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Lessons From Multi-decadal Oceanographic Monitoring at an Estuarine Ecosystem in Argentina

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ABSTRACT: Both climate change and anthropogenic impact are creating a dynamic of continuous changes in ecosystems. While the expected consequences of these changes are global, the occurrence of extreme events and specific environmental problems are usually local or regional phenomenon. In particular, the coastal ecosystems are among the first vulnerable areas to show those changes; in spite of this, are the least studied. The Bahia Blanca estuary, Argentina, is located at 38º 40´ S and 62º 09´ W with an area of 2300 km^2. Along the northern shore of the estuary it is found the most important deepwater harbor of the country, where most of the agricultural and industrial products are exported. For the first time, based on multi decadal oceanographic monitoring and meteorological data of this ecosystem, a co-relational analysis approach was outlined considering several documented changes at various trophic levels; namely, phytoplankton and zooplankton assemblages, commercial crustaceans and fisheries. As results, several novel emerging hypotheses regarding cause-and-effect relationships were formulated. These unprecedented findings represent substantial information for the focus of the future ecosystem management and research, revealing gaps in the present knowledge of the coastal ecosystem which can be extrapolated to other worldwide coastal systems.

Key words: Long-term Oceanographic monitoring, Temperature, Salinity, pH, Dissolved oxygen, Coastal ecosystem, Phytoplankton, Fisheries

INTRODUCTION

Coastal zones are characterized by a rich diversity of ecosystems and a great number of socioeconomic activities. They are widely used for a range of overlapping issues such as tourism, coastal development and residential living, commercial and recreational fisheries, aquaculture, navigation, trade, national defense, and mineral resource extraction. Increasing population and therefore a rising in anthropogenic pressure on world's coastlines is certain to continue. These ecosystems are intrinsically linked to planetary biological and geochemical cycles, being critically important to the health of the planet as a whole (NOAA, 2000). Added to this, climate change is affecting the physical, biological, and biogeochemical characteristics of the coasts at different time and space scales, modifying their ecological structure and functions through climate driven variables or parameters. The main "climate drivers" that produce consequences for coastal areas and marine resources are: temperature, coastal currents and dynamics, atmospheric storms, freshwater inputs from land and sea level variations (NOAA 2000). A significant long term change of these parameters on a given region will generate important consequences; for instance, an increase in precipitation will automatically increase rivers runoff in estuaries; therefore, changes in freshwater inflow will affect the stability of the water column and this effect may be enhanced due to changes in water temperatures. In this scenario, water vertical density gradients are likely to increase, which could decrease vertical oxygen transport and create bottom conditions favorable for the development of

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hypoxia or anoxia (Justic *et al.*, 1996). Increased freshwater inflow, therefore, may also affect coastal phytoplankton communities by increasing or decreasing a potential for single nutrient limitation and overall nutrient balance; thus, long term changes may affect the productivity of coastal waters (Justic *et al.*, 1997; Justic *et al.*, 2003). In fact, these interlinks are starting to be demonstrated stating that the observed changes in marine and freshwater biological systems due to rising water temperatures, changes in ice cover, salinity, oxygen levels and circulation are close linked to the shifts in ranges and changes in algal, plankton and fish abundance (Solomon *et al.*, 2008).

While there are a number of long-term biological time series on land, there are relatively few in marine environments (Edwards *et al.*, 2010). This is highlighted by the fact that the IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment Report noted 28586 significant biological changes in terrestrial systems, but only 85 from marine and freshwater systems (Rosenzweig, 2008; Richardson *et al.*, 2008). Then, the present paper deals with this worldwide knowledge gap. Although the present area of study has historically been subject of thorough multidisciplinary critical research (Arias *et al.*, 2010; Cabezali *et al.*, 1994; Fernandez Severini *et al.*, 2010; Ferrer *et al.*, 2006; Lanfranchi *et al.*, 2006), there is a lack of long-term research studying the linking of the physical-chemical dynamics to the ecosystem's changes. Consequently, this paper presents for the first time the results of the analysis of about 30 years of oceanographic physicochemical data measured at the Bahia Blanca Estuary, in South America, aiming to set trends and evaluate correlations, linking the coastal chemistry to biological documented changes. These findings will be of high relevance for the international conversation on the anthropogenic pressure and climate's induced changes over the coastal ecosystems. The Bahia Blanca Estuary (38 º 40´ S and 62º 09´ W, Argentina, South America) is counted among the marine systems showing substantial changes on plankton, crustacean and fish communities (Conde *et al.*, 2008; Berasategui *et al.*, 2009; Hoffmeyer *et al.*, 2009). The area has a total surface of 2300 km^2, of which about 410 km^2 of islands and 1150 km^2 of intertidal sector. It is a meso-tidal system with little fluvial input covered by extensive tidal flats and salt marshes (Piccolo *et al.*, 1990), surrounded by extensive agriculture used lands. The estuary is usually eutrophic with levels of ammonium and phosphorous always available. Concerning the biological primary production, the most important season is the late winter and early spring, when the highest phytoplankton blooms have historically occurred. At that time, the nutrients (N, P and Si) are largely available, and both the temperature and light intensity are low enough (~5 to 7 ºC, and 400-700 µE m-2 s-1, respectively) as required by the always dominant diatom species (*Thalassiosira curviseriata*), main responsible for the mentioned bloom. The very high amount of organic matter generated by these biological processes sustains a rich and well documented diversity which allows several socioeconomic activities like angling and commercial fishing.

