Vulnerability and Adaptation of Estuarine Systems of the Río de la Plata

A Final Report Submitted to Assessments of Impacts and
Adaptations to Climate Change (AIACC), Project No. LA 32

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2006

Published by
The International START Secretariat
2000 Florida Avenue, NW
Washington, DC 20009 USA
www.start.org

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About AIACC

Assessments of Impacts and Adaptations to Climate Change (AIACC) enhances capabilities in the developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities. These activities are supporting the work of the United Nations Framework Convention on Climate Change (UNFCCC) by adding to the knowledge and expertise that are needed for national communications of parties to the Convention.

Twenty-four regional assessments have been conducted under AIACC in Africa, Asia, Latin America and small island states of the Caribbean, Indian and Pacific Oceans. The regional assessments include investigations of climate change risks and adaptation options for agriculture, grazing lands, water resources, ecological systems, biodiversity, coastal settlements, food security, livelihoods, and human health.

The regional assessments were executed over the period 2002-2005 by multidisciplinary, multi-institutional regional teams of investigators. The teams, selected through merit review of submitted proposals, were supported by the AIACC project with funding, technical assistance, mentoring and training. The network of AIACC regional teams also assisted each other through collaborations to share methods, data, climate change scenarios and expertise. More than 340 scientists, experts and students from 150 institutions in 50 developing and 12 developed countries participated in the project.

The findings, methods and recommendations of the regional assessments are documented in the *AIACC Final Reports* series, as well as in numerous peer-reviewed and other publications. This report is one report in the series.

AIACC, a project of the Global Environment Facility (GEF), is implemented by the United Nations Environment Programme (UNEP) and managed by the Global Change SysTem for Analysis, Research and Training (START) and the Third World Academy of Sciences (TWAS). The project concept and proposal was developed in collaboration with the Intergovernmental Panel on Climate Change (IPCC), which chairs the project steering committee. The primary funding for the project is provided by a grant from the GEF. In addition, AIACC receives funding from the Canadian International Development Agency, the U.S. Agency for International Development, the U.S. Environmental Protection Agency, and the Rockefeller Foundation. The developing country institutions that executed the regional assessments provided substantial in-kind support.

For more information about the AIACC project, and to obtain electronic copies of AIACC Final Reports and other AIACC publications, please visit our website at www.aiaccproject.org.

Summary Project Information

Regional Assessment Project Title and AIACC Project No.

Vulnerability and Adaptation of Estuarine Systems of the Río de la Plata (LA 32)

Abstract

The Rio de la Plata basin and estuary have been substantially influenced by human activities in recent decades, and are highly sensitive to climate extremes and changing precipitation patterns caused by climate change and variability. This project will develop regional hydroclimatic scenarios and assess impacts and vulnerability to climate change and variability in socioeconomic and environmental sectors for the Rio de la Plata. The study will include the development of reference projections (5-30 years) for a range of climate and non-climate factors to understand ecosystem response and obtain credible estimates of future impacts on salinity, nutrient-pollution, net ecosystem metabolism, fisheries resources, and aquatic biodiversity. Research will address a number of crosscutting factors important for assessing vulnerability, including changes in baseline socioeconomic conditions and assessment of adaptation costs. In order to orient scientific efforts toward effective management or policy decisions at the regional or national level, the project will lay the framework for an Adaptation Control Information System, which provides information and recommendations for developing anticipatory adaptation measures. The project team will identify, in consultation with other scientists and policy makers, which policies are most in need of immediate implementation, and analyze the costs and benefits of alternative adaptation strategies and current practices.

Administering Institution

Facultad de Ciencias de la Universidad de la República (UdelaR), Iguá 4225, Montevideo, Uruguay

Participating Stakeholder Institutions

Unit of Climater Change, Ministery of Housing, Planning and Environment, Montevideo, Uruguay

Unit of Water Quality, Ministery of Housing, Planning and Environment, Montevideo, Uruguay

Directorate of Water Resources, Ministery of Public Works, Montevideo, Uruguay

Countries of Primary Focus

Uruguay and Argentina

Case Study Areas

Estuarine Waters of the Rio de la Plata and coastal systems of Uruguay

Systems and Sectors Studied

Climate, Biodiversity, Regional Economy

Estuarine Ecosystems, Regional Climate Scenarios and Modeling, Sea Level Rise, Coastal Zone, Water Resources, Fisheries, Health

Groups Studies

Subsistence Fishermen

Sources of Stress and Change

Changes in mean annual/seasonal climate; Precipitations (increase in droughts, inundations and river floods) ; River Flow; Temperature; Sea Level Pressure; Winds / Storm Surges; Sea Level (both eustatic and non-eustatic); Other stresses (non-climatic); Population Growth; Land Use Change; Damming; Nutrient inputs

Project Funding and In-Kind Support

AIACC: US 100,000 grant; Ministery of Housing, Planning and Environment: Project GEF-FREPLATA: US 6,250; Facultad de Ciencias In-Kind Support

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Executive Summary

Research Problem (as thought by 2001 and updated to 2004).

The Third Assessment Report (TAR) of the IPCC (2001), referred to as TAR, identified two main environmental problems in South America: Land Use Changes and ENSO variability. The Rio de la Plata basin (RPB) and estuary (RP) have been substantially influenced by human activities in recent decades and are highly sensitive to climate extremes and changing precipitation patterns. The Paraná-Uruguay system river water discharge increased by ~30% since 1961 with the consequent increase in river flow (Q_V) and decrease in salinity (Nagy *et al*. 1997, 2002).

The RP is susceptible to develop symptoms of eutrophication (Nagy et al., 2002c). As a result of the changing climatic and nonclimate conditions over the past fifty years both the natural susceptibility (vulnerability) to flush and dilute nutrients and the development of symptoms of eutrophication (impact) increased. Within the frontal zone or estuarine front (EF) such processes like nutrient removal, in situ production of organic matter (CH20), and denitrification are estimated to be high (Nagy, 2000). The main symptoms of eutrophication are an increase of organic matter (CH20) "expressed" as increased algal biomass (B) and production (P), oxygen stress, and Harmful Algal Blooms (HABs).

The increase in river flow variability vary both the location and structure of the Estuarine Front, affecting the sites of reproduction and catch of fishes. Thus, coastal fisheries are impacted because of the changing accessibility of the fishing area (i.e. 1987-1988 and 1997-1999).

Primary objectives and expected outputs of the project updated to 2004.

Overall goal of the project was: i) to assess vulnerability and impacts of/on the estuarine waters (hydrology and ecosystem), coast and resources of the RP and ii) to plan adaptation strategies for coastal fisheries (Adaptive Control Information System-ACIS) in order to cope with climate variability and change, weather conditions and nonclimate scenarios. The key questions to be addressed were:

- How sensitive is the system to Climate Variability and Change?
- Is eutrophication related to Climate Change and Variability?
- Is the coastal fishery system sustainable under increased river flow variability?
- Will the coastal zone be heavily impacted over the next few decades?

The secondary questions to be answered were:

- How would an increase of River flow (Q_V) and Nutrient input (N_I) affect trophic state and symptoms of eutrophication (i.e. oxygen stress and HABs), especially along the Canal Oriental?
- Is the frontal zone role as a site for reproduction, nursery and feeding of fisheries resources modified by short- and long-term hydroclimatic variability?
- How do the consecutive occurrence of hydroclimatic extremes (i.e. the 1998-2000 period), affect the adaptive capacity of the estuarine ecosystems?

The exposed analyzed units were:

i) the estuarine frontal zone and ii) the Santa Lucía river lower basin, estuary and associated coastal zone. We focused on the understanding of ecosystem response in order to obtain credible estimates of future vulnerability and impacts on:

- trophic status changes (increase in symptoms of eutrophication),

- coastal fisheries and associated livelihood vulnerability, and
- water resources, trophic state changes (TSC) and sea-level rise (SLR) in the Santa Lucia river lower basin and estuary (SLRE).

Time horizons considered were from the past 30 years and present through 2030 / 2050 / 2080.

Approach

The overall approach taken in this multisectoral research has consisted of combining several methods. We can divide them into three main ones:

- Empirical / Statistical;
- Global Circulation Models (GCM) and
- Downscaling techiniques.

Empirical / Statiscal. We reconstructed climatic, enviromental, hydrological and oceanographic time-series from available data and proxy variables.

Global Circulation Models. We selected seven available runs from IPCC Distribution Data Center, using socioeconomic SRES-A2 and B2 forcing scenarios. We have compared sea level pressure (SLP), surface air temperature and precipitation from the models, against observed climate fields, trying to estimate regional performance of the control simulations (1961 – 1990 baseline). The comparison between the monthly and annual SLP fields shows that only four models (HADCM3, CSIRO-mk2, ECHAM4, GFDL-R30) have an acceptable agreement with the observed SLP field. All scenarios underestimate precipitation. The future climate change scenarios, for precipitation and temperature were constructed for 2020, 2050 and 2080s.

Statistical and dynamical downscaling experiments. In order to generate precipitation and temperature daily time series based on future climate change scenarios from the GCMs we selected the both statistical and dynamical techniques for downscaling to bridge the spatial and temporal resolution gaps between climate models and vulnerability assessments requirements. We made use of statistical downscaling technique trough the SDSM model (*Wilby et al.,* 2001). This model showed to be a valuable tool to represent some of the characteristics that existed in the regional precipitation data. Another tool used to generate future high resolution scenarios over Southeastern South America was PRECIS (Hadley Center's regional climate modeling system).

Overall framework for vulnerability and adaptation

The overall Framework of this research is the second generation assessment (SEI, 2001, Figure 1).

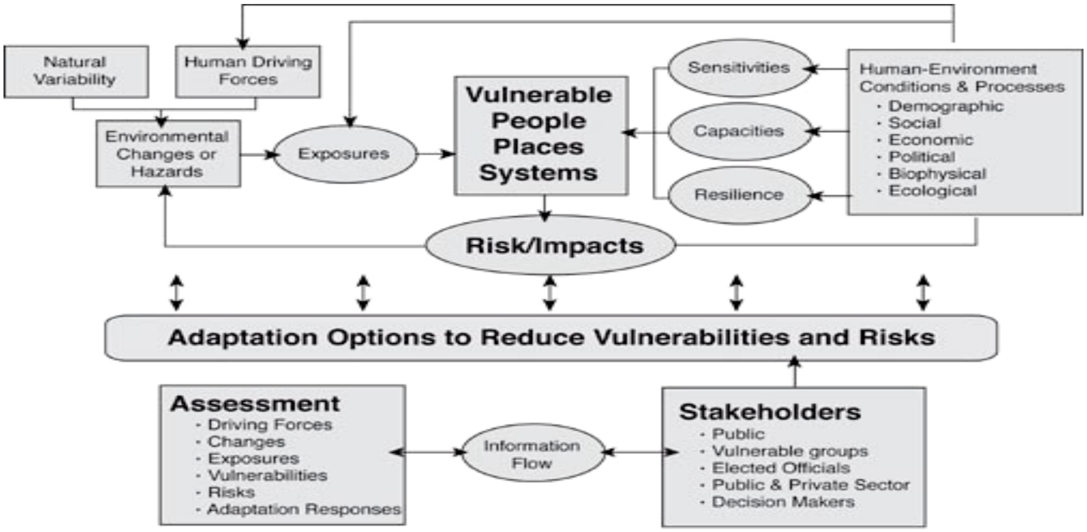

Fig. 1: Vulnerability, Adaptation and Responses: assessments (from SEI, 2001).

Scientific findings and questions

Main climatic changes in the RPB are the increase in ENSO variability and precipitation (≥ 20%), southward displacement of the Atlantic subtropical high pressure circulation-SAHP and changes in frequencies of the prevailing winds; increase in air and water temperatures (≥ 0.8 ºC), as well as changes in runoff, soil moisture and the Pantanal's extent (Díaz et al., 1998; Camilloni and Barros, 2000; Escobar et al., 2004; Bidegain et al., 2004; Liebmann et al., 2004).

Climate Trends

We have updated climate, hydrologic and oceanographic yearly long-term trends up to 2000 / 2003 (temperature, precipitation, sea level pressure, river flows, sea level rise, salinity).

Coastal Fishery System

Goal: To assess overall vulnerability of the Coastal Fishery System (CFS) in the Estuarine Front of the Rio de la Plata to cope with Global Environmental Change.

Problem: An artisanal fleet exploit fisheries a few miles off the Uruguayan coast in the estuarine front (EF) of the Rio de la Plata. Both, the observations and the economic scenario suggest: In case of an increase in climatic constraints only performant and better adapted fishermen should be able to remain within the frontal zone fishing area.

Trophic State and Eutrophication: Even if nutrient inputs to the Rio de la Plata are well below the figures for developed countries, they are higher than they were by 1950. Summarizing:

Eutrophication in the Rio de la Plata system can be thought of as a syndrome (a suite of symptoms) that change with the seasons, years and decades, showing an increasing trend of pressure and state indicators since the mid 1940s, and a shift during the 1970s and 1980s. Natural processes must have been accelerated due to the increase in hydroclimatic means and extremes that led to an increase in soil erosion and diffuse sources of nutrients. These processes, combined with human activities such as damming, which have indirectly altered the trophic *status* by modifying the physical environment (e.g., residence time, local warming), determine that the increase in nutrient load over the last five decades, even if it was well below the figures for developed countries, has altered the natural trophic *status* background and/or stimulated the development of new symptoms, whose drivers are expected to increase (since 1990) in the next few decades (López and Nagy 2005).

Sea Level Rise and coastal vulnerability of the Western Coast of Montevideo: The western coastline of Montevideo (~80 km including fishermen settlements, Santa Lucía river estuary and mouth, beaches and wetlands) was previously defined by several qualitative assessments as one of the most vulnerable of the country to sea level rise-SLR (Saizar, 1997; Nagy et al., 2005). The solely long-term tide-gauge record in Uruguay is located within this coastal section (Punta Lobos). We used a quantitative index of vulnerability and objectivley classified this coastal section as highly vulnerable.

Santa Lucia River Estuary and Coastal Zone: Interannual variability of Santa Lucia river flow (Q_{SL}) is strongly ENSO-related in the middle basin from August to February. Such as a relationship with ENSO was not expected because previous works indicated that it's signal was relatively weak in Southern Uruguay (Bidegain and Caffera, 1989). The evolution of trophic state changes (TSC) showed a strong relationship with the increase in freshwater (October 2002 to May 2003) which enhanced physical controls on TS other than temperature. This control blocked the expression of symptoms of eutrophication (i.e., chlorophyll-a) when salinity was <1 in the estuarine zone. Once both Q_V and Q_{SL} were within their normal range, salinity increased to 4-7 as well as chl-*a* did up to eutrophic levels.

Summarizing, hydrology, which is partially ENSO-controlled, is a strong physical control of biogeochemical processes and TSC of Santa Lucia river estuary. River flow fluctuations induce enviromental within this system and in the adjacent coastal waters of the EF of the RP.

Future Climate Scenarios and environmental vulnerability*:* We selected seven available runs from IPCC Distribution Data Center, using socioeconomic SRES-A2 and B2 forcing scenarios. We have compared sea level pressure (SLP), surface air temperature and precipitation from the models, against observed climate fields, trying to estimate regional performance of the control simulations (baseline climate scenarios). The comparison between the monthly and annual SLP fields shows that only four models (HADCM3, CSIRO-mk2, ECHAM4, GFDL-R30) have an acceptable agreement with the observed SLP field and are able to represent the position and intensity of the pressure systems and the annual cycle. In all cases, precipitation is largely underestimated within the Río de la Plata basin. The comparison between the monthly and annual temperature fields shows that in general all the models have an acceptable agreement with the observed fields.

The future climate change scenarios for precipitation and temperature, over Southern cone of South America were constructed for 2020, 2050 and 2080s.

Statistical and dynamical downscaling experiments: In order to generate precipitation and temperature daily time series based on future climate change scenarios from the Global Climate Models (GCMs) we selected the both statistical and dynamical techniques for downscaling to bridge the spatial and temporal resolution gaps between climate models and vulnerability assessments requirements. We made use of statistical downscaling technique trough the SDSM model (*Wilby et al.,* 2001). The selected predictor variables (taken from NCEP reanalysis) for daily precipitation are sea level pressure, zonal and meridian wind components at 850 hPa. We selected four locations in Southeastern South America during the period 1996 – 2001: Buenos Aires, Santa Fe, Montevideo and Salto. SDSM model showed to be a valuable tool and is capable of representing some of the characteristics that existed in the precipitation data of the temperate region of South America.

Another tool used to generate future high resolution scenarios over Southeastern South America was PRECIS (Hadley Center's regional climate modeling system). These scenarios are being developed at present and will be used in impact, vulnerability and adaptation assessments as well as in third National Communication to the UNFCC behalf the Unit of Climate Change (Ministry of Environment).

Some conjectures about plausible climatic and environmental scenarios: Current environmental scenarios (1971-2003) in the Rio de la Plata basin (RPB) and estuary discussed all along this report are dominated by the following main stresses:

- increases in temperature, precipitation, river flows, sea-level rise and onshore winds.
- increases in population, damming, use of natural resources and export of nutrients.
- increases in economic activities, land use changes, soil erosion and runoff / infiltration ratio.

Current climate and future scenarios (time horizon 2020 - 2050) for the RPB and estuary suggest a change in precipitation, temperature and sea-level rise within the ranges +5% to +20%, +1 to +2°C and 10-15 cm respectively, whereas during the last few decades these changes have being + 20 to 25% for precipitation, +0.5 to +0.8°C for temperature, 5 cm for SLR, as well as + 25 to 40% for river flows (Q_V).

Trends for Q_{Vs} are very difficult to be estimated because of both the uncertainty of regional human drivers and because of the varied regional scenarios from different GCMs. Main uncertainty is related to the understimation of precipitation and the relative amounts of potential and actual evapotranspiration rates in the future. Under a future scenario (2020-2050) in which streamflow remains similar or slightly lower (i.e. 0% to -10%), we do not expect a significative increase in present environmental stresses on the estuarine system (which are already moderately high) with the expection of N inputs and further TSC. Our concern is about a future scenario where Q_V increases within the range around 10-25%, together with projected temperature increases and economic growth, for which significant impacts are expected in the estuarine and coastal systems.

Considering the fact that seasonal temperature, precipitation and streamflow cycles are not superposed, any changes should modify seasonal circulation and mixing state or stability (vertical difference in salinity as a function of depth: dS/dZ), inducing further environmental shifts and changes (i.e. Δ gas and nutrient exchanges, Δ P-R, increase in HABs occurrence, with a probable increase in both the degree and occurrence of hypoxic events, as well as an increase in the vulnerability of fishermen and low-lying areas.

Capacity building outcomes and remaining needs

Capacity building

LA 32 team members have developed Earth System Science and Global Change lectures for a course devoted to High School teachers of Earth and Space Sciences.

LA 32 team members attended to about ten workshops and courses devoted to climate scenarios, climate modeling, vulnerablity and adaptation assessment methods, GIS and Environmental Monitoring, Estuarine Systems, Remote Sensing, Global Enviromental Change and Participatroy Processes..

GJ Nagy, A Ponce and G Sención attended to the AIACC Workshop on Vulnerability and Adaptation in Trieste, Italy (2002).

LA 32 team members developed lectures on Global Change for a Graduate International course (UdelaR-AEO-Scripps) on Ocean Color for Latin American students.

LA 32 team members updated the course on Earth System Science and Global Environmental Change for the Master of Science in Env. Sciences, Facultad de Ciencias, UdelaR.

LA 32 team members were invited by DINAMA (Uruguay) to present their results on June 2005.

Remaining needs

1. To improve our capacities in:

- Vulnerability mapping
- Integrated climatic, environmental and socioeconomic analysis.
- Quantitative multicriteria assessments of stakeholders perception
- Particpatory proceesses and stakeholders engagement

2. To develop an update socioeconomic national scenario including all sectors involved in our research. We assume that this task will be conducted during the the 3rd National Communication (TNC).

National communications, science-policy linkages and stakeholder engagement

LA-32 team members participated / were engaged or will participate in:

- the revision of the 2nd National Communication SNC) Draft under the UNFCC.
- in several workshops (2003-2005) organized by the Ministry of the Environment: Synergies of the three conventions: Biodiversity, Climate Change and Desertification.
- G J Nagy was nomitated by the IPCC to act as a Lead Author of Chapter 13 (Working Group II, Latin America – coasts). He was supported by the Directorate of the Environment of the Uruguayan Ministry of Foreign Affairs, the Unit of Climate Change of the Uruguayan Ministry of the Environment and AIACC.
- a series of 4 Prospective workshops organized by the Minisitry of the Environment: "Reflections on Uruguay 2025" (Coastal Zone Working Group).
- a LA-26 stakeholders meeting in Buenos Aires (July, 2004).
- the draft draft on coastal systems vulnerability and adaptation (Unit of Climate Change of the Ministry of the Environment in order to plan the Third National Communication.
- LA-32 team members were engaged by the UCC-ME to update climate and environmental time-series for the main watersheds and coastal zone of Uruguay and develop high resolution climate models (PRECIS). This information will serve to write the 3rd National Communication (TNC) under the UNFCC.
- a meeting with the GEF consultant (*Pascal Girot*) whos evaluated the capacity to undertake vulnerability and adaptation assessments and climate modeling for the coastal systems, fresh and estuarine waters during the TNC.

Policy implications and future directions

LA-32 team members participated / were engaged or will participate in:

- the development of cooperation with the Directorates for Water Resources (Min. Of Public Works) and Hydrography and Oceanography (Min.of Defence), the Public system of education (elementary, high and technical schools) and an agreement with the Russian Academy of Sciences Institute of Oceanology.
- the Peruvian Report on Vulnerability to Climate Change CONAMA-Perú, 2005).
- a pre- and full proposal on *Global Change and Sustainable Livelihood in the Rio de la Plata Basin (IAI-CRN II call*). If approved, this project will be the core of future development of global change and sustainability research during the period 2006 – 2010.

- a presentation on current and future climatic and environmental scenarios for the Uruguay river basin and stream (Bi-national Uruguay river Management Committee: Argentina - Uruguay). If future cooperation is agreed, vulnerability assessments and adaptation policies to cope with global envrionmental changes should be planned.
- a presentation on current and future climatic and environmental scenarios and impacts for the Rio de la Plata Basin and Estuary to ONGs, journalists and congressmen.

1 Introduction

1.1 Problem

The Third Assessment Report (TAR) of the IPCC (2001), referred to as TAR, identified two main environmental problems in South America: Land Use Changes and ENSO variability. The Rio de la Plata basin (RPB) and estuary (RP) have been substantially influenced by human activities in recent decades and are highly sensitive to climate extremes and changing precipitation patterns. The weight of scientific evidence suggests that there is now a discernible human influence on environmental deterioration within the RPB (3,2 x 1011 km2) and RP (3.6 x 104 km2) in addition to a change of precipitation patterns with the consequent increase in river flow (QV) and decrease in salinity.

The Paraná-Uruguay system river water discharge increased by ~30% since 1961 (Nagy et al. 1997, 2002). The region is highly sensitive to climate extremes such as ENSO, and also suffers from increasing land cover change and misuse of land, which in turn have changed the infiltration: runoff ratio. On the other hand, both the population increase (> 1% y-1) and fertilizer application (> 20 kg ha-1) have led to an increase in N and P input to the coastal waters.

Population of the RPB increased by 90% from 1961 to 1994 (Baethgen et al., 2001) leading to an increase in pressures on watersheds. For instance they are heavily utilized for agriculture, damming, fertilizer application, and there is a heavy discharge of wastewater from point sources (wastewater treatment from domestic input is ~ 20%), and of nutrients from non-point sources. (Pizarro and Orlando, 1985; Tucci and Clarke, 1998; Nagy, 2000; Nagy et al., 2002a).

The Uruguay River Basin (URB) has an area of 297,000 km2 in Brazil, Argentina and Uruguay and a population density of 25 /km2. Some relevant land-use data are: 4% of wetlands, 2% of protected areas, 44% of cropland and 45% of grassland areas. Main enviromental deteriortation data are: 20% of eroded area, 92% lost of original forest, a rate of 12% of deforestation. There are two large dams on the River Uruguay (WRI, 1998).

Coastal waters provide habitat for some of the most productive ecosystems on earth. These resources are in danger from excess input of nutrients (NCR 2000). Nearly all estuarine waters now exhibit some symptoms of eutrophication, although the level of nutrient inputs required to produce the symptoms is variable (sensitivity). As a result of the changing climatic and nonclimate conditions over the past fifty years both the natural susceptibility (vulnerability) to flush and dilute nutrients and eutrophication (impact) increased. The RP is susceptible and eutrophic. Within the frontal zone such processes like nutrient removal, in situ production of organic matter (CH20), and denitrification are estimated to be high (Nagy, 2000). The main symptoms of eutrophication are an increase of organic matter "expressed" as increased algal biomass and production, oxygen stress, and Harmful Algal Blooms (HABs).

The increase in QV variability vary both the location and structure of the Estuarine Front-EF, affecting the sites of reproduction and catch of fishes. Coastal fisheries are impacted because of the changing accessibility of the fishing area (i.e. 1987-1988 and 1997-1999) as shown in Figure 2. The Canal Oriental behaves as a conduit channel of QU that should control stratification, phytoplankton blooms and high levels of in situ CH20 production, which in turn is oxidized below the halocline. Stratification induce the development of hypoxic conditions, leading to a heterotrophic state (destruction of CH20 and source of CO2). The pronounced reduction of QV during La Niña, i.e. in November 1999, and the consequent increase in flushing time (ft), led to eutrophic symptoms (Nagy et al., 2001a).

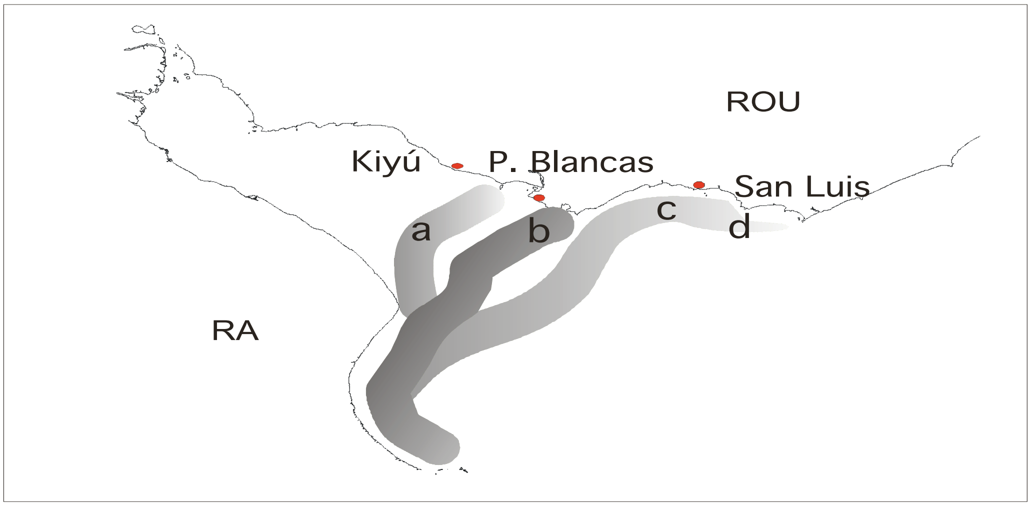

Fig. 2: Estuarine Front location under different ENSO conditions: a) Strong La Niña event (1999-2000), b) Typical c) Moderate El Niño (winter 1987) d) strong El Niño 1997-1998 / 2002 – 2003; c + d: estuarine plume (modified from Nagy et al., 2002b).

1.2 Primary Objectives and Expected Outputs of the Project by 2001 updated To 2004

Overall goal of the project was: i) to assess vulnerability and impacts of/on the estuarine waters, coast and resources of the RP and ii) to plan adaptation strategies for coastal fisheries (Adaptive Control Information System-ACIS) in order to cope with climate change and nonclimate scenarios. The key questions to be addressed were:

- How sensitive is the system to Climate Variability and Change?
- Is eutrophication related to Climate Change and Variability?
- Is the coastal fishery system sustainable under increased river flow variability?
- Will the coastal zone be heavily impacted over the next few decades?

The secondary questions to be answered were:

- How would an increase of Q_V and N_I affect eutrophication (i.e. oxygen stress and HABs) of the estuarine subsystems?
- Is the frontal zone role as a site for reproduction, nursery and feeding of fisheries resources modified by short- and long-term hydroclimatic variability?
- How does the consecutive occurrence of hydroclimatic extremes, i.e. 1998-2000 period, affect the adaptive capacity of the estuarine ecosystems?

1.3 The Main Expected Outputs of the Project

These were:

1. To improve the analysis of current climatic and nonclimate baselines.

2. To develop reference projections of a range of hydroclimatic and nonclimate factors which are anticipated to change in order to obtain credible estimates of future impacts in salinity, eutrophication, trophic *status*, fisheries resources and ecosystem services.

3. To obtain economic values of the impacts affecting direct use activities and indirect uses, according to the projected scenarios.

4. To study a set of short-term processes, i.e. oxygen stress, to explain the possible response of the ecosystem to hydroclimatic and non-climatic changing scenarios.

5. To improve the systems and methods for long-term monitoring and understanding the consequences of climate change and other stresses on the environmental systems.

6. To foster science capacity building to undertake the assessment of vulnerability and adaptation to climate and nonclimate change.

7. To plan an Adaptive Control Information System (ACIS) for implementing anticipatory measures, to offset adverse effects of changing scenarios.

1.4 The Exposed Analyzed Units

These were:

i) the estuarine frontal zone (Figure 2) and ii) the Santa Lucía river lower basin, estuary and associated coastal zone. We focused on the understanding of ecosystem response in order to obtain credible estimates of future vulnerability and impacts on:

- trophic state changes (increase in symptoms of eutrophication),
- coastal fisheries and associated livelihood vulnerability, and
- water resources, TS and SLR in the Santa Lucia river lower basin, estuary and coastal zone.

Time horizons considered were from the past 30 years and present through 2050 / 2080.

2 Characterization of Current Climate and Scenarios of Future Climate Change

2.1 Activities Conducted on Current Climate Baselines

We have engaged or worked with scientists from national institutions devoted to climatic and environmental monitoring. We gathered and bought data, updated several climate and non-climate trends and built capacity to pursuit data analysis. Most relevant baselines and trends (temperature, precipitation, sea level pressure, river flows, sea level rise, salinity), were almost completed beyond the initial goal of the project.

2.2 Scientific Methods and Data

The overall approach taken in this multisectoral research has consisted of combining several approaches and methods. We can divide them into three main ones: 1. Emiprical / Statistical; 2- Global Circulation Models (GCM) and 3- Downscaling techiniques.

2.2.1 Empirical / statiscal

We gathered, reanalyzed and reconstructed climatic, hydrological and oceanographic time-series from available data and / or proxy variables when needed to fill gaps. Regression models and cross-correlation between time-series were the main statistical method.

2.2.2 GCMs

We used all the IPCC GCMs and compared their results to current baselines of sea level pressure, temperature and precipitations (1961-1900). We selected seven available runs from IPCC Distribution Data Center, using socioeconomic SRES-A2 and B2 forcing scenario. We have compared sea level pressure, surface air temperature and precipitation from the models, against observed climate fields, trying to estimate regional performance of the control simulations (1961 – 1990 baseline climate scenarios). The comparison between the monthly and annual SLP fields shows that only four models (HADCM3, CSIRO-mk2, ECHAM4, GFDL-R30) have an acceptable agreement with the observed SLP field and are able to represent the position and intensity of the pressure systems and the annual cycle. In all cases, precipitation is underestimated within the Río de la Plata basin. The comparison between the monthly and annual temperature fields shows that in general all the models have an acceptable agreement with the observed fields.

The future climate change scenarios, for precipitation and temperature, over Southern cone of South America were constructed for 2020, 2050 and 2080s.

2.2.3 Statistical and dynamical downscaling experiments.

In order to generate precipitation and temperature daily time series based on future climate change scenarios from the GCMs we selected the both statistical and dynamical techniques for downscaling to bridge the spatial and temporal resolution gaps between climate models and vulnerability assessments requirements. We made use of statistical downscaling technique trough the SDSM model (*Wilby et al.,* 2001). The selected predictor variables (taken from NCEP reanalysis) for daily precipitation are SLP, zonal and meridian wind components at 850 hPa. We selected four locations within the RdlP basin during the period 1996 – 2001: Buenos Aires, Santa Fe, Montevideo and Salto. SDSM model showed to be a valuable tool to represent some of the characteristics that existed in the regional precipitation data.

Another tool used to generate future high resolution scenarios over Southeastern South America was PRECIS (Hadley Center's regional climate modeling system). These scenarios are being developed and we do not have results yet.

2.2.4 Overall framework and Methods

Overall framework for vulnerability and adaptation research was the Framework for second generation assessment" (SEI, 2001).

- a multi-level indicator of vulnerability to climate change (adapted from Moss, 1999) as presented in Figure 3.
- a driver–Pressure-State-Impact-Response (d-PSIR) framework (as shown in trophic state; section 3.3).
- vulnerability indicators, index and matrices, regression models, fishing activity. A combination of objective values and expert judgment was used in order to assess social, economic, environmental and legal indicators of sensitivity of the fishermen's community as well as to assess HABs impact. Non-climate projections, SRES A2 / B2 climatic scenarios and GCMs. Each indicator was classified as low, moderate and high and was given values 1, 2 and 3 respectively.
- causal loop diagrams (Ford, 1999) for water resources, ecosystem, coastal fisheries and settlement (as shown in coastal fishery sytem; section 5.2).

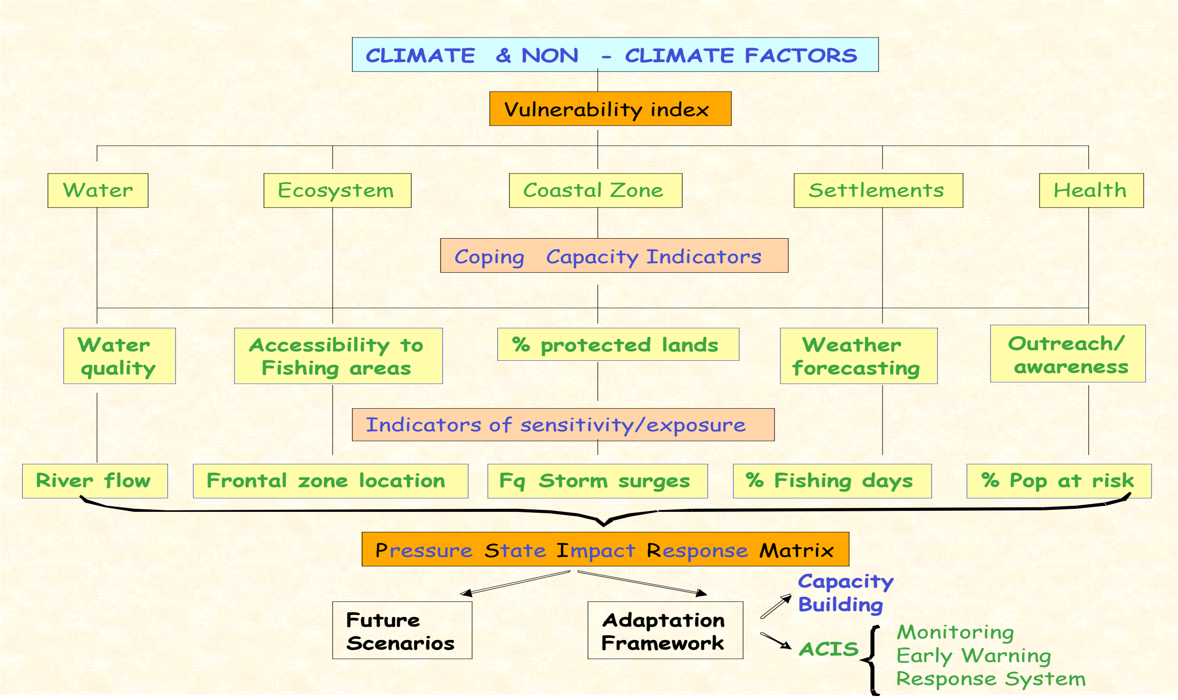

Fig. 3: Multi-level indicator of Vulnerability to Climate Variability and Change for coastal systems of the Rio de la Plata (modified from Ponce et al., 2002, adapted from Moss et al., 1999).

- Guidance for Vulnerability and Adaptation Assessment (US Country Studies Program, 1994).
- Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessments (Carter *et al.*1999), TAR Working Group II), IPCC data and models (DDC) vii) adapting to Climate Change: Assessments and Issues (Smith *et al.* 1996).

- United Kingdom Climate Impact Programme Technical Report. Climate adaptation: Risk, Uncertainty and Decision-Making (UKCIP, 2000).
- an empirical-statistical approach to investigate ecosystem impacts, responses and adaptive capacity, and vulnerability to climatic variability and extremes, and to non-climate pressures based on Observations, Data, Current Baselines and Incremental scenarios of appropriated climate and non-climate variables.

2.3 Selected Climate Models

Selected socioeconomic scenarios, time horizons and GCM were A2 and B2, 2020 / 2050 / 2080, HADCM3 and ECHAM4/OPYC3 respectively. There is a lack of appropiate spatial resolution suggesting the need of improving downscaling techniques to validate scenarios for the spatial scale of Uruguay. Lack of daily outputs from both selected models precludes to perform statistical downscaling with SDSM model for future climate scenarios.

2.4 Indicators and Proxy Variables

Vulnerability = V; Impact = I; Adaptive Capacity = AC

2.4.1 Environment (weather/water quality/ecosystem/coastal zone)

N-S: (nutrient sources - nutrient sinks)
V: Stratification index; Stratification-Circulation Parameter (S-C)
V: Residence Time; Flushing Time; 1/dilution Vs Flushing ; River Flow / upper layer volume
V-I: Multivariable Enrichment state Index; TRIX state index
V: NOAA (nutrient) export potential
V-I: Nb of reported and verified organisms outbreaks (HABs) over the last five years.
V-I: ENSO indices (several ones); multivariable index.
V: Nb of days (past 5 years) during which the Mx wind speed > than 20% higher than the average for that month
V: Nb of 5-days precipitation events > than 20% higher than the average for that year.
V: Nb of storm surges with run up greater than 2 m above mean seal level at Montevideo.
V-I: Fertilizer consumption / surface unit
V-AC: Irrigated surface / population
V: Coastal Vulnerability Index (tide range, wave height, shoreline erosion, SLR, slope)
V-I: HydroClimatic Index (temp., precipitation, river flow, SL pressure and gradients, SLR)
V-AC: % Land managed
V: Population at flood risk from sea level rise and storm surges
V: % of land area less than 5 m above sea level.

2.4.2 Coastal Fishery System

(water resources/ecosystem/fishery/settlements)
V-AC: % of income from fishing
V-I: ENSO indices (several ones); multivariable index.
V: Stormy days (% winds > 8 ms-1); fishing days;
V-I-AC: Fishing days (F) / stormy days (F /S)
V-AC:Nb and weight of fishing boats activity / month
V-I: Fish catch (CB: biomass and CI income)
AC-I: D F/CB and/or F/CI (increase: Adaptive capacity; decrease: Impact)
V-AC: Human Development Index (national and community level)
V-AC: GDP (national /regional/community level), Gini Index

V-AC: Literacy (%); % of female literacy.
V-AC:% of total income from fishery activity
V-I: Number of industrial fishing boats
V: Population at flood risk from sea level rise and storm surges: Impact)
V-AC: Human Development Index (national and community level)
V-AC: GDP (national /regional/co
V-I: % of fisheries stocks over-fished
V-AC: Number of expanded fisheries efforts over the last five years (within the frontal zone)

Several of these indicators have not been used yet, whereas other were recently adopted and are explained in the text.

2.5 Results of Long-Term Climatic, Hydrologic and Oceanographic Trends

We have updated climatic, hydrologic and oceanographic yearly long-term trends up to present (temperature, precipitation, sea level pressure, river flows, sea level rise, salinity)1.

2.5.1 Temperature.

Air temperature at Montevideo has increased ~0.8 C during the period 1883 – 2003 (*Bidegain et al., 2005*) as presented in Figure 4, mostly during the last three decades, when the increase reached about 0.9 C with a maximorum of 17.8º C in 2001(Figure 4).

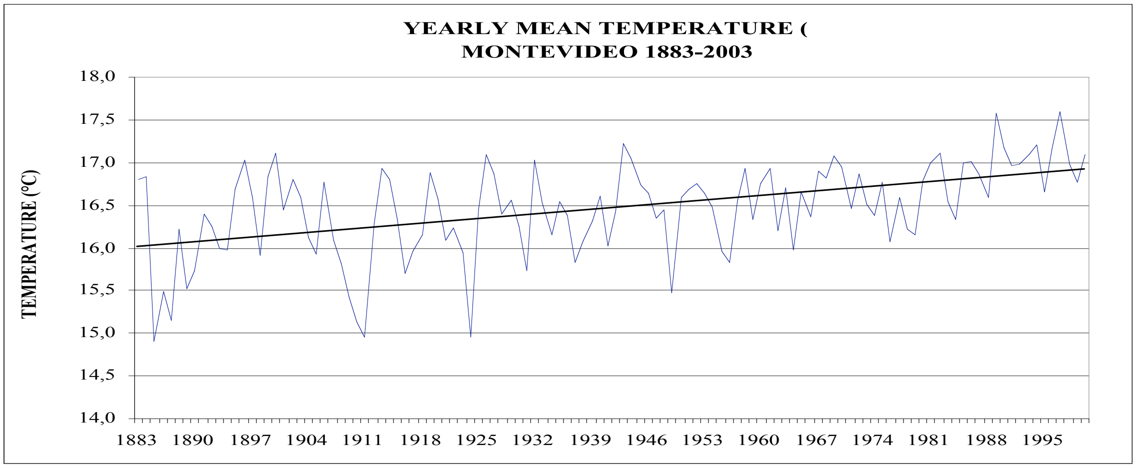

Fig. 4: Evolution of yearly air temperature at El Prado, Montevideo (1883 – 2003). From Bidegain et al., (2005).

2.5.2 Precipitation

Precipitations have increased during the last three to four decades all over the RP basin and Uruguay by ≥ 20% (Kane et al., 2002; Berbery and Barros, 2002; Blixen et al., submitted). In Figure 6 we show the time-series of yearly precipitation at Montevideo (1883-2003). Both the trend line and the minima have significant increased, as well, in a less degree, the maxima. This increase is

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[1] This section is based upon a technical report to the Ministry of the Environment (AIACC LA-32).

inequally distributed all along the year, being maximum during October and November. These patterns are very similar for other stations in Southern Uruguay (Bidegain et al., 2005).

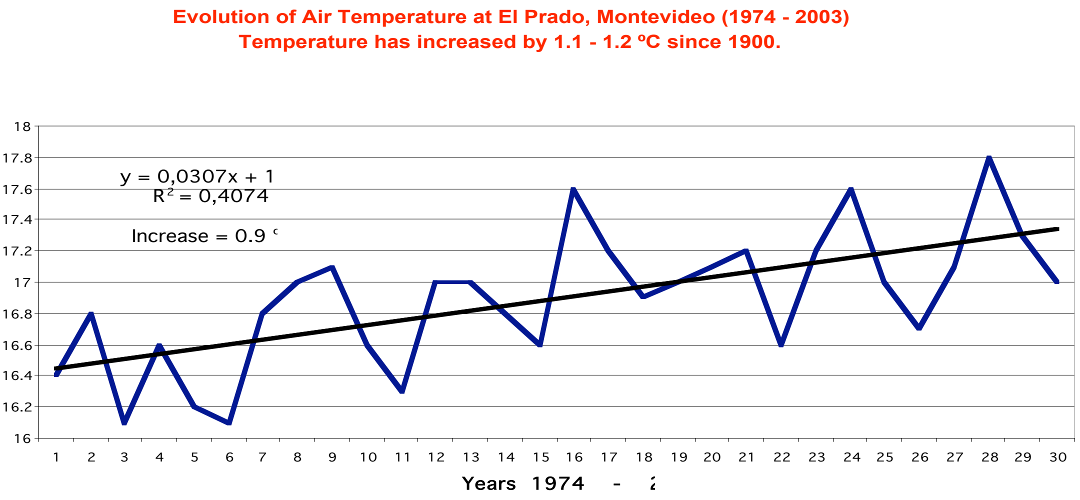


Fig. 5: Evolution of yearly air temperature at Montevideo (1974-2003). From Nagy et al, (2004).

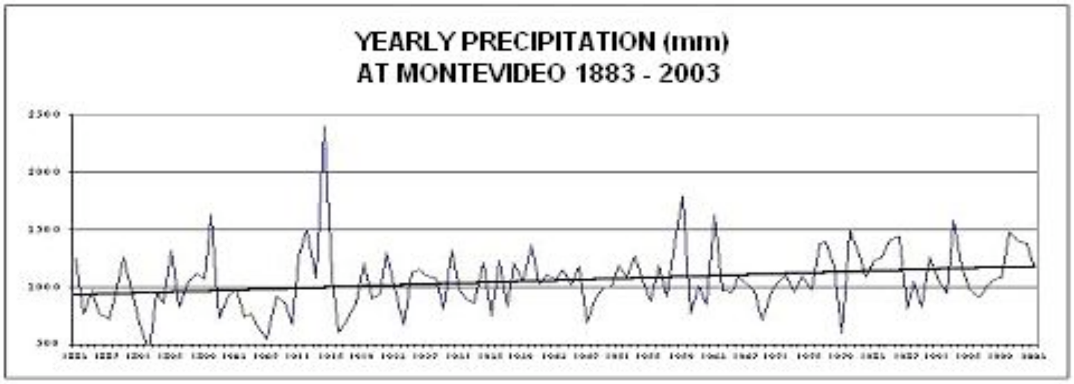


Fig. 6: Evolution of yearly precipitations at El Prado, Montevideo (1883 – 2003). From Bidegain et al., (2005)

2.5.3 River flows

Flows of Rivers Paraná and Uruguay have increased by at least 35% during the last four to five decades (Figures 7, 8) approximateley one fourth to one third more than the increase in precipitations. Part of these trends and most fluctuations are associated with ENSO events, which is shown for the period 2000-2002 (Figure 9).

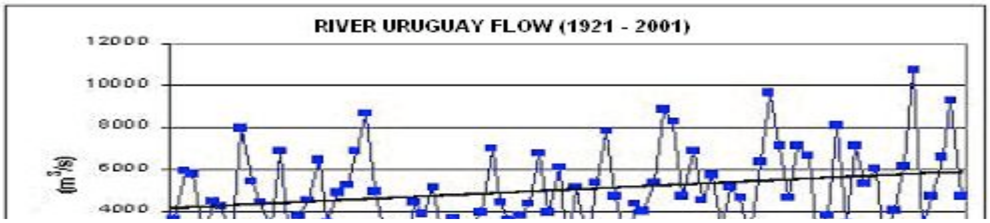


Fig. 7: River Uruguay flow at Salto from 1921 to 2003. From Bidegain et al., (2005).

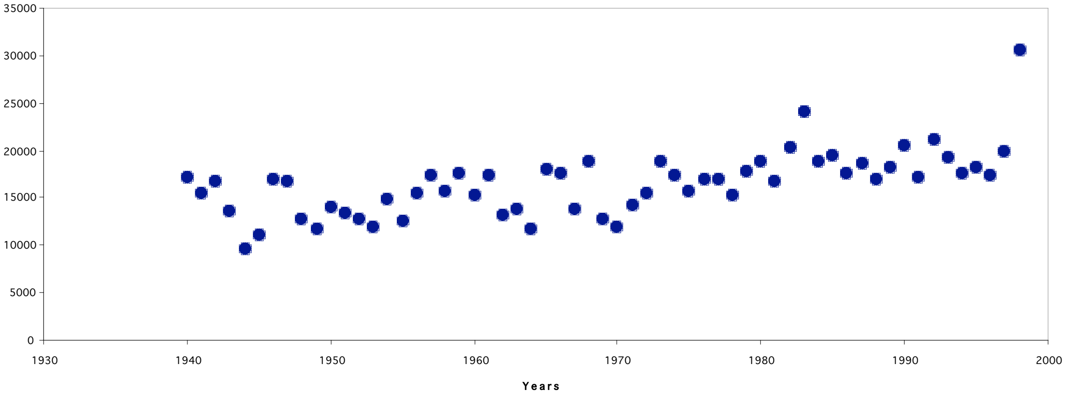


Fig. 8: River Paraná flow from 1940 to 2000. From Nagy et al., (2002c).

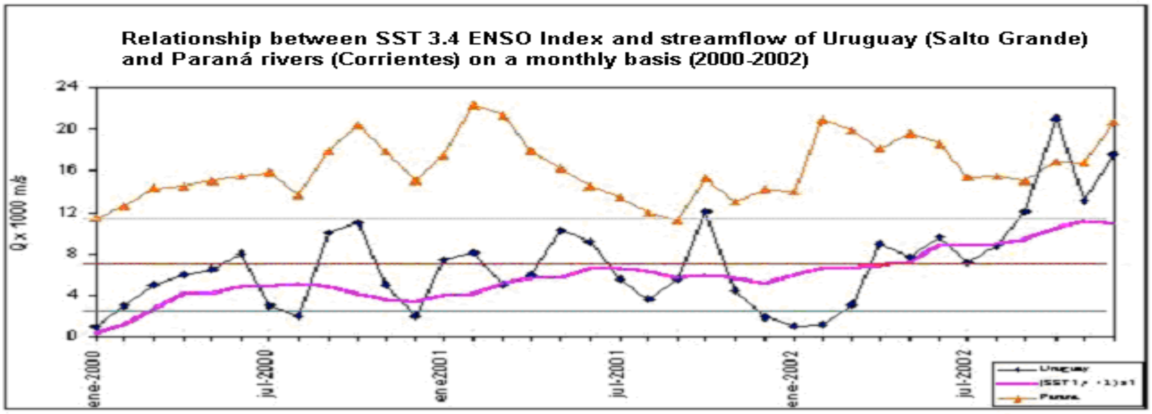


Fig. 9: Relationship between monthly SST 3.4 and river flows of Rivers Uruguay (black) and Paraná (red) from January 2000 to December 2002. Horizontal lines indicate strong La Niña (bottom), neutral and Strong El Niño (upper). A better relationship is found for River Uruguay, especially in 2002 (modified from Severov et al., 2004 and Nagy et al., submitted).

2.5.4 Sea level pressure.

Sea Level Pressure (SLP) at Montevideo decreased by 1.3 hPa during the period 1901 – 2001, which is assñociated to the southward displacemente of the subtropical high pressure belt (Bidegain et al., 2005) as presented in Figure 10.

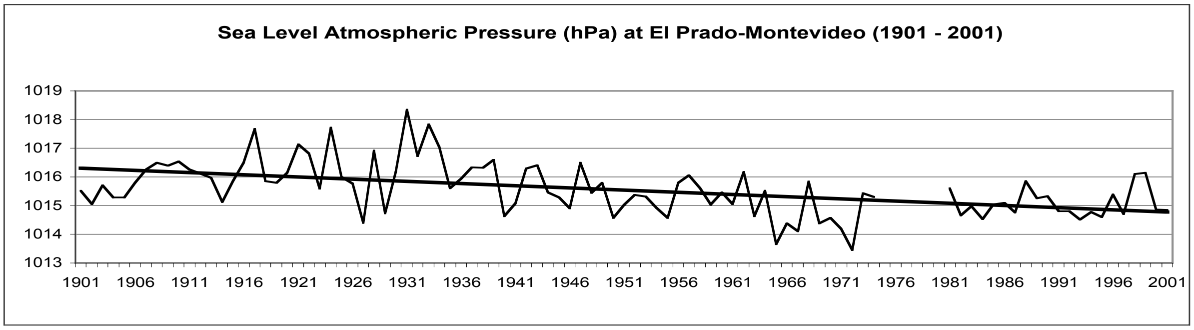


Fig. 10: Evolution of Sea Level Pressure at El Prado, Montevideo (1901 – 2001).

2.5.5 Sea level rise

Sea Level Rise (SLR) has increased by 11 cm during the period 1901 – 2003 (Nagy et al., 2005) as presented in Figure 11.

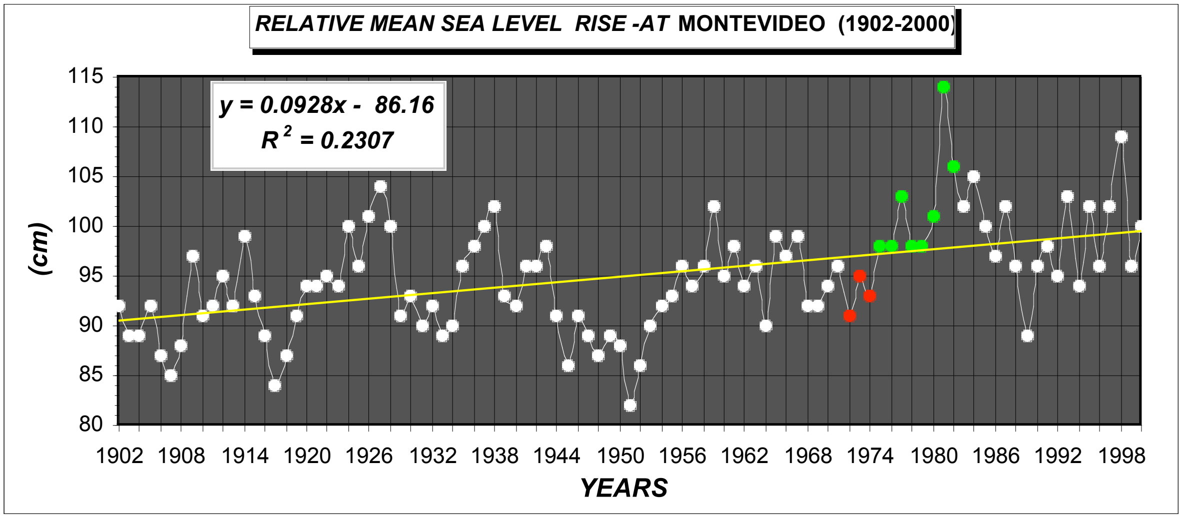


Fig. 11: Sea Level Rise at Montevideo for the period 1902 – 2000 (Pshennikov et al., 2003).

2.5.6 Salinity

Salinity has decreased by ~3 during the period 1906 – 2000 (Bidegain et al., 2005) as presented in Figure 12. Time-series is discontinuous but allows to depict that at the beginning of the past century salinities were 10-12 and that during the last five decades have decreased to ~8, in agreement with the increase and fluctuations of river flows (i.e. maximum salinity during the drought period 1942 - 1947). The value reported for 1919 is the centered mean of the period 1917-1926 calculated from monthly means because yearly data are not available.

Fig. 12: Evolution of yearly mean salinity at Montevideo (discotinuous time-series 1906-2000).

2.6 Socio-Economic Futures

We modified the scenarios developed by the Unit of Climate Change-UCC (Ministry of the Environment) for 2000 and 2050 (Table 1) and socioeconomic SRES-A2 and B2 forcing scenarios for regional climate modeling. These scenarios are an approach to the future availability of resources to cope with eventual climatic changes (UKCIP, 2000). SRES-A1 assumes global economic convergence, better income distribution, technological changes, high environmental pressures, and annual rates of WGP and NGP of 3.7 % and ≥ 4.0 % respectively, whereas SRES-B2 assumes low economic growth (1%) and an increase in environmental concern. For the latter, an index was developed which takes into account the ratio environmental investments / NGP. Increases in economic and dependency proxy variables suggests a better and worst adaptive capacity respectively, whereas enviromental variables are useful to estimate pressures over the vulnerability and adaptive capacity of the environment. We have also developed scenarios for coastal fisheries activity (see adaptation).

Sc. A1 - Variables	**Units**	**Year 2000**	**Year 2050**	**Var % total**	**% annual**
Population	10^6 persons	3.337	4.262	27.72%	0.49
NGP	U$S year 2000	20.042	142.432	610,67	4,00
NGP/capita	U$S year 2000	6.006	33.419	456,67	3,49
Land use	10^3 Ha				
Non-agricultural		1.168	1.168	0	0
Agriculture / Cattle		16.334	16.334	0	0
Agriculture		985	950	-3.55	-0.07
Cattle breeding		14.431	13.250	-8.18	-0.17
Forestation		639	2.000	212.98	2.31
Others		279	134		
Water Resources	10^6 m^3				
Offer		4.200	4.200	0	0
Production		380	690	81.6	1.20
Withdrawal		200	421	110.5	1.50
Urbanization	%	0.91	0.95	4.39	0.086
GINI Index	%	0.50	0.45	-0.1	-0.21

Sc. B2 - Variables	**Units**	**Year 2000**	**Year 2050**	**Var % total**	**% annual**
Population	10^6 persons	3.337	4.262	27.72%	0.49
NGP	U$S year 2000	20.042	32.292	64,46	1,00
NGP/capita	U$S year 2000	6.006	33.419	456,67	0,51
Land use	10^3 Ha				
Non-agricultural		1.168	1.168	0	0
Agriculture / Cattle		16.334	16.334	0	0
Agriculture		985	950	-3.55	-0.07
Cattle breeding		14,431	14,150	-8.18	-0.04
Forestation		639	1,100	212.98	1,09
Others		279	134		-1,46
Water Resources	10^6 m^3				
Offer		4.200	4.200	0	0
Production		380	512	81.6	1.20
Withdrawal		200	291	110.5	1.50
Urbanization	%	0.91	0.95	4.39	0.086
GINI Index	%	0.50	0.50	0.1	0
Environmental Index	EI / NGP (%)	0,05	0,1	100,0	

Table 1: Current (2000) and future (2050) national socioeconomic scenarios (SRES A-1, top) and B-2 (below) (modified from data from the UCC; Sención, 2002; Nagy et al., 2002-).

3 Impacts and Vulnerability

The aim of this section is to describe the exposed systems, sub-systems and sectors. First of all, we focus on the physical and biogeochemical processes in order to understand the vulnerability, impacts and adaptive capacity of /on estuarine waters, ecosystem state and coastal fisheries resources. Secondly, we present the assessment of vulnerability and adaptive capacity, including the pilot coastal zone study site (Western Montevideo).

3.1 Description of the Studied System and Vulnerable Sectors

3.1.1 Location and geomorphology of the Rio de la Plata river estuary

The Rio de la Plata (34º00'-36º10' S and 55º00'W) covers an area of 38 x 10^3 km^2, draining the second largest river basin of Latin America (3,1 x 10^6 km^2; Figure 13). From a geomorphologic point of view it can be defined as "a funnel-shaped coastal plain tidal river with a semienclosed shelf area at the mouth and a river palaeovalley at the northern coast that favours river discharge and sediment transport to the adjacent shelf (*López Laborde and Nagy 1999*).

3.1.2 Meteorology, climatology, hydrology and hydrography

The general atmospheric circulation is controlled by the influence of the quasi-permanent South Atlantic high pressure system and the continuous passage of low pressure systems. This general circulation is modified by semi-permanent low pressure system located over Chaco (Paraguay) generating prevailing NE to SE winds.

Rio de la Plata's usual weather is controlled by several factors. One of them is the passage of polar air masses. They penetrate into the continent from the patagonian region with a NE direction. When air masses cross over the Rio de la Plata, wind direction changes from North to South, often generating strong wind gusts and rainy events. When the air masses reach Brazil their movement is reduced and the air is warmed. Later, warm airmasses return to the South originating norhterly winds, which carry new maritime or continental tropical warm and moist air masses. Northern winds stop when a new polar air mass begins to advance from the Patagonian region to the North. The most frequent storms affecting the Rio de la Plata are called "Sudestadas" (Southeasterlies winds). They are produced when both a frontal system (with SW-NE trajectoires) is located over the mouth of the RP and a low presure system is located along the Uruguayan Atlantic coast, generating strong SE-winds. Usually the storms affect the area for several days. The coastal area is also affected by southwesterlies winds ("Pampero"). They originate from the passage of polar air masses arriving from the south of the Andean Mountain Range. The Pampero is a strong (13-25 m s^{-1}), dry and cold wind (*López Laborde and Nagy 1999*).

The estimated freshwater inflow (Q_V) to the system is fed by the Paraná river branches (Paraná Guazú ~58%, Paraná Las Palmas ~17%) and River Uruguay (25%). This inflow trifurcates due to the presence of banks and tidal channels (*López Laborde and Nagy, 1999*). It is directed into three flow corridors (northern, middle and southern ones), corresponding to the flows of rivers Uruguay, Paraná Las Palmas and Paraná Guazú respectively (Figures 4 and 6), where advection predominates over turbulence and lateral mixing (*Menéndez, 2001*).

A hydroclimatic shift occurred in the Río de la Plata basin in the early seventies (*García and Vargas, 1998*), and runoff fluctuations and trends have increased partly associated with ENSO related variability (*Nagy et al, 1997*). Seasonal and interannual total freshwater discharge (Q_V) typically varies between 22000 and 28000 m^3 s^{-1} on both seasonal and interannual time-scales (mean Q_V ~26,000 m^3 s^{-1} for the nineties), with extreme values during El Niño (more than 30,000 m^3s^{-1}) and La Niña (less than 20,000 m^3s^{-1}) (*Nagy et al. 2000b*). The major monthly variability of salinity off Montevideo (1998-2000) is explained by Q_U which in turn has high correlation with ENSO variability (Nagy et al., 2002b). This flow is estimated to be the main contribution to the northern corridor (Uruguayan coast) from ~April to ~October (Nagy et al., submitted).

Climatologically, the Río de la Plata has maximum discharge in March-April, associated with the River Paraná flood; in June, associated with both rivers discharge, and in September-October, associated with a secondary flood of the River Uruguay. The minimum discharge usually occurs around January. During recent El Niño years, the flow of River Uruguay tended to increase in April as well. Extremes three to four times greater than the average are often associated with El Niño.

Therefore, winds and river discharge have similar temporal patterns in relation to their effect on salinity fields distribution and turbidity front location, with onshore winds and low discharge during Summer, and offshore winds and high discharge in Fall-Winter (*Framiñán & Brown, 1996; Guerrero et al., 1997; Nagy et al., 1997*). *Simionato et al.* (2002) used river discharges of 20,000 and 30,000 m^3 s^{-1} as low and high discharge forcings (*Nagy et al., 1997*) to perform 3-D baroclinic experiments. They concluded that: The winter conditions is mainly explained by a combination between the river discharge and the Coriolis effect, which deflects the fresh water plume to the N along the coast. During the summer, even if the amount of river discharge is large enough to produce a similar picture to the one observed in winter, the predominant easterly wind inhibit the plume extension and force the fresh water to the W along the Uruguayan coast, and SW on the Argentinean side. Finally, *Escobar* et al. (2004) suggests that the subtropical Atlantic anticyclone has tended to move towards the south in recent decades, contributing to an increase in the easterly wind over Rio de la Plata and subjacent sea.

According to the terminology of the stratification-circulation (S-C) pattern classification of *Hansen & Rattray* (1966) the Río de la Plata is a "Type 2b" system (the flow reverse with depth, corresponding to the partially mixed estuary with appreciable stratification; López Laborde and Nagy 1999). This pattern varies with river flow, wind and tidal height/depth ratio from 1b (net flow is seaward at all depths) to 4 (salt wedge highly stratified). The latter is often found in the Canal Oriental where stratification lasts over successive tidal cycles (*López Laborde et al., 1996; Nagy et al. 2002b*).

The average (for the 1990s) residence time of water within the estuary was estimated to be 35 and 40 days for the surface layer and bottom layers, respectively (QV= 26,000 m^3 s^{-1}; end member salinities = 0.3 and 29; surface and bottom salinities= 15 and 27 psu, respectively) (*Nagy 2000; Nagy et al. 2002b*).

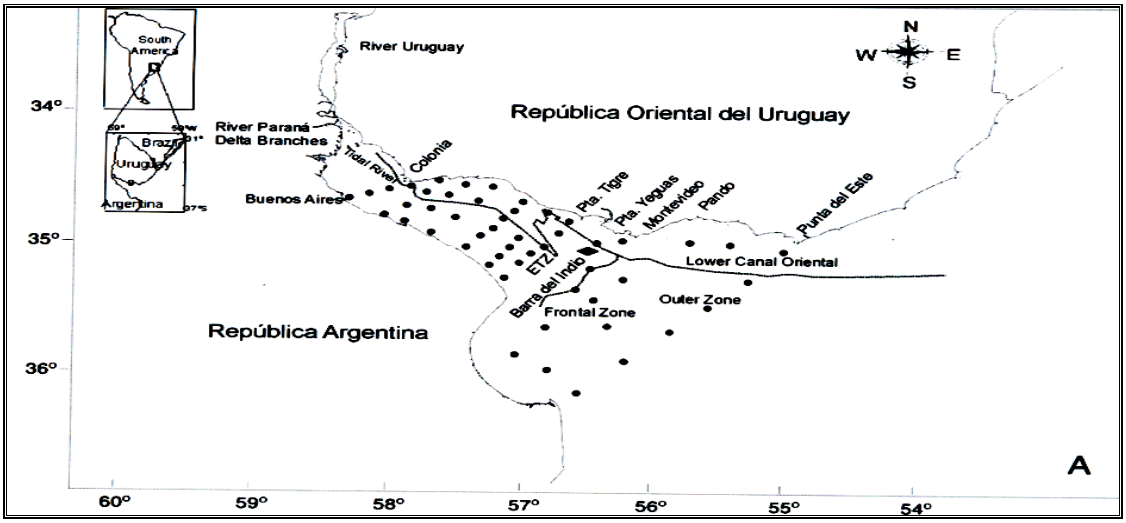


Fig. 13: Rio de la Plata location and cited regions.

3.1.3 Estuarine waters dynamics, ecosystem and services

Research on the estuarine waters of the Rio de la Plata was concentrated on four subjects,

- Estuarine Front Dynamics.
- Water Column Structure and associated biogeochemical processes.
- Coastal Fishery System.
- Trophic State Changes and Symptoms of Eutrophication.

all of which are interrelated and strongly dependent on hydroclimatic variability (ΔQ_V).

By definition estuaries are mixing zones between rivers and the sea. The inputs from both ends and the gradients established are quintessential features of estuarine ecosystems. Changes in the delivery of fresh water may, therefore, produce among the most important responses of estuarine ecosystems to future climate variability and change (Boesch, 2002).

A coupled model diagram of the feedbacks affecting the hydrologic cycle and coastal ecosystems of the RdlP is shown in Figure 14.

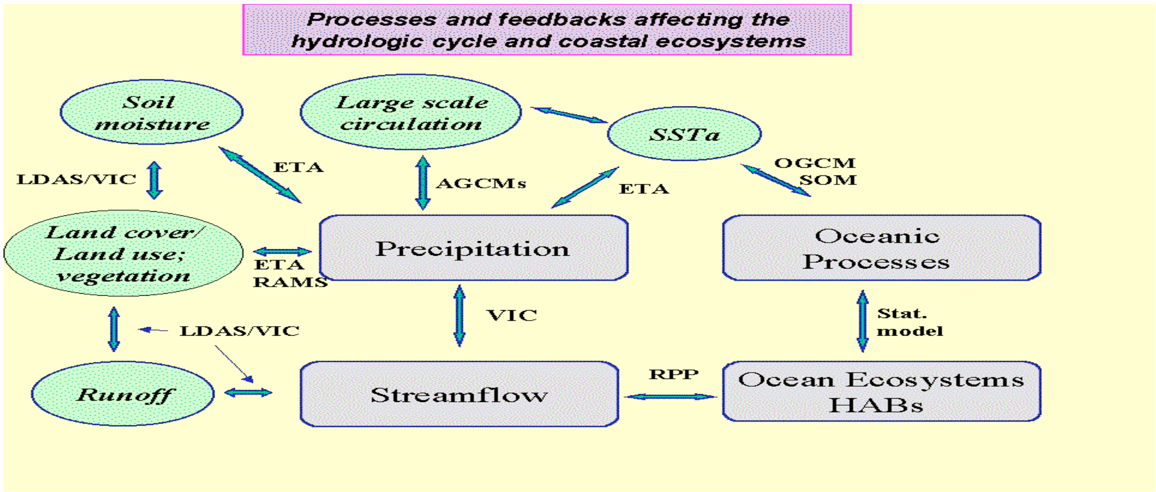


Fig. 14: Coupled model diagram of the processes and feedbacks affecting the hydrologic cycle and coastal ecosystems of the Rio de la Plata Basin and coastal ecosystems (from Berbery et al., 2003).

3.1.4 Estuarine front (EF)

Estuarine frontal dynamics (location, displacement and structure) was studied on weekly, monthly and yearly timescales as a function of river flow fluctuations (climatic timescale: seasonal and ENSO-driven fluctuations) and synoptic timescale (weather development <10 days). The EF, a physical feature related to the salt intrusion limit (Figure 15), is the main physical and ecological subsystem of the RP. It is the site for reproductive cycles and early stages of life of several commercial estuarine species, as well as of a high assimilation of primary nutrients and primary production of organic matter (P) in the upper water column, degradation of organic matter (R), oxygen consumption and denitrification in the bottom water column (*Nagy 2000; Nagy et al 2002c; Norbis et al., 2004; Lappo et al., 2005*).

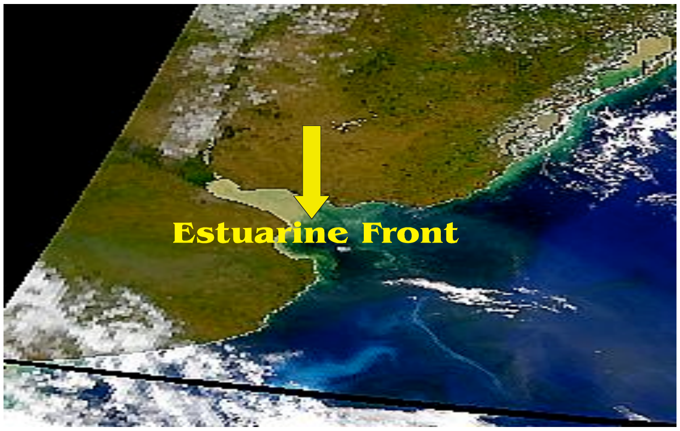


Fig. 15: Estuarine Front (EF) of the Rio de la Plata (SeaWIFS image)

Thus, ecological goods and services such as coastal fisheries and primary production show peaks within the EF and depend on it's dynamics, which is ultimately controlled by climatic forcings in the RP basin.

This research was conducted together with Udelar funded project CSIC-*Frontal Variability of the Rio de la Plata* (PI: Professor DN Severov, Investigators: Valentina Pshennikov, Juan J Lagomarsino and student Maite de los Santos) and the Joint Program between the Russian Academy of Sciences (RAS) and the Facultad de Ciencias-UdelaR (with the participation of Dr. Evgeni Morozov, RAS).

Up to four distinct fronts are distinguished: Main Turbidity Front (MTF), Main Marine Front (MMF), Secondary Turbidity Front (STF) and Secondary Marine Front (SMF) between riverine, estuarine and marine waters (Figure 16). Their number, location and shape are related to the volume and timining of freshwater discharge of each tributary. For instance, along the Uruguayan coast most of the variability in salinity and turbidity fields are associated with the flow of River Uruguay. Over the studied period the influence of both La Niña (beginning of 2000) and El Niño (April 2002 – beginning of 2003) was observed superimposed to seasonal variability.

Both long-term river flow series of freshwater discharge and future climate scenarios for Southeastern Southamerica suggest that a drammatic change in the location of fronts is occurring since 1970 and could continue over the next few decades (*Severov et al., 2004; Nagy et al., submitted*).

Sequential weekly downloading of SeaWIFS images, visual observation from the coast and oceanographic cruises along the Canal Oriental allowed to study the location, vertical structure and displacement of fronts from January 2000 to December 2004. A sketch of the location of the fronts of the RdlP was drawn (see Figure 16) after Severov et al. (2003, 2004), data taken from the RAS Research Vessel *Akademik Sergei Vavilov* on November 2003 (*Lappo et al., 2005*) and a SeaWIFS image (November 27, 2003).

A synthesis of the main results about the EF dynamics and the different fronts presented in Figure 16 is presented in table 2.

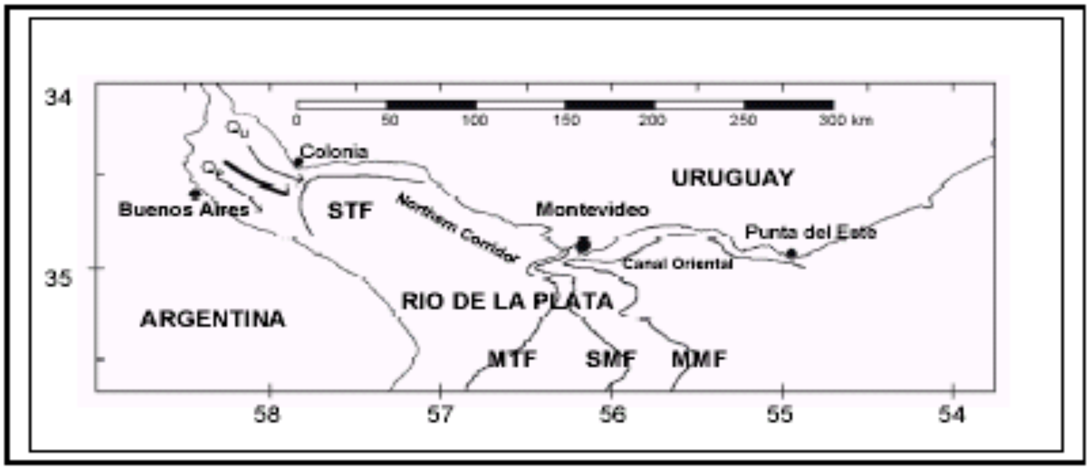


Fig. 16: Sketch of the river flow corridors and front-lines of the Rio de la Plata. Distance down-river from Colonia is shown in Km.. The estuarine front includes the MTF and SMF (Nagy et al., submitted to JASR).

a- Average Location **b- Extreme Locations**

Front	**MTF**	**SMF**	**MMF**		**Month / year**	**Q_V (m^3/s)**	**Q_U (%)**	**MT**	**SMF**	**MMF**
Mean (km)	139	183	292		03 / 00	15	10	15	20	135
St. deviation	49	56	66		01 / 01	22	23	20	50	375
Maximum	280	360	375		01 / 02	16	15	30	140	170
Minimum	15	20	135		07 / 00	22	29	265	360	375
Salinity	1-3	10-12	20-22		10 / 02	20	35	180	270	350
Nitrates	10-20	3-6	1-3		04 / 02	24	18	250	320	380
Chlorophyll	1-3	3-20	2-5		05 / 03	27	30	270	380	320

Table 2: a- Average fronts loci down-river from Colonia (DRC), ranges of salinity, nitrates (uM) and chl-a (ug/l), and 3-months running mean of extreme QV (103 m3/s),% QU, and b- extreme fronts loci (MTF, SMF, MMF) (from Nagy et al., submitted to JASR).

3.1.4.1. Water column structure and associated biogeochemical processes

We aim to briefly describe the state of the art of water column structure and the processes that cause variability in coastal waters over timescales of hours, days, weeks and longer in the RP, including some results obtained by AIACC LA-32.

Variations in a number of water column physical, chemical and biological properties can be driven by either internal processes such as biological activity and chemical reactions (i.e. P and R of organic matter-CH_20), and mixing of waters, or by external forcing from the atmosphere, from runoff and inputs from land, or from exchanges with offshore waters of energy, mass, and biota.

Of primary interest are salinity, temperature, dissolved oxygen and chlorophyll because their variations encompass a wide range of processes such as: i) *in situ* photosynthesis, ii) air-sea gas exchange (0_2, $C0_2$, N_2 and N_20), iii) response to meteorological conditions (solar radiation, wind velocity, heat exchange), iv) physical processes such as tidal mixing and stratification (bottom salinity – surface salinity: ΔS), v) runoff from land, and vi) anthropogenic inputs (N, P and organic matter- CH_20).

We selected six oceanographic cruises since the early 80' which were conducted under different physical forcings within the typical range of river flow (Q_V: 20-32 x $10^3 m^3 s^{-1}$) and wind velocity < 8 m/s (not able to mix the deep water column with a depth > 10 m). Cruises are ordered according to the increasing persistence of stratification conditions (Table 3) from mixing by strong winds (A) to two weeks (B) and five weeks of vertical stability with calm weather (C), high river flow (D-E), and (F) long-term average.

Oceanographic Cruises

Variables	A	B	C	D	E	Mean
Q_V ($10^3 m^3 s^{-1}$)	25	24	21	30	31	~26
Mixing Index *	0.02	0.39	0.41	0.44	0.45	~0.4
A0U (µM)**	18	152	286	429	402	180
$N0_X$ (µM)***	0.4	3.0	6.2	8.6	10.4	3
DIN (µM)****	3.2	6.6	8.0	10.6	12.0	6
DIP (µM)*****	0.5	1.1	1.6	1.7	1.9	~1
N/P	~6	~6	~6	~6	~6	~6

* Bottom salinity – surface salinity (ΔS) / water column average salinity (Z_S)

** Apparent Oxygen Utilization (oxygen anomaly) = expected theoretical value as a function of temperature and salinity) – observed value.

*** Typical value in surface waters: 2-4 µM

**** DIN ($N0_X + NH_4$)

***** Typical value in surface waters: 0.5-06 µM

Table 3: Evolution of mean dissolved oxygen and nutrients in the botton layer of the water column (depth > 10 m; salinity > 20, winds < 8 m/s) from mixing (by wind) to prolonged stratification conditions (modified from Nagy et al., 2000; Nagy et al., 2002c).

Vertical stability (density stratification) isolates bottom waters from the atmospheric and surface waters reservoirs of 0_2. Thus, degradation of CH_20 consumes 0_2, produces $C0_2$, $N0_3$, $P0_4$ (remineralization) and triggers hypoxia and denitrification (conversion of $N0_3$ into N_2).

Linear and non-linear relationships were calculated between the following variables: i) stratification vs apparent oxygen consumption (A0U), ii) A0U Vs DIP (Dissolved Inorganic Phosphate - $P0_4$), iii) A0U Vs $N0_X$ (Dissolved Nitrates plus Nitrites), and iv) Q_V Vs residue of A0U Vs $N0_X$. They show the effect of stratification over oxygen consumption (also called oxygen anomaly) in the deep water column, between oxygen consumption and nutrient remineralization ($N0_X$ and DIP), and between Q_V and $N0_X$ not attributable to oxygen consumption (residue A0U Vs $N0_X$). This residue is supposed to be related to pre-existent concentrations before remineralization and dilution or salinity gradient (*Nagy et al., 2000; 2002c*).

These results are strong evidence of the role of wind and river flow over mixing and stratification (ΔS / ΔZ) and how the stratification-destratification cycle (mixing state) govern biogeochemical processes such as oxygen state, degradation (R) of CH_20 and nutrient availabilty in deep waters (suclinal environment), which in turn flows to the upper column (supraclinal environment) during mixing (by wind) events (wind velocity greater than 8-10 m^3 s^{-1}; *Nagy et al., 2002b.; Nagy et al., submitted*). For shallow waters (depth < ~6-8 m) tidal mix and resuspension is also important (*Nagy et al., 2002c*).

Multivariate analysis of subclinal nutrient concentrations show that both [N] and [P] are mainly explained by two independent variables: A0U and salinity, as well as the other primary nutrient – $N0_3^{-1}$ or $P0_4^{3-}$ when equated, and secondary by temperature, with correlations > 0.8 (*Nagy et al., 2000*).

These concepts are key for the understanding of the physical forcing of trophic state (P-R), biogeochemical processes and symptoms of eutrophication.

3.2 Impacts, Vulnerability and Economic Scenarios of Coastal Fisheries

3.2.1 Goal

To assess overall vulnerability, economic scenarios and adaptive capacity of the Coastal Fishery System (CFS) in the Estuarine Front of the Rio de la Plata to cope with Global Environmental Change.

3.2.2 Problem

An artisanal fleet exploit fisheries a few miles off the Uruguayan coast in the estuarine front (EF) of the Rio de la Plata .

The location of the EF (Figure 17), therefore the accesibility of exploited resources, depends on ENSO-related interannual variability of River Flow (Figure 18). Kiyú is the extreme river-ward site of fishing during extreme La Niña events (1988-89 and 1999-00). San Luis is a desaggregation of fishermen that migrated from western Montevideo (EF zone). Within the EF or frontal zone two sharp color disconituities are observed, the main turbidity front (MTF) and secondary marine front (SMF) (Severov et al. 2003, 2004), 140-180 down-river from Colonia on an average (see table 1).

Artisanal fishermen boats (Figure 17) and fishing are higly vulnerable to weather conditions (winds), whereas the coastal fishery system is vulnerable to both climate and non-climate constraints (Figure 20 and table 2).

Coastal communities have low to moderate adaptive capacity (Table 2).

The development of symptoms of eutrophication during the last two decades is deteriorating the ecosystem posing new threatens to fishery livelihood.

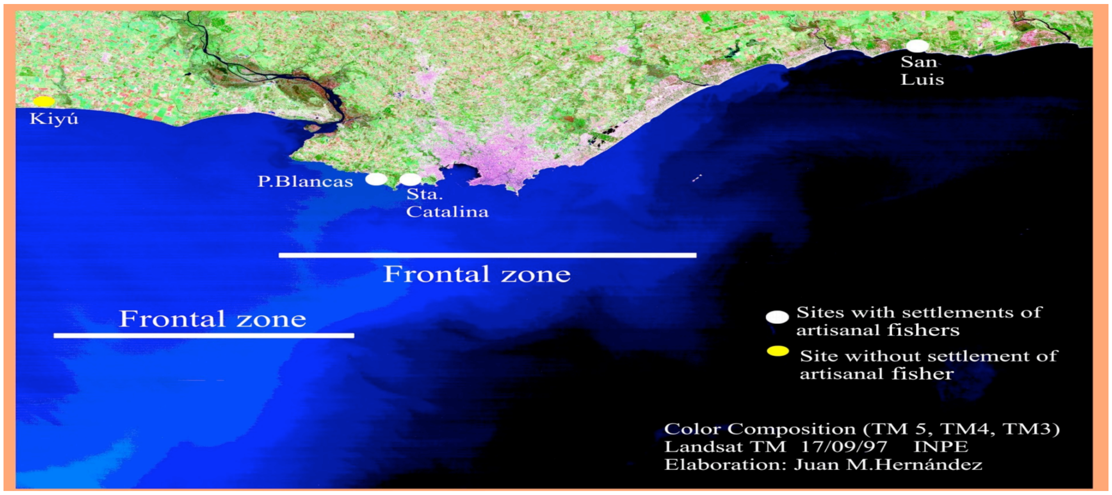


Fig. 17: Frontal zone of the Rio de la Plata and location of sites of fishermen settlements (white). Urban areas of the metropolitan Montevideo city (pink) (from Hernández and Rossi, 2002).

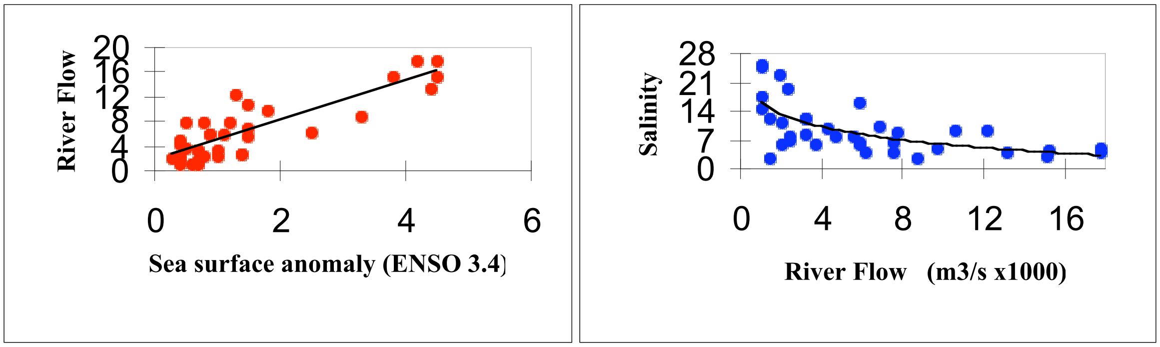


Fig. 18: Monthly relationships between ENSO SST 3,4 vs Uruguay River flow (left) and Uruguay River flow vs salinity off Montevideo for the period January 1998 – Decemeber 2000 (from Nagy et al., 2002b)

Main divers of impacts, change and factors of vulnerability, adaptive capