this region. Some resources, notably pink shrimp, white-mouth croaker and grey-mullet are estuarine-dependent species as their life cycles depend on a brackish water environment. The ENSO cycle and climate changes may impact the estuary. In this essay, we sought to qualitatively analyze these environmental changes impact on estuarine secondary production and fisheries. We ponder the currently available knowledge about the species and regional climate models which show a maximum 2ºC increase in the next 30 years, with rainfall rates showing little change. However, the lagoon outflow should increase due to changes on the hydrographic basin, which would increase the limnic and decrease the saline influence in the estuary. This scenario may impact the biology and dynamics of estuarine-dependent species and their fisheries, because temperature influences metabolism, which affects the growth of individuals. Larvae natural mortality may increase due to metabolic stress, although increased growth rates may also reduce the vulnerability period of young to predation. A decrease in the species maximum size is also expected, as well as a shift in biomass peaks and changes in the fishing calendar.

Keywords: temperature and rainfall increase, estuarine fishery resources, climate impacts

Resumo. Um ensaio sobre os efeitos potenciais das alterações climáticas sobre a pesca na Lagoa dos Patos, Brasil. Importantes pescarias artesanais dependem dos recursos estuarinos da Lagoa dos Patos (sul do Brasil). Estima-se que 3.500 pescadores trabalhem na região. Alguns recursos (camarão-rosa, corvina, tainha) são estuarino-dependentes, tendo seus ciclos de vida ligados ao ambiente salobro. Este ensaio analisa qualitativamente os impactos que as mudanças climáticas terão sobre a produção secundária e a pesca estuarina. Considerou-se os conhecimentos disponíveis sobre a biologia e dinâmica das espécies envolvidas e os modelos climáticos. Estes apontam um aumento máximo de 2ºC na região nos próximos 30 anos, com pouca mudança na precipitação. Entretanto, a vazão da lagoa deve aumentar, devido às mudanças antrópicas na bacia da Lagoa dos Patos, aumentando a influência límnica e reduzindo a influência salina no estuário. Nesse cenário, esperam-se impactos na biologia, dinâmica e pesca das espécies estuarino-dependentes, pois a temperatura influencia o metabolismo, afetando o crescimento individual. A mortalidade natural larval aumentaria, devido ao estresse metabólico, mas o aumento das taxas de crescimento reduziria o período de vulnerabilidade juvenil à predação, diminuindo a mortalidade natural. É esperada uma diminuição no tamanho máximo das espécies, assim como um deslocamento dos picos de biomassa e mudanças no calendário de pesca.

Palavras-chave: aumento de temperatura e chuva, recursos pesqueiros estuarinos, impactos climáticos

Introduction

Until the Industrial Revolution (early nineteenth century), anthropogenic actions (e.g., deforestation, the regional extinction of species, destruction of the natural landscape) had only regional or perhaps even continental impacts. After the Industrial Revolution, however, the impacts of human activities became global (based on the premise that climate changes are the result of anthropogenic actions and that they are related to the carbon concentration in the atmosphere) (IPCC 2007).

The Industrial Revolution marks the beginning of the use of fossil fuels, resulting in the production of greenhouse gases such as carbon dioxide (IPCC 2007). These gases increase the retention of heat in the atmosphere, causing global warming and climate change on the planet (Mitchell 1989, Cline 1991). At present, there is a great deal of emphasis within the academic community on continuing studies on the consequences of global warming, how it may be prevented and on the adoption of mitigation measures.

The delay of many countries in adopting measures to reduce greenhouse gas emissions have resulted in steady and rapid increase in levels of carbon in the atmosphere, such that the current concentration is the highest in the last 450,000 years (King 2007).

The carbon absorption capacity of the oceans, which are the largest absorbers of carbon dioxide on the planet, seems to have reached its limit and has decreased over recent years (Khatiwala *et al.* 2009). This means that more greenhouse gases will remain in the atmosphere and will continue to drive climate change.

According to Solomon *et al.* (2009), many of the effects of climate change are already irreversible (King 2007) because of the high degree of inertia of the oceans and other climate control systems, which respond slowly to environmental changes (Caldeira *et al.* 2003). If emissions were reduced to zero today, the temperature of the planet would still continue to rise for over a thousand years (Solomon *et al.* 2009).

Thus, reversing the climate change process and returning the planet to a pre-Industrial Revolution climate appears to be an almost impossible task. Because of this, it will be necessary to make adjustments to the new climate of the planet by undertaking measures to minimize further impacts on mankind.

The analysis of likely future climate change scenarios and characterization of their biotic impact can support this adaptation.

The study presented in this essay is a qualitative analysis of the influences of climate change in the Patos Lagoon estuary and the biological response of some fish species there. It is based on the best information that is currently available without making a distinction between natural and anthropogenic effects. The synergistic effects of living beings and their adaptive capabilities are also disregarded.