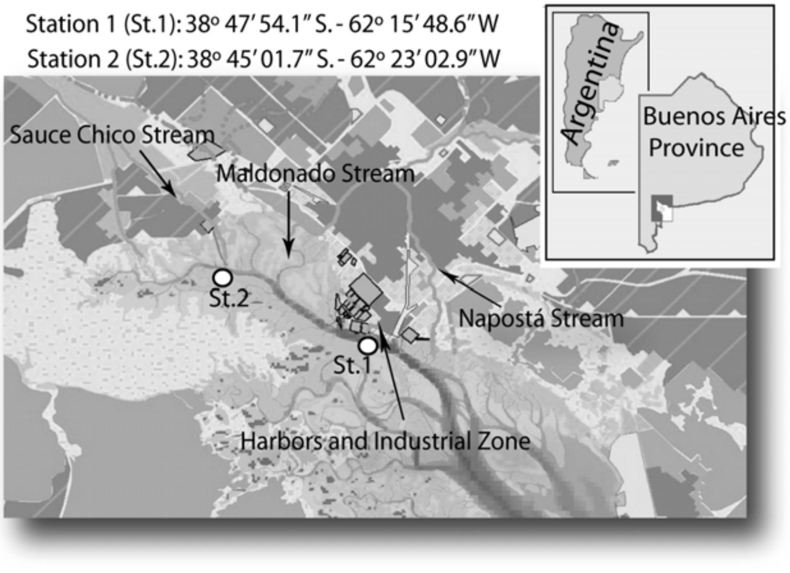

Fig. 1. Area of study and sampling stations

MATERIALS & METHODS

The data used in the present analysis belongs to the Argentinean Oceanography Institute's (IADO) oceanographic data base. It consists in the routine observations made by the IADO between 1974 up to 2008. The first set of the data consists in water temperature and salinity routinely determined at two oceanographic stations, namely, Ingeniero White Harbor (St.1) and Cuatreros Harbor (St.2) (Fig. 1). The second set includes Dissolved Oxygen and pH measures, which were taken in discontinuous series of about ten years. For both series the monitoring periodicity was usually fortnightly, except for occasions when it was performed in a weekly basis. To determine the seasonal variability of the physical-chemical parameters of the estuary, at first it was taken into account the annual cycle of each parameter, considering for this parameter value vs. Julian day. Secondly, to determine the interannual variability throughout the whole period of observations, a polynomial regression was performed for each parameter, including the whole set of observations. Then, such variability was estimated by the procedure of anomalies calculation: for each parameter and station, an anomaly value was determined by subtracting the measured data vs. the regression-modelled value for that parameter in that station on the corresponding year day. For discussion and data complimentary analysis, historical meteorological data was provided from the National Meteorological Service (MLA, 2003) and from Scian, B. (2002, data available online).

RESULTS & DISCUSSION

Water temperature ranged from 4.1 ºC in (S1 and S2) to 25.7 (S2) along the whole period. On the one hand, considering the average annual cycle, the minimum occurred at day 200 (Julian day) in the S2 station (June, winter season), about three weeks after the occurrence of the minimum temperature in S1 station (day 178). On the other hand, the maximum values exhibited a spatial distribution, registering the maximum in S1 about 0.8 ºC above that in S2.
Regarding the anomalies in water temperature, the two sampling sites were taken into account for the calculation of average anomalies and the resulting values were considered as a proxy for the estuarine water temperature anomalies (Fig. 2).

Results showed that from 1975 and up to mid-80´s, the water temperature anomalies varied from 0 to -2 ºC. On the contrary, during the 1990 decade, the water

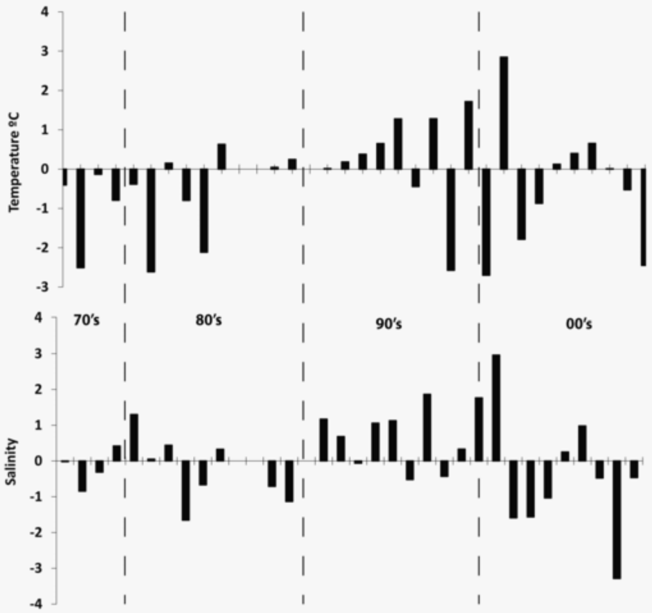

Fig. 2. Water Temperature and Salinity anomalies calculated by year from 1975 to 2008

temperature anomalies were positive, from 0 to +2 ºC (with exception of the years 1995 and 1998), achieving its maximum by the year 2000. In fact, this last year was the warmest of the studied period (Fig. 2). Since then, the water warming continuous trend was interrupted. Then, in the years which followed, positive and negative anomalies occurred alternatively in the estuarine water temperature.

First we considered the average monthly precipitation in the city of Bahía Blanca, as a proxy for freshwater input to the system. These data were correlated with the mean annual salinity, considering the 35 years of records. Results showed that the salinity annual cycle was highly asymmetric and differed within stations (Fig. 3). For instance, the minimum values were achieved during winter end and early spring (day 260-270 and 240-260 for S2 and S1, respectively; Fig. 3), a period which matched with the beginning of the rainy season -this period was also characterized by less solar radiation, which is a limiting factor for the evaporation rate-. Similarly, the evaporation process appeared to be specifically relevant during the late spring and summer (from day 300 to day 60), when despite of the relative high precipitation records (Fig. 3), the salinity achieved its maximums values.

Regarding the annual salinity anomalies, considering the period from 1975 to the beginning of 90's, the anomalies were occasionally beyond the unit, variating from 0 to 0.6 units (positive and negative scores, Fig. 2). In contrast, during the 1990's it was recorded a positive shift from about 1 to 2 units. The year 2000 (the warmest of the period) achieved the maximum anomaly of all years, scoring up to 3 salinity units over the average. Similarly to the water temperature anomalies, this trend was reverted in the subsequent years, showing alternatively positive and negative anomalies.

The average pH (8.2 ± 0.25) did not showed significant differences between stations along the sampled period. Considering the pH annual cycle, the highest pH values were recorded just after the occurrence of the summer precipitations which also correlated with the highest water temperatures. As for the interannual variations, the extreme values of pH occurred during the wettest year of the period. Figure 4 shows the interannual variability considering the available data from 1997 to 2008. The results show that during 2001 and 2002 the occurrence of the climatic event "El Niño Southern Oscillation" produced the highest rainfall of the decade in line with the higher pH values. In particular, during those years and taking into account the previous condition of acid-base balance, there was a significant change in the acidification of water to its alkalization. In fact, during that period, the pH increased significantly more than 0.5 units, doubling the average standard deviation in

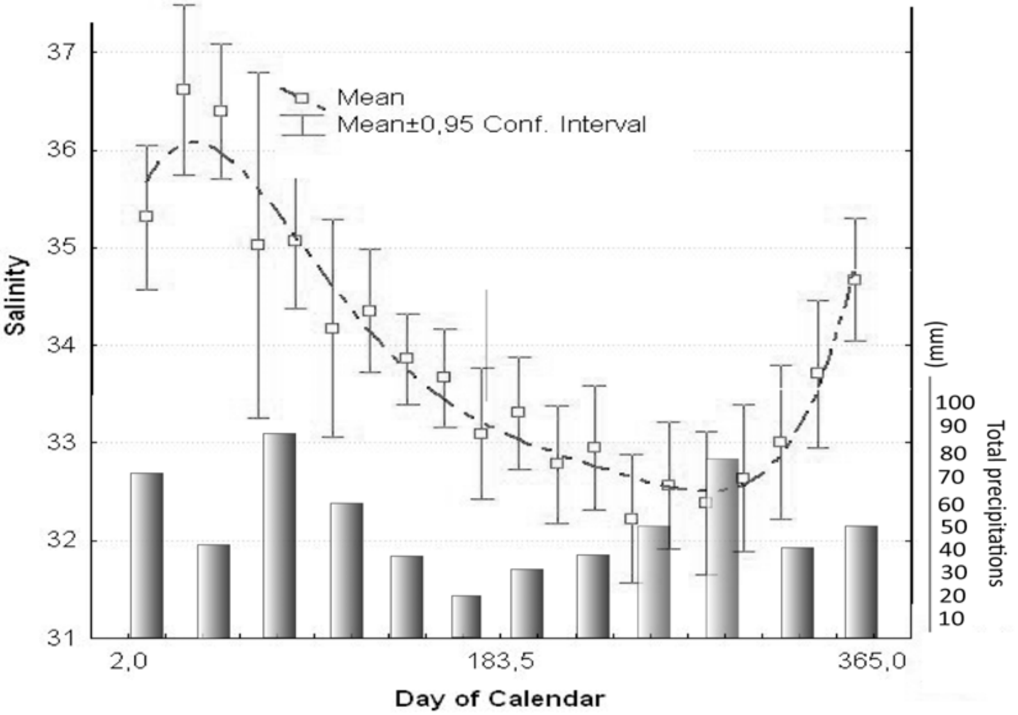

Fig. 3. Salinity (curves) and precipitation (bars) average annual record

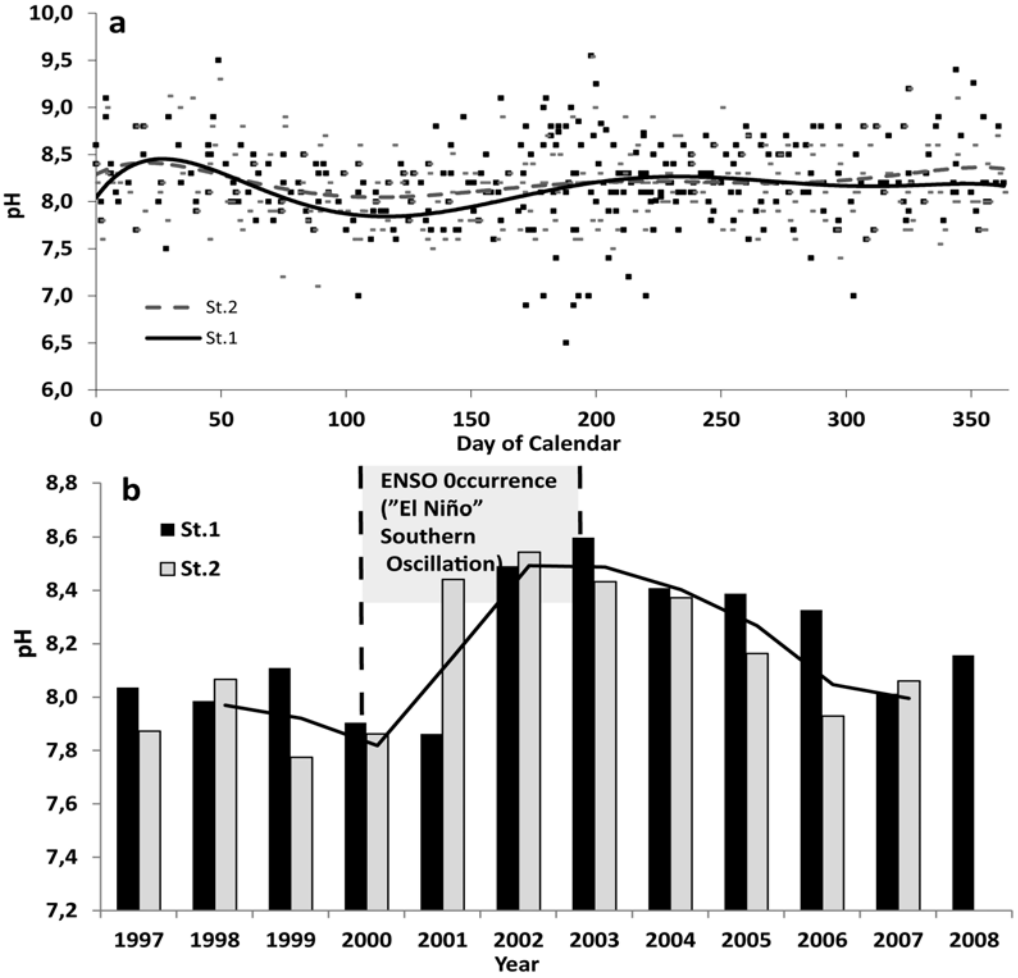

Fig. 4 a. pH average seasonal variability by day of calendar. b. pH annual's averages from 1997 to 2008

less than a year (Fig. 4). Thereafter, pH values gradually returned to general acidification trend.

The analysis of the Dissolved Oxygen's data (from 1997 to 2008) showed that the annual cycle was bimodal, reaching the two maximums in summer and winter (Fig. 5). The minimum DO values were, in average, around 5.8 ppm and the maximum around 8.5 ppm; however, unusual years (2001, 2003 and 2007) showed values as low as 4 ppm and beyond 10 ppm. The variability between years showed an irregular pattern, alternating periods of 2 to 3 years of increasing/ decreasing average DO's values. As a highlight, during the year 2001-2002 there was a remarkable increase in the annual average concentration of dissolved oxygen. This event was strongly correlated with a climate event: the "El Niño" Southern Oscillation (ENSO). As part of the same phenomenon, there were increases in the average water temperature as well as unusual freshwater inputs through rainfall and augmented tributaries' inputs. Since then, the following four years showed an increasing trend in average DO values.

Marine ecosystems have been clearly reviewed as dynamic systems that respond to changes in ocean and climate over a wide range of spatial and temporal scales (Aragao *et al.*, 2008; Arnone, III *et al.*, 2008; Atkinson *et al.*, 2009; Behrenfeld *et al.*, 2006; Clarke *et al.*, 2007; Cury *et al.*, 2008; Graham *et al.*, 2008; Kelly *et al.*, 2009).

In recent years, there have been several documented changes in global ecosystem composition, showing evident consequences, for instance, in commercial fisheries (Hsieh *et al.*, 2009; Sherman *et al.*, 2009; Stram *et al.*, 2009; Vass *et al.*, 2009).

These changes could be indirectly ascribed to anthropogenic activities and climate induced changes, which diversely impact through variations in food webs under "bottom-up" and "top-down" controls (Beaugrand *et al.*, 2003; Montes-Hugo *et al.*, 2009; Perry

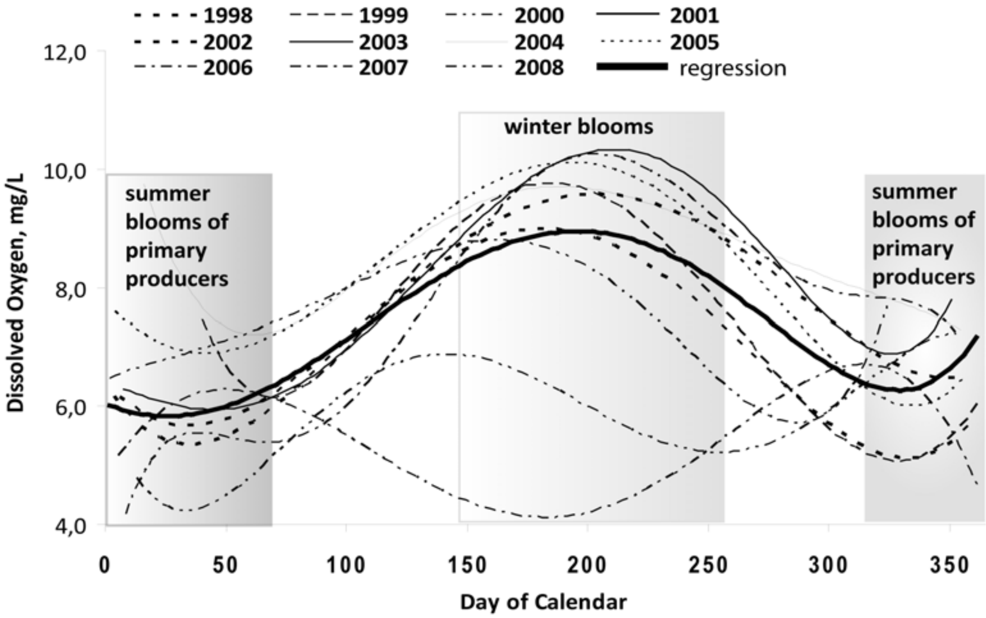

Fig. 5. Dissolved Oxygen seasonal variability by day of calendar

et al., 2007; Ware *et al.,* 2005). It is also known that the chemical environment directly regulates metabolic factors such as activity and feeding rates, as well as swimming speeds and reproduction (Portner 2001; Portner 2002; Portner *et al.,* 2007). As a consequence, several biological communities (for instance, plankton assemblages and crustaceans communities -which are found or seek a limited range of hydrographical conditions-) can be re-distributed, leading to changes in regional flora and fauna. In this order, temperature is the climate variable that is most dominant in terms of its influence on marine ecosystems (Byrne *et al.,* 2009; Collie *et al.,* 2008; Drinkwater *et al.,* 2005). As a matter of fact, there are numerous works describing changes in distributions of eurythermal species and non-migrating inhabitants related to water temperature (Adams *et al.,* 2009; Askeyev *et al.,* 2005; Crabbe2008; Nakashima *et al.,* 2002). Water pH is another driver of marine environmental changes. This parameter is directly linked with the atmosphere-oceans CO_2 equilibrium. In fact, surface-ocean Dissolved Inorganic Carbon increases long with pCO_2 as a consequence of uptake of "excess" atmospheric CO_2, a process known as "ocean carbonation". The concurrent drop in surface-ocean pH is a mirror image of the pCO_2 increase and amounts to 0.3 - 0.4 pH units (Riebesell2008). This may have negative effects on a myriad of organisms, in special for those planktonic organisms that use calcium carbonate to build their skeletons and appear to play important roles in ocean-atmosphere interactions (Anthony *et al.,* 2008; Doney *et al.,* 2009 Guinotte *et al.,* 2008).

Salinity is another ecological key- parameter. It is well stated that deviations from average salinity seasonality may have serious biological implications: for instance, salinity anomalies may affect planktonic resting or dispersal stages (Schumann *et al.,* 2006), species invasion (Kube *et al.,* 1996) or drastic reduction of macrophyte vegetation (Pankow and Wasmund, 1994) as observed in coastal systems of the Baltic Sea. Besides, the dynamic patterns of dissolved oxygen concentration in estuaries are the result of complex interactions among physical (in e.g., temperature, salinity, bathymetry, circulation and meteorology), chemical (in e.g., freshwater and sewage discharges) and biological processes (respiration, photosynthesis and nitrification processes) (Kemp *et al.,* 1990; Diaz *et al.,* 1992; Diaz and Rosenberg, 1995; Borsuk *et al.,* 2001; Diaz, 2001; Best *et al.,* 2007). Changes in this parameter have numerous direct effects in marine organisms: lethal and sub lethal responses, alterations in feeding rates, spawning seasons and migratory patterns (Best *et al.,* 2007; Rosas *et al.,* 1999; Portner *et al.,* 2002).

As descripted in the above paragraphs, the environmental conditions' change -expressed in water temperature, salinity, pH and dissolved oxygen variations- are well linked to several effects on the ecosystem, namely, phytoplankton and zooplankton assemblage's changes and commercial crustaceans and fisheries decrement. Following these, the next sections discuss case studies of these biological communities' impacts and their hypothetical causes linked to oceanographic parameters' long-term monitoring.

As mentioned before, oceanographic parameters change may affect the abundance and distribution of plankton assemblages, leading to invading and harmful algal blooms and thereby influencing diseases of aquatic organisms as well as human health. In fact, it is well known that the physicochemical changes in water can lead to increased or diminished incidence of pathogens infections (i.e.; spread of *Perkinsus marinus* linked to high temperatures, USA, (Cook *et al.*, 1998)). In particular, these kind of alterations are expected to affect the size distribution of the phytoplankton community, either through the timing of phytoplankton development or dominance of small (<20 µm) vs. 'large' (>20 µm) cells (Montes-Hugo *et al.*, 2009). For example, a greater dominance of small phytoplankton over 'large' phytoplankton (e.g., diatoms) communities has been hypothesized by Prezelin et al. as a response to the regional warming of cold regions such as the Antarctica (Prezelin *et al.*, 2004). Fortunately, to assess the occurrence of this phenomenon at the area of study - both phytoplankton and the physical-chemical parameters- have been thoroughly and systematically studied during the last 20 years (Gayoso1998; Gayoso1999; Popovich *et al.*, 1999; Popovich *et al.*, 2008). The diatom´s annual cycle is widely characterized by a winter/early spring bloom which includes very recurrent species (Gayoso1999). Although inter annual variations in the bloom's composition are a usually observed in other coastal environments (Yamamoto *et al.*, 2004), for the BBE region *Talassiosira curviseriata* has been identified as the most recurrent and dominant species (Gayoso1998; Gayoso1999). In spite of this, in 2003, a non-identified centric diatom with solitary cells and valve diameters < 20 µm was dominantly observed (90 %) during the winter diatom bloom (Spetter et al. 2011, *in preparation*), breaking the aforementioned trend for the first time in twenty years. Then, the hypothesis by which the physical-chemical parameters' dynamics was the driving force of the phytoplankton's assemblage change must be addressed.

Taking in consideration the climate variability during 2000, 2001 and 2002, there was a warm ENSO occurrence (El Niño Southern Oscillation) at the southern Buenos Aires region during that period. As a consequence, positive anomalies in the precipitation record were achieved at those years, (i.e., 819.3 mm/yr in 2002 vs. the 30 years normalized value of 626 mm/yr.). As shown in Fig. 2 and 6, the augmented freshwater input resulted in decreased salinity records. Joint to these, the year 2002 was colder than the previous and the years which followed (Fig. 2 and 6). On the one hand, considering the mechanistic functioning of algal blooms, it is well known that cold water influx leads to upwelling of nutrients (and consequent eutrophication) over worldwide coastal zones. Then, this mechanism could be firstly stated as a major contributor to the eutrophic condition of the BBE waters; however, up to the moment, the upwelling mechanism has not been demonstrated to occur at the BBE (Freije and Marcovecchio, 2004). On the other hand, the augmented freshwater input (precipitations and estuary tributaries), which represented increased nutrients inputs, could have set a new eutrophic scenario during those years (2001 and 2002). This scene was opposed to the drought registered in 2003, when the precipitation reached up to 477.3 mm/yr (Scian B, 2002), shifting the salinity and dissolved oxygen and limiting nutrients such as Phosphorous and Nitrogen (Spetter *et al., in preparation*). We postulate that cold eutrophic waters in 2001-2002 were capable enough to sustain and control the growth of "large" cells in the phytoplankton's bloom and that the dramatic alteration of the scenario originated a change in the phytoplankton's cell size by 2003.

About the control of the cell size, for example, Smith and Lancelot proposed that eutrophication factors (such as cold water up-welling mechanisms) mainly control the growth of 'large' phytoplankton cells, while top-down (e.g., microzooplankton grazing) environmental forcing will preferentially control communities dominated by 'small' phytoplankton cells (Smith *et al.*, 2004). This is in agreement with the hypothesis by which environmental key parameters could have restricted the growth in the 2003 (higher salinity and temperature and lower nutrients), leading to other factors (i.e., grazing) the size control of the phytoplankton assemblage. As a probable result, 'small' cells dominated the bloom that year. Recently, a similar phenomenon was registered in phytoplankton assemblages of the Western Antarctic Peninsula (WAP) (Montes-Hugo *et al.*, 2009). These authors observed abrupt transitions toward dominance of small (<20 mm) phytoplankton cells coincided with a switch on ENSO and SAM anomalies as well as increase of heat content of shelf water over the WAP region.

The same as for phytoplankton, the oceanographic parameter's variability were correlated with changes in the zooplankton's assemblage. In 2007, the area of study showed lower annual water temperature and higher salinity in winter, in comparison to previous years (Fig.7). Until then, the copepod *Eurytemora Americana* had been generally observed in relatively low abundance in comparison to other copepods like *Eurytemora affinis*, *Eurytemora hirundoides*, *Acartia tonsa* or *Acartia clausi* (Jeffries, 1962; Heron, 1964; Sage and Herman, 1972; Avent, 1998). In fact it has been reported solely as an invader

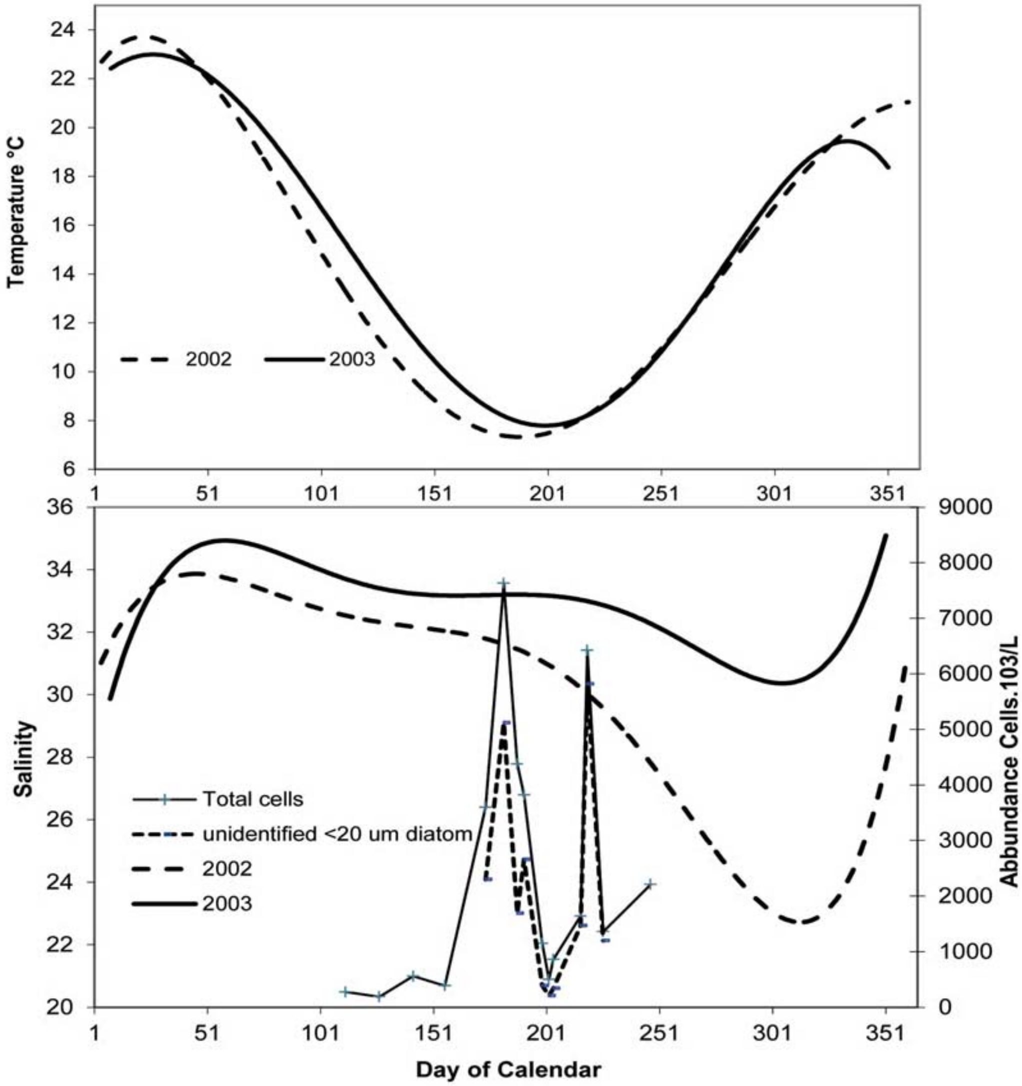

Fig. 6. Water Temperature and Salinity variability between 2002 and 2003 and the unusual nanophytoplankton dominance in 2003's winter bloom

at the area of study (Hoffmeyer1994; Hoffmeyer *et al.*, 2000).

E. Americana is adapted to cold-temperate temperatures (<1-15 ºC) and intermediate salinity, with values ranging between 10 and 33 (Avent, 1998) or around an average of 24 or less (Sage and Herman, 1972). During the past ten years, researchers found that its population density increased towards its dominance over A. tonsa population at the area of study; in fact, Berazategui *et al.*, demonstrated for the first time the complete dominance of *E. Americana* over the rest of the species (Berazategui *et al.*, 2009). As seen in Fig. 2, our data showed that during the 2007 the water temperature was below the average. During that winter, an unusual environment condition related to a polar wave of Antarctic origin which affected the south of South America lowered the temperature of the estuarine water. Simultaneously, a drought period occurred in the temperate eastern coast of South America, postulated as an effect of an ENSO episode (La Niña) (Barros *et al.*, 2002; Silvestri2005). Although the annual average of the water salinity was below the historical mean (Fig. 4), the drought produced less freshwater inputs into the estuary, thus generating high salinity records in winter (Fig. 7) and probable lowered nutrients inputs. In agreement with the statements of Berazategui *et al.*, which found that the combination of low temperatures and high salinities had an important role in the 2007's pulse, we postulate that the changing scenario could have been responsible of the observed change of species, leading to the invasive occurrence of *Eurytemora Americana*.

One of the rough subjacent hypotheses in the commercial fisheries field is that the oceanographic parameters variations are responsible of the diminished captures. In this section, this hypothesis was approached for the first time based on the government statistics for shrimp (mainly *Pleoticus muelleri*) and prawn (mainly *Artemesia longinaris*) catch, from 1998 to 2003. These data was correlated with our oceanographic parameters database for the period.

First, one of the remarkable items was that when a strong interannual variability in water temperature occurred, this was correlated with diminished catch amounts of commercial crustacean's species, as shown in Fig. 8. In particular, from 1998 to 2001, when the absolute temperature variation between years was the highest (from 4 to 5.5 ºC, Fig. 4), the amount of catch was the lowest (mostly below 10 kg/net). On the opposite, in the period from 2001 and 2002, when the water temperature variability did not exceed the degree, the maximum catch rates were achieved (up to 70 kg/net, Fig. 6). Thereafter, moderated interannual variations occurred and correlated with commercially acceptable catches (>10 Kg/net).

As is well stated, the development of marine species is close affected by thermal tolerance and dissolved oxygen (DO) availability (Portner *et al.*, 2002). Then, DO anomalies were calculated following the same procedures as for the water temperature and then matched with the crustaceans catch's statistics. Our data revealed that DO levels showed a drop of up to 1.7 ppm between 1998 and 2000, matching the period that registered the highest water temperature anomalies (4 to 5.5 ºC, Fig. 8). During these oceanographic conditions, there were registered the lowest catches of prawn and shrimp. Taking these items, and in agreement with the subjacent hypothesis it can be proposed in a sounder way that those temperature anomalies in summation with a drop in the water oxygen could have resulted in poor catches of commercial crustaceans. According to these, several research papers support this statement since numerous shrimp species have been demonstrated to be extremely

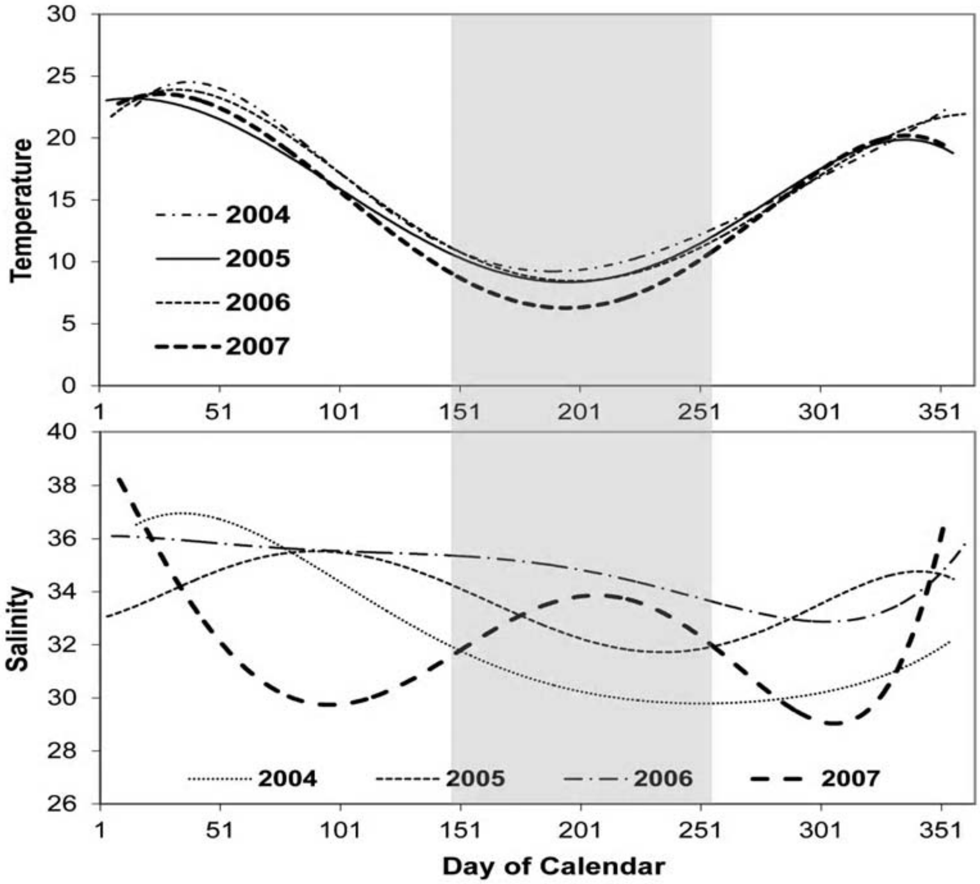

Fig. 7. Water temperature and Salinity during 2007 in comparison to the previous years, showing the anomalies which could have led to the observed changes in the zooplankton assemblage

sensitive to changes in DO concentrations (Rosas *et al.*, 1999). In example, Egusa (1961) found critical concentrations of oxygen for *Penaeus japonicus* between 4.5 and 5.0 mg/L and Liao and Chien (1994) reported critical levels between 4.0 and 4.3 mg/L for *Penaeus monodon*. Other studies indicate that below 2 mg/L the growth rate of *Penaeus vannamei* and *Penaeus monodon* were significantly reduced (Seidman and Lawrence, 1985). Rosas et al. have reported critical levels between 4.5 and 5.0 mg/L for *Penaeus setiferus* (white shrimp) exposed to different salinity levels (1997). A reduction between 3.9 and 26% of respiratory metabolism was generally observed when DO diminish below the critical concentration.

Finally, it has been demonstrated that the *Penaeus aztecus* (brown shrimp) and *Penaeus setiferus* juveniles are capable of detecting and avoiding hypoxic water (Renaud *et al.*, 1986). This could emerge as a second mechanism explaining the diminished catches at the cited oceanographic conditions. This lateral hypothesis would be particularly relevant if it is demonstrated for *Pleoticus muelleri* at the area of study, where this species is known to develop a seasonal reproductive migration to offshore waters (Wyngaard and Bertuche, 1982). The present finding undoubtedly reveals a gap in the knowledge of the Pleoticus sp.'s behaviour in relation to the dynamics of several oceanographic variables. This data set up the needing of new research over this highly relevant socioeconomic activity, in order to establish actual future perspectives.

Since 1989, world capture production of fish, crustaceans, and molluscs has been declining annually by ≈233,000 tons. Recent changes in the distribution and productivity of a number of fish species can be ascribed with high confidence to regional climate variability, such as the "El Niño" Southern Oscillation (ENSO). The climate-related drivers include oceanographic parameters like water temperature, salinity, wind fields, oxygen, pH, and the density

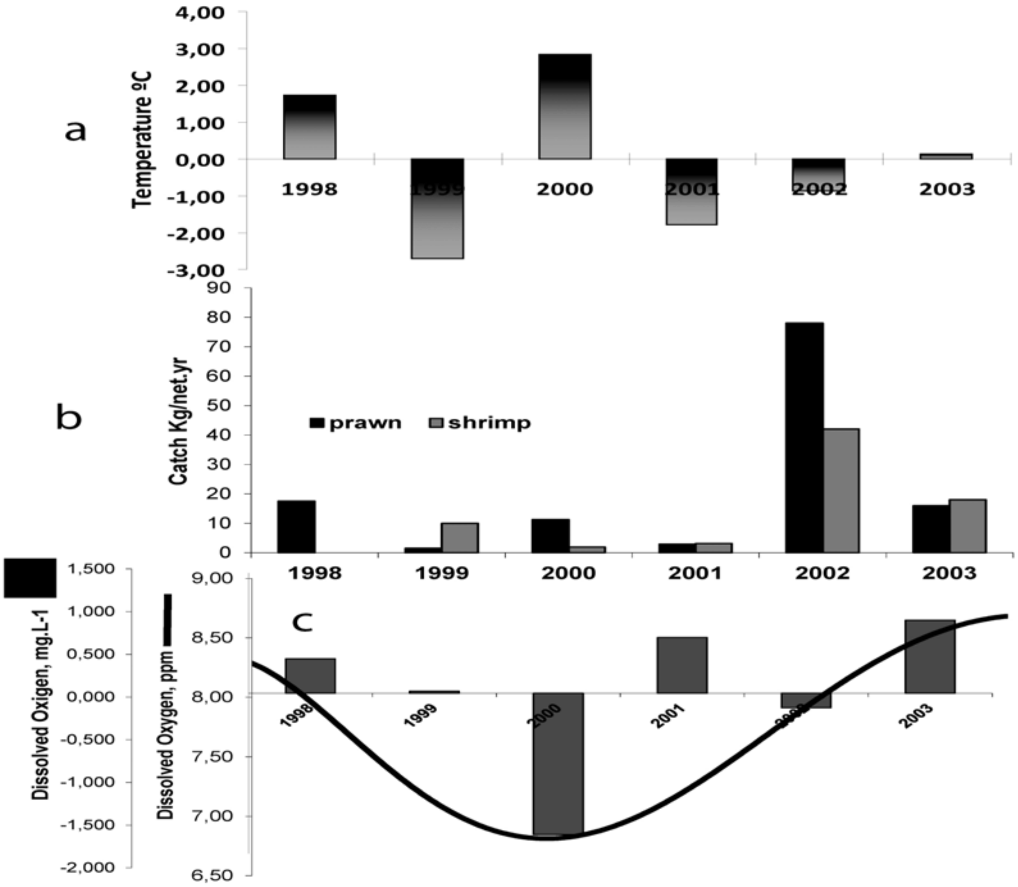

Fig. 8. Correlation between water's temperature and dissolved oxygen with the commercial prawn and shrimp catches at the area of study, from 1998 to 2003. A: water temperature anomalies; B: commercial crustacean's catches; C: Dissolved Oxygen concentration its anomalies

structure of the water column (Southward et al. 2005; Brander *et al.*, 2007; Portner and Knust 2007). In agreement with the worldwide observed trend, a declining trend on the capture production of fish has been observed at the area of study over the last decades (Conde *et al.*, 2009). Moreover, from a higher point of view, The National Fisheries Council (CFP) of Argentina determined the occurrence of a declining trend in biomass and coastal resources, joint to a vulnerability scenario for many commercial species, namely, *Macruronus spp.*, *Malacoraja senta, Mallotus villosus, Merluccius spp.*, *Micropogonias spp.*, *Mugil cephalus, Cynoscion guatucupa, Paralichthys orbignyanus, Lycengraulis olidus*, etc. (CFP, 2001). Against this background, several researchers have raised their hypothesis. On the one hand, López Cazorla and Sardiña set the hypothesis from which changes in phytoplankton assemblages emerges as the main cause of the decreased catches, attributing these changes to an anthropogenic origin, in this case, port activities, dredging, sewage and industrial effluents (2005).On the other hand, these authors and others set out a second hypothesis by which the inappropriate fishermen management of the resources (e.g., overfishing) would be responsible of the catches' decrease (Perrota *et al.*, 2007). Taking in consideration the oceanographic data presented, a third hypothesis is postulated, by which the variability in several oceanographic parameters (water temperature, salinity, and dissolved oxygen) could be driving the observed fisheries trends. It is noteworthy to say that this hypothesis includes the first one and does not exclude the second one. In order to test the hypothesis, firstly the compiled data of the catches from local fisheries (Conde *et al.*, 2009; White's Fisheries Cooperative Ltd., 1998 and Ministry of Agriculture, Livestock and Fisheries, 2007) were correlated with the variability in water temperature and salinity.

As shown in Fig. 3, in the late 80's began a trend of increasing water temperature, especially in spring and summer. This trend was maintained and improved in the 90's and occurred with high interannual variability and large anomalies in salinity, at least until 2001 (Fig. 2 and 9). Surprisingly, taking into account the published data about fisheries catches by Conde *et al.*, since the beginning of these oceanographic anomalies, the catches showed a sustained declining trend, reaching their bottom values by 2001(Fig. 9). Then, in the following years, when temperature and salinity anomalies decreased and the interannual variability was also minor, a small catch recovery was recorded. A second observation from this data is that as a general rule, the years with highest salinity corresponded to the lowest catches and vice versa

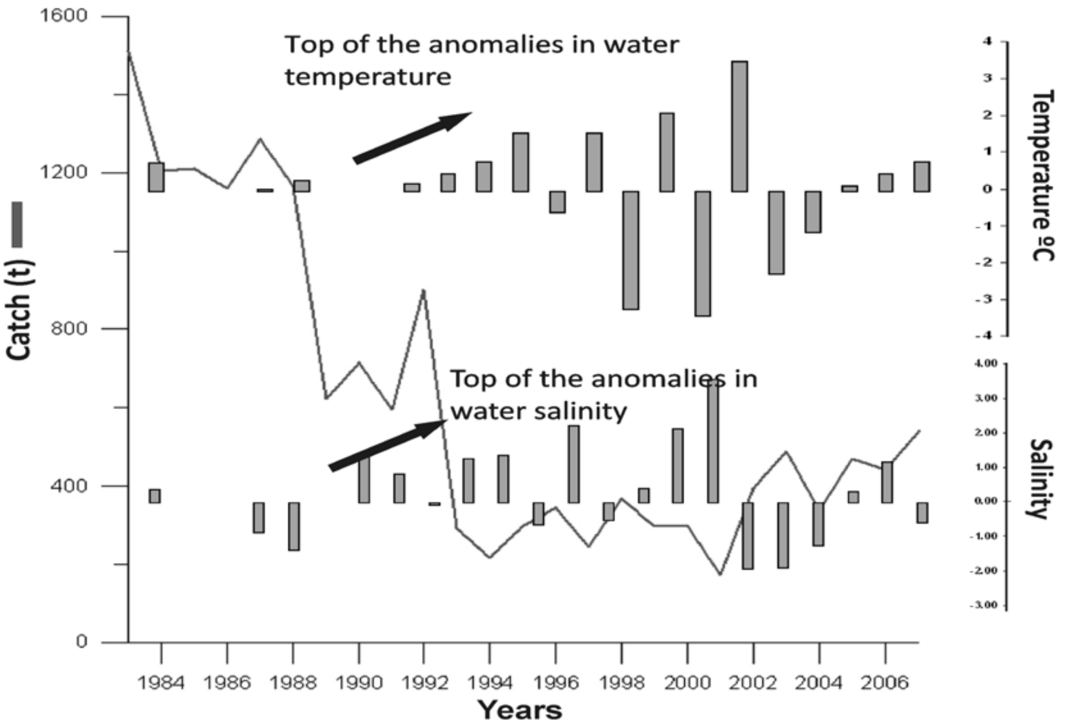

Fig. 9. Correlation between water temperature and salinity anomalies with fish catches at the area of study through the last 20 years (catches data adapted from Conde *et al.*, 2008)

(Fig. 9). This is in agreement with a previous observation: as mentioned before, higher salinities are the result of less precipitation and freshwater inputs, thus limiting the nutrient access and development of plankton assemblages and therefore the rest of the food chain.

In summary, taking these observations into account, and assuming that the fishing fleet and committed workforce was maintained through the years, it can be raised the hypothesis by which "low water temperature and salinity interannual variability favours higher fishing yields at the Bahia Blanca Estuary". This hypothesis is firstly supported by numerous literature researches either observational or dealing with its underlying mechanistic basis. In example, the recent decreasing frequency of colder winters and increased occurrence of warmer summers have impacted the marine population structure and community composition worldwide, as observed in the German Wadden Sea (Portner *et al.*, 2007), Texas bay and estuaries (Tolan *et al.*, 2009), Mediterranean sea (Mazaris *et al.*, 2008; Tolan *et al.*, 2009) and three regions in the western North Pacific: the Oyashio, the subtropical water, and the southern Japan/East Sea (Chiba *et al.*, 2008). In addition, it has been demonstrated in Japan that colder regimes are being dominated by sardines while warmer years are dominated by anchovies (Takasuka *et al.*, 2007). At last, ambient temperature has also the property of influence reproductive parameters of clupeoid fish (Funamoto *et al.*, 2004) (Graham *et al.*, 2009; Tveiten 2008) and other commercial species.

In addition, as mentioned before, salinity deviations have been pointed as critical for fisheries, as they may affect planktonic assemblages or the macrophyte vegetation (Pankow and Wasmund, 1994; Schumann *et al.*, 2006), which indirectly affects fisheries catches through the alteration of the lowest rungs of the food chain.

CONCLUSION

This paper presented one of the most common approaches used to collect and analyse data in the field of environmental perturbation: observation and correlation. This means that the collected data (in terms of spatial and temporal scale) provided valuable preliminary results, from which emerging hypotheses regarding cause-and-effect relationships were formulated. However one of the major attributes which strengthened the results was the use of a multi-decadal observational data base.For the first time, long-term variations on oceanographic parameters (water temperature, salinity, pH and dissolved oxygen) were correlated with documented ecological effects at the Bahia Blanca Estuary, in Argentina. Based on the results and analysis new evidence emerged and the following hypotheses were raised:

- "The variations in water Temperature, pH, DO and Salinity can restrict the growth of the phytoplankton assemblages, leading to other factors (i.e., grazing) the size control of the cells"
- "Considering the ecosystem's averages, negative deviations from the average water temperatures in conjunction with positive deviations from average salinity set a proper scenario for a switch in zooplankton species"
- "A strong water temperature interanual variability joint to decreased DO values results in poor commercial crustaceans catches (<10 Kg/net, *Pleoticus muelleri* and *Artemesia longinaris*)"
- Regarding fisheries, "the low interannual variability of water temperature and water salinity favours higher fishing yields at the Bahia Blanca Estuary and vice versa"

These unprecedented findings represent substantial information for the focus of the future ecosystem research and management, revealing several gaps in the present knowledge. They are also of high relevance for the international conversation on the anthropogenic pressure and climate's induced changes over the coastal ecosystems. Despite this, this paper is correlating variables with effects and discussing those relations but not determining causation. In this sense, the hypotheses are still suggestive. Therefore, they have to be tested in controlled environments and further ecological research and field experiments will be needed in the area.

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