Patos Lagoon

Patos Lagoon (Fig. 1), which is located in the coastal plain of Rio Grande do Sul, is 250 km long and has an average width of 40 km, covering a total area of approximately 10,360 km^2. This makes it the largest coastal lagoon of the choked type in the world. It can be classified as a shallow lagoon having an average depth of 5 m. The topography of the main lagoon body is characterized by major natural and artificial channels (8 - 9 m), wide adjacent areas (<5 m) and marginal shallower embayment areas (Seeliger *et al.* 1998).

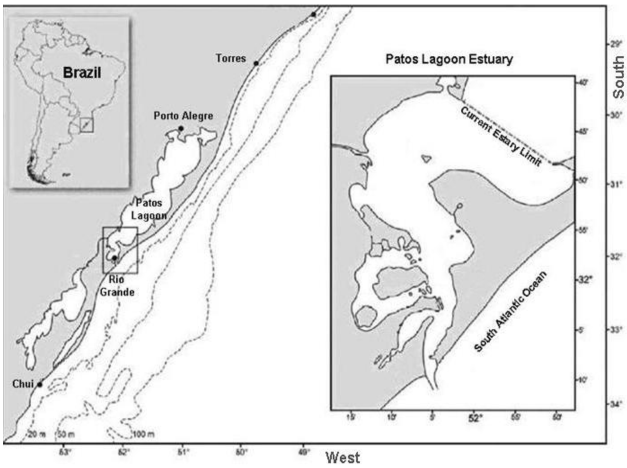

Figure 1. Coastal plain of Rio Grande do Sul state in southern Brazil showing in detail the Patos Lagoon Estuary.

The Patos Lagoon estuary occupies approximately 10% of the total area of the lagoon and is characterized by large regions of banks (80%), where the depth varies between 1 and 5 m. The connection of the estuary with the Atlantic Ocean occurs through a narrow entrance (750 m wide) with an access canal that has an average depth of 15 m and a maximum depth of 20 m. This canal acts as a filtering buffer, confining much of the tidal influence to the tapered portion of the estuary and strongly attenuating its amplitude (Möller *et al.* 2009).

The limit for inland penetration of salt water is up to 60 km from the mouth of the estuary and is related to wind conditions and river discharge, which results in seasonal variability. The annual average salinity of the estuary is 13, with values at a particular time ranging from 0-34. The strongest longitudinal salinity gradient is always observed to the north of the channel entrance. Lateral gradients are observed where the cross-sectional area increases, and vertical gradients can vary from the saline wedge to the well-mixed type (Fernandes *et al.* 2005).

Why the Patos Lagoon Estuary?

This estuary in southern Brazil was used for this study because it is an area that has been studied by the University of Rio Grande (FURG) in detail since the 1970s (Seeliger *et al.* 1998). It is also a region with a high degree of socio-environmental importance in the Southwest Atlantic (Seeliger *et al.* 1998) as a fishing ground for artisanal fisheries, as a nursery area for larvae and juveniles of many species (Chao *et al.* 1985, Haimovici *et al.* 2006) and because of its agro-industrial, tourist and port activities (Seeliger *et al.* 1998).

Rice production in the region reached more than eight million tons in 2008 (Instituto Riograndense de Arroz 2009). The port of Rio Grande (the only seaport in the state) processed more than 21.5 million tons of cargo in 2003 and served as a port for almost three thousand ships (Superintendência do Porto de Rio Grande 2009).

The artisanal fishermen community in the region, which depends on these resources, fluctuates around approximately 3,500 people who are directly involved in fishing (Haimovici *et al.* 2006), highlighting the socio-economic importance of the region.

Materials and Methods

Climate Models

For future climate projections, we used the future scenarios A2 (pessimistic) and B2 (optimistic) of the Intergovernmental Panel for Climate Change (IPCC 2007). The A2 scenario describes a very heterogeneous world that is characterized by a high degree of self-sustenance with the identities of local populations being preserved. Birth rates in this scenario continue to be higher than mortality rates, resulting in continuous population growth. Economic development is regionally oriented, and economic growth and technological changes are more fragmented and slower than in other scenarios.

The B2 scenario describes a world with an emphasis on local solutions for economic, social and environmental sustainability. It is a world with a continuously growing global population, though at a rate lower than in the A2 scenario, and with intermediate levels of economic development. Technological change will be less rapid and more diverse than in scenarios B1 and A1. This scenario is also more oriented towards environmental protection and social equality focused on both local and regional processes.

From these scenarios, the National Institute for Space Research (INPE) created thirty-year future climate models (2010 to 2040), aimed at understanding expected changes in rainfall and local air temperature (Marengo 2007).

Time Series

In this study, the following time series were used: rainfall and river flow of the main rivers contributing to the Patos Lagoon basin (Costa *et al.* in press) (Fig. 2) rainfall (Steinmetz 2007, Costa *et al.* in press) (Fig. 3) and air temperature in the city of Pelotas, which is located in the margin of the estuary region (Steinmetz *et al.* 2007) (Fig. 4).

Fishing Resources

Among the 28 species that are exploited through fishing in this region, five have historically been the most important: pink shrimp (*Farfantepenaeus paulensis*), corvina/whitemouth croaker (*Micropogonias furnieri*) miragaia/black drum (*Pogonias cromis*), tainha/grey-mullet (*Mugil platanus*) and bagre/white sea catfish (*Genidens barbus*). However, according to the present profile of artisanal fishing, only three species (pink shrimp, whitemouth croaker and grey-mullet) were selected for the study because the black drum and catfish have been heavily over-exploited and their catches are no longer significant (Haimovici *et al.* 2006).
Together, the three species represent more than 30% of the landings and nearly 45% of the revenue from fishing in this region (Haimovici *et al.* 2006, Castello *et al.* 2009). Thus, it is possible to characterize them as the most important socio-economic resources of the estuary. As such, it can be assumed that characterizing the impacts on these three fisheries is equivalent to characterizing the impacts on the entire estuarine fishing in the region.

The reproductive peak of the whitemouth croaker takes place from September to October, with spawning occurring at the mouth of the estuary. The eggs and larvae of this species penetrate the estuary by being passively transported by the current, particularly in late spring and early summer, and come to occupy the shallower marginal areas. As their development progresses, the croakers will move to the deeper areas of the estuary, and they will return to the sea upon reaching adulthood (Castello 1985, Oliveira & Bemvenuti 2006).

The grey-mullet also spawns in the open sea between the coasts of the neighbour states of Rio Grande do Sul and Santa Catarina in the late fall and early winter. Juveniles then migrate to shallower waters and enter the estuaries, particularly during the spring. Upon reaching maturity, they return to the ocean in shoals, generating the so-called "mullet race" (Oliveira & Bemvenuti 2006).

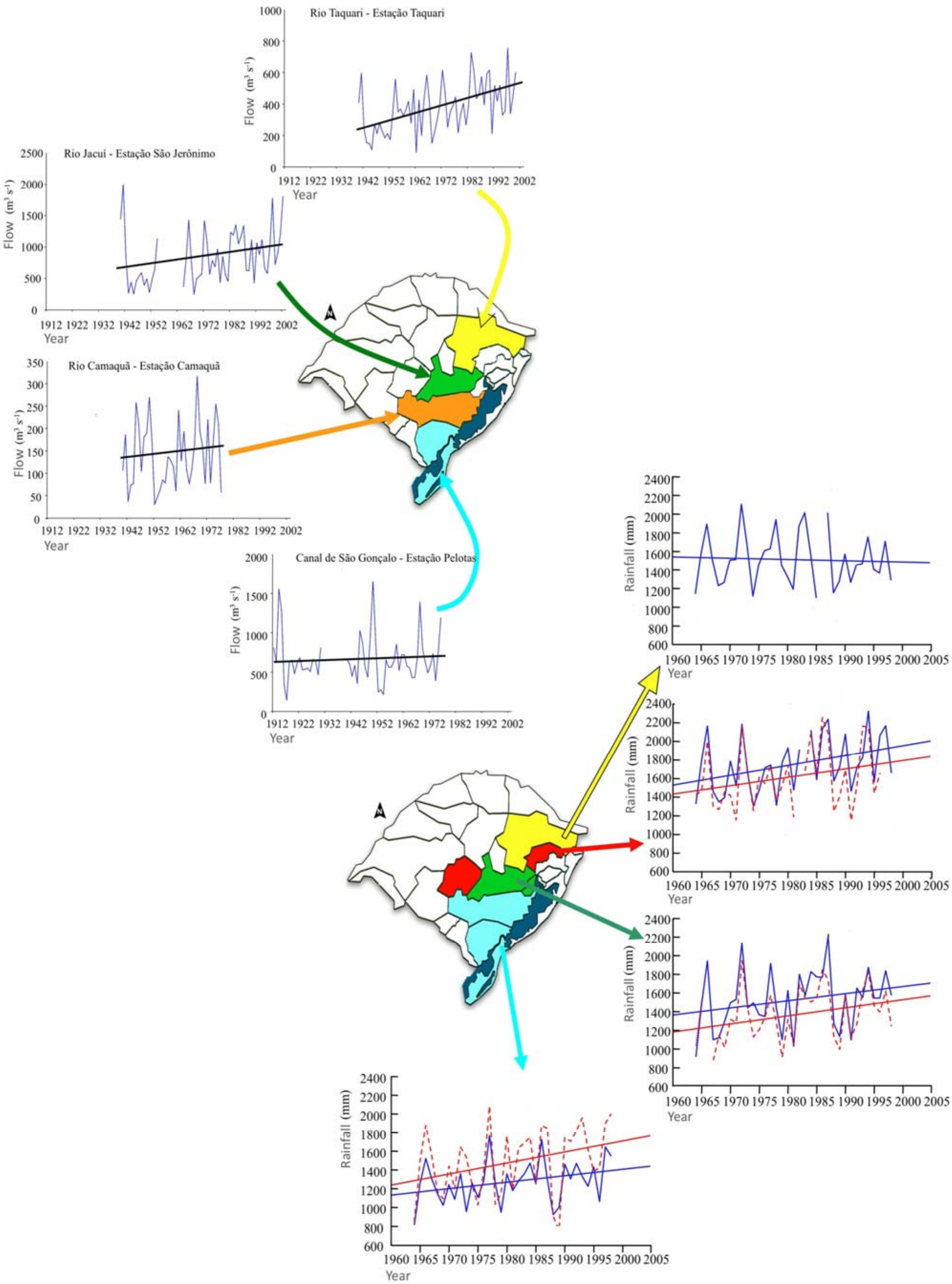

Figure 2. Rainfall time series (right) in the drainage basin and flow (left) of the main rivers contributing to Patos Lagoon. The study period is 40 years (1960 to 2000) for the rainfall series and 90 years (1912 to 2002) for the river flow series. (Costa *et al.* in press).

Pink shrimp breed in the spring on the shelf at the coastal front of Santa Catarina. The larvae migrate in a passive manner into the Patos Lagoon estuary in the form of megalopae (D'Incao 1991). They will remain there for three to four months in the shallower embayment areas of the estuary until they reach the juvenile or pre-adult stage, at which point they will return to sea in autumn-winter (Ribeiro *et al.* 2004).

Combining the INPE predictions and the time series, we chose to create a future climate scenario for the next 30 years.

A conceptual model was developed based on the main stages of the life cycle of a cohort (Fig. 5). From this, we identified the stages and parameters of the life cycle that could be altered by climate change.

In Figure 5, the rectangles represent the biomass (B) of a cohort at each time point (T). At each time transition, there is an effect of growth (G), natural mortality (M) and, after a certain age, fishing mortality (F). The sub-index 1 represents larvae and juveniles, 2 represent the recruits, and 3 represents the sexually mature (breeders). Tr and Lr identify the age and size at the time of recruitment, respectively. Analogously, Tc and Lc identify age and size at the time of the first catch, respectively. Age and length at first maturation, which is the time of first breeding, are designated by Tm and Lm. Closely connected to this whole process, there is migration between the mating, breeding and feeding sites.

To carry out this study, we used the following premises:

- All of the determinants that affect climate, and estuarine characteristics and processes and/or the biology of fishing resources were considered without distinguishing between natural and anthropogenic forces.
- The adaptive capacities of species were not considered.
- The 30-year scenario was chosen as the most prudent because future knowledge shall come into play if predictions are made for longer periods.

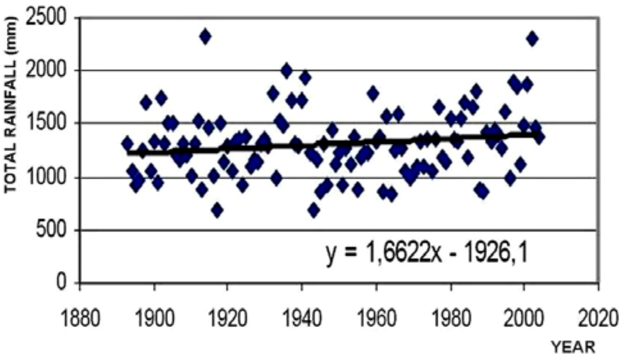

Figure 3. Rainfall time series for the city of Pelotas (city marginal to the estuary) during the period from 1880 to 2002. The line shows a variation of 184 mm in 111 years (Steinmetz *et al.* 2007b).

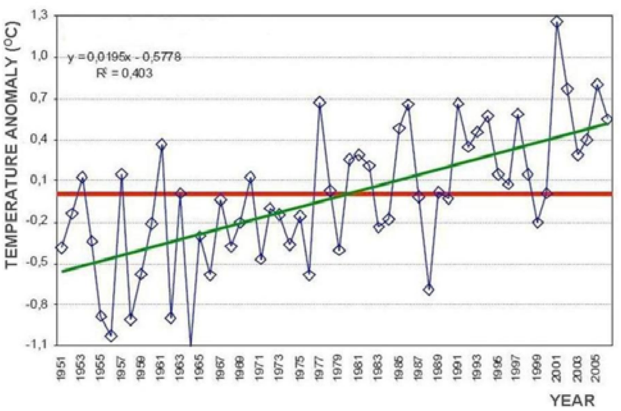

Figure 4. Air temperature anomaly time series for the city of Pelotas (from the portion of the city marginal to the estuary) during the period from 1951 to 2006 (Steinmetz 2007).

Results and Discussion

Future Scenario

Precipitation and salinity

The INPE climate models (Marengo, 2007) do not indicate rainfall anomalies for this region, i.e., climate change will not affect rainfall in the drainage basin of Patos Lagoon in the next thirty years independent of the analyzed scenario (A2 or B2). However, the spatial and temporal resolution of these climate models is low and large-scale and does not take into consideration local characteristics of each region.

During the discussions of the First Brazilian Workshop on Climate Change in Coastal Zones (held in Rio Grande/RS; 13-16/09/2009), the need to increase our knowledge on the specifics of how climate change is occurring was remarked. This would attend the purpose of producing models that are better predictors of climate change in the future (Rede Clima 2009).

In contrast with the INPE models, the flow time series of the major rivers contributing to the Patos Lagoon (Fig. 2) shows a clear upward trend. The Taquari River nearly tripled its flow over the past 65 years; the flow of the Jacuí almost doubled; the Camaquã had a smaller increase of about 20%; and the contribution of the Mirim Lagoon remained almost stable with a slight increase. This means that there is an increasing amount of fresh water reaching the estuary.

This increase in outflow is associated with rising rates of rainfall in the drainage areas of these rivers (Fig. 2). At the same time there is a superimposed decadal cycle. Costa *et al.* (in press), for a shorter time period, found a much higher increase in rainfall rates (up to 40% in 40 years) when compared with the data from Pelotas.

Toldo *et al.* (2006) points to an increase in sedimentation rate in Patos Lagoon in the last 150 years, i.e., before and after the agricultural colonization of the banks of its hydrographic basin. Soil impermeabilization (due to building cities and roads), destruction or reduction of riparian vegetation and agriculture all decrease the rates of water penetration into the soil, causing more water (and therefore more sediment) to be carried to Patos Lagoon. This process, along with increased rainfall in the drainage areas of the rivers basins, may explain the increased outflow of contributing rivers.

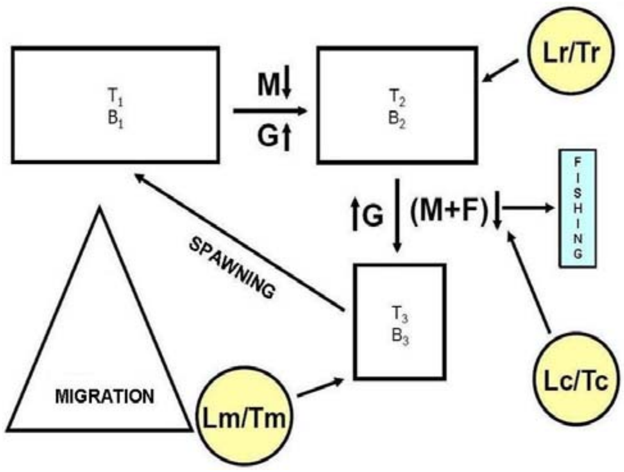

Figure 5. Conceptual model of the evolution of a cohort.

This scenario may be relieved by the high rates of evaporation in the Patos Lagoon, estimated to be approximately 600 m^3/s (Hirata & Möller 2006). As evaporation is directly proportional to temperature, increased heat in the region should increase evaporation rates, reducing the amount of water available.

Assuming that freshwater input will increase (in a linear fashion or in a decadal cycle) in the system despite the evaporation rates, more fresh water will be carried to the estuary over the next 30 years resulting in 'limnification', therefore, decreasing the size of the estuary (Costa *et al.* in press).

The 'limnification' process increases the fresh water in the estuary, reducing the salinity in its entire area of influence. Therefore, the position of zero salinity which determines the upper limit of the estuary, should move towards the sea, reducing the area of influence of the salt and the brackish water that is present in the southern region of Patos Lagoon (Costa *et al.* in press). Still, it is expected that this process shall be intensified when increasing the length of the rocky man-made pair of jetties located in the mouth of the estuary (Fernandes *et al.* 2005).

An increase of the outflow of the estuary is also expected because there is an increase in the volume of displaced water into the lagoon. In parallel, the speed at which the water exits through the rocky jetties should increase, resulting both from the volume of the outflow and renovation work that is done on them (Fernandes *et al.* 2005).

Temperature

Air temperature is expected to rise in the region. The INPE model points to an elevation of between one and three degrees Celsius, depending on the season and model that is analyzed. Although there are no historical data on water temperature in the lagoon and estuary, the low average depth and residence time of the water there indicate that it will follow the trends that have been verified for the air (i.e. increasing temperature).

The time series (Fig. 4) shows an upward trend in temperatures in the region, reinforcing the conditions outlined in these models.

Estuary of Patos Lagoon - 30 years

In light of the data presented above, it can be predicted that, in 2040, the estuary would be smaller, less salty and warmer, with stronger outflow and weaker inflow currents at the mouth of the estuary.

Response of fish stocks

Over time, the evolution of a fish cohort that is not fished behaves according to the conceptual model in figure 6. The number of individuals in the cohort is maximal at time zero, i.e., immediately after larval eclosion. As these individuals grow, the cohort biomass increases, while mortality reduces the number of individuals. The cohort biomass peak occurs when the natural mortality removes a large enough number of individuals that the growth of the survivors can no longer compensate the biomass of the cohort. This point occurs at the intersection of the curves for number and weight of individuals (Fig. 6).

When fishing is added to the model (Fig. 7), the curve representing the number of individuals declines even more due to increased mortality from death by fishing. The biomass and numbers of a cohort decrease with the increase in fishing mortality.

Estuary Reduction and Limnic Influence

The reduction in the estuary area should result in an increase in inter-and intra-specific competition among brackish water species, for both space and food. If we start with the premise that the number of individuals should not decline (at least at first instance), the population density in shallow areas with conditions of suitable salinity and vegetation will be higher. This means that embayment areas, with seagrass meadows, which are conducive to the proliferation of fish and crustaceans (Seeliger *et al.* 1998), should bear a greater density of consumers.

It is thus likely that the available food, which previously supported a lower density of individuals in areas with brackisk waters, will be competed for more severely. This situation can create stress in the populations, increasing mortality of the estuarine-dependent species. On the other hand, grey-mullet, which lives and growths in the fresh water area, will probably be affected during recruitment time.

While studying the effects of 'El Niño' on the estuary, Garcia & Vieira (2001) noticed that the phenomenon caused a local reduction in salinity due to high rainfall in the lagoon drainage basin. He also found that freshwater species, particularly *Parapimelodus nigribarbis*, *Astyanax eigenmaniorum* and *Oligosarcus jenynsii*, had subsequently become more frequent in the estuary.

These species will also compete for space and food with the estuarine-dependent species, and may, especially in the case of the carnivore *O. jenynsii*, represent one more predator of larvae and juveniles in the region.

The influence of 'limnification' can cause changes in the dynamic movements of estuarine-dependent species. 'El Niño' events reduce the recruitment of juvenile grey-mullets, negatively affecting the next growing season (Vieira *et al.* 2008) and the reproductive migration ("mullet race").

However, the variation in salinity should not affect the biology of the species, since the fluctuation of salinity in the estuary is common, ranging from marine to limnic conditions (Seeliger *et al.* 1998). These changes are, however, ephemeral, while the changes that will occur due to climate change are expected to be of a more constant nature.

Thus, with the reduction of the estuary size and the influence of 'limnification', increased mortality of the estuarine-dependent species and changes in migration and population dynamics are expected, reducing the available population for fishing.

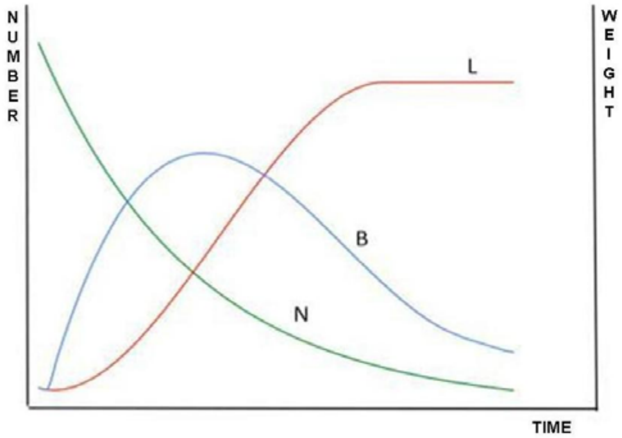

Figure 6. Model of a "virgin" cohort. The curve L represents the weight of individual species. Curve B represents the biomass curve, and N is the total number of individuals.

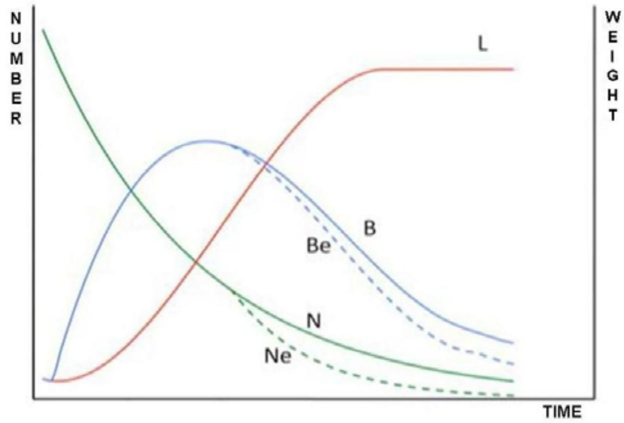

Figure 7. Model of an exploited cohort. Curve L represents the size of individual species, B the biomass, Be the biomass with exploitation, N the number of individuals and Ne the number of individuals with exploitation.

Increased temperature

Temperature is determinant to metabolism in fish, in a manner that the second is proportional to the first and that affects the rate of growth at all life stages. Because the Patos Lagoon is shallow (average depth of 5 m), variations in air temperature are quickly transmitted to the water column.

Krummenauer *et al.* (2006) pointed out to the low water temperature of the estuary in the autumn-winter period as a limiting factor for the cultivation of pink shrimp throughout the year. Therefore, a higher temperature could extend the growing season for shrimp and increase their growth rate.

Okamoto *et al.* (2006) discussed the advantages of higher temperatures on the development of juvenile grey-mullet. At a higher temperature, the feed-to-weight gain ratio increases (i.e., the same amount of food generates a greater amount of body mass). Higher growth and fattening rates with higher temperatures are also observed.

This rapid growth should affect the age of first maturity and result in an earlier start for reproduction in the species. Thus, the maximum length of the species (L_∞) should decrease (Beverton & Holt 1957, Weatherley 1972).

With individuals growing faster, the biomass peak of the species should shift, occurring earlier in the year. However, as the L_∞ should decrease, the peak of biomass should follow this trend, decreasing as well.

With higher growth rates, larvae will quickly pass through the periods of greater vulnerability, being exposed to "windows" of predation for less time. This should cause a decrease of the natural mortality rate, allowing more individuals to reach youth.

However, increased temperature can also cause metabolic stress on larvae, causing an increase in their natural mortality. Okamoto *et al.* (2006) found 5% higher mortality rates at higher temperatures compared with lower temperatures.

Yet, metabolic stress is a response to temperature stress, or a sudden change in temperature. Climate change results in small, incremental changes in warming rates of less than one degree Celsius every ten years. Therefore, there is the possibility that physiological adaptations may arise to circumvent the effects of temperature change on metabolism.

With accelerated growth rates and likely changes in the timing of migrations, the fishing calendar for the main species in the estuary may change. Haimovici *et al.* (2006) have, in fact, previously reported changes in this calendar (Fig. 8).

It is worth noting that there was a decrease in the peak of production, and an increase in the overall time of harvesting. There were changes of some harvested species, for example, catfish, between the periods from September-November (spring) to June-September (winter).

These changes are not unambiguously a result of climate change. They may be associated with specialization and adaptation of fishermen to different patterns of abundance caused by over-fishing (Kalikoski & Vasconcellos 2007). However, because of changes in travel patterns and population dynamics, we cannot dismiss the possibility of changes occurring as a result of climate change. Temperature and salinity are known factors for triggering migrations into or outward the estuary; therefore, an increase in temperature and a decrease in salinity may affect the timing of migration of estuarine dependent species (Pitcher 1993).

Currents at the Mouth of the Estuary

The larvae, post-larval individuals and juveniles of the three main fishery resources enter passively into the estuary, carried out by currents (Möller *et al.* 2009, Vieira *et al.* 2008, Garcia & Vieira 2001). Thus, the balance between the inflow and outflow currents of the estuary is of paramount importance for successful migration to occur.

Möller *et al.* (2009) have discussed the effects of rainfall anomalies (and consequently, the acceleration of the output current of the estuary) on the harvest of shrimp in the estuary and found an inverse relationship in which more rain resulted in less shrimp in the following harvest.

Vieira *et al.* (2008) performed a similar analysis for the grey-mullet, concluding that, with increased rainfall intensity and outflow current, juvenile recruitment would be hampered, reducing amounts of both current and future catches.

Thus, the increase in the speed of outflow currents constitutes the largest impact on these fisheries, hindering the entry of larvae and post-larvae into the estuary and affecting the life cycles of these species.

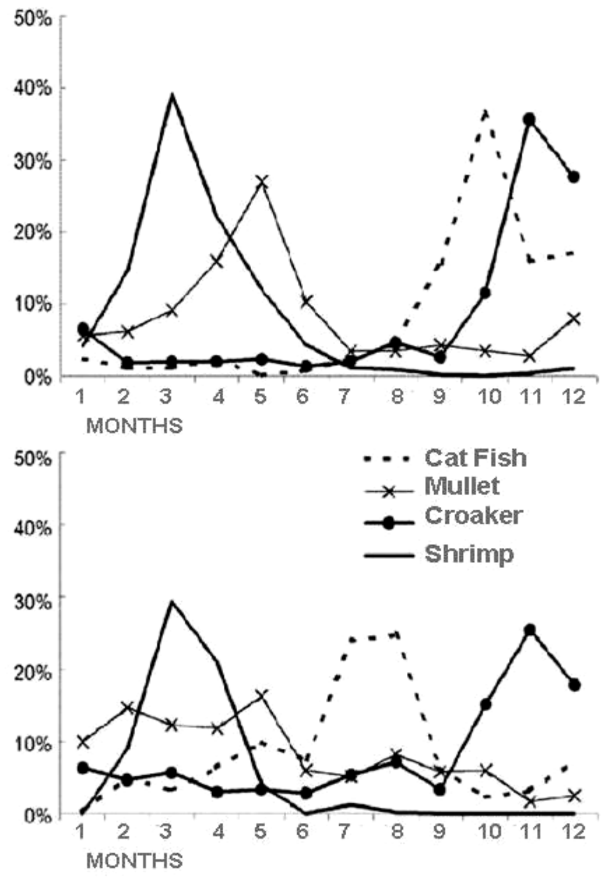

Figure 8. Calendar of artisanal fisheries in the 1960s (above) and 1990s (below). The lines represent the proportion of the total catch in each month (Haimovici *et al.* 2006).

Sedimentation rates

Toldo *et al.* (2006) have demonstrated that the sedimentation rate of the Patos Lagoon had increased from 5-11 times over the past 150 years. Suspended material that is transported by water increases the turbidity of the water column, reducing light penetration and, thus, impairing primary production, which is generally already at a low level in estuaries (Barnes 1974).

Visual predation by fish, such as the whitemouth croaker, is also affected by increased turbidity (Figueiredo & Vieira 2005). Turbidity reduces the visual field and acuity, thus undermining a visual strategy of predation. This may alter their food intake and consequently, their growth rates.

Marshes and submerged grasslands

Submerged marshes and seagrasses are the nurseries of the main fish stocks in the estuary. They provide shelter from predators, which have difficulty traveling in these densely vegetated environments.

These regions are also providers of food because they trap organic matter that is carried out by currents and retain the debris that is generated locally. They also house a whole community of benthos and plankton and even bacterial biofilms on the vegetation, which serve as food for larvae and juveniles.

Just as these environments trap organic matter, they also cause the retention of sediments. With the increase in the amount of suspended matter, sedimentation rates at these sites should also increase.

Thus, silting of seagrass meadows and marshes can occur, reducing the footprint of these highly productive areas. Copertino (2010) shows that climate change may impact the estuarine seagrass fields, reducing its area. Therefore, the “nursery” area would also be reduced, increasing mortality of the species that depend on it.

In contrast, scavenging species such as pink shrimp and grey-mullets would benefit from this condition. The nutrition of these species comes from two sources, allochthonous and autochthonous. With more material being trapped, the allochthonous amount that is available increases, so there is more food for scavengers. This could result in increased growth rates and decreased natural mortality for these species, representing a trend in the opposite direction to the previous case.

Conclusion

Climate change will have both positive and negative impacts on fish stocks in the Patos Lagoon estuary.

For the next 30 years, the main factor affecting fisheries in this region should be the acceleration of the outflow current at the mouth of the lagoon. This current will be intensified, both by climate changes and by anthropogenic actions from the occupation of the banks of the Lagoon and from work on the pair of jetties located in the mouth of the estuary.

With decreases in the age of recruitment, catch and first maturity, changes are also expected to occur in population structure and dynamics. There is also expected to be a reduction in the maximum size of specimens (L_∞) and their life expectancy. An advance in the timing and a reduction in the size of the biomass peak are also expected (Fig. 9), as are changes in migration patterns.

Importantly, no single factor can be considered totally positive or negative. Many of the effects are beneficial when analyzed from one perspective and detrimental when analyzed from others. The best example is the increase in turbidity that should affect the predatory strategy of the whitemouth croaker but will introduce more food into the system for the grey-mullet. Future, more complex models and new data may increase our level of understanding of climate change effects.

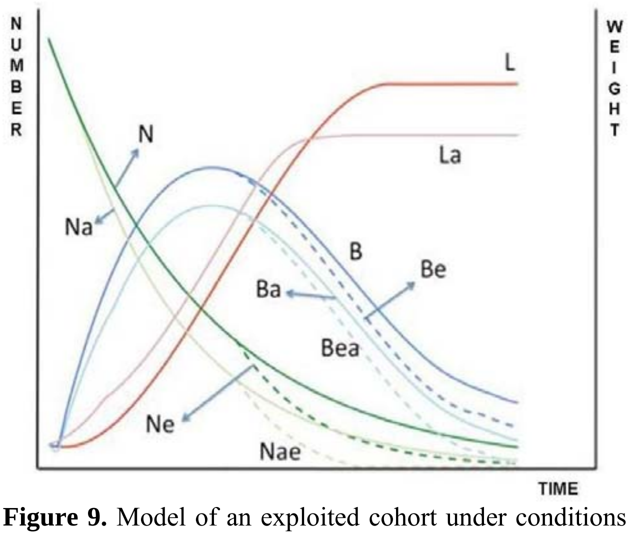

Figure 9. Model of an exploited cohort under conditions of climate change. The curve L represents the size of individual species, La the individual size with climate changes, B the biomass, Be the biomass with exploitation, Ba the biomass with climate changes, Bea the exploited biomass with climate change, N the number of individuals, Ne the number of individuals with exploitation, Na the number of individuals with climate changes and Nae the number of individuals with exploitation and climate change.

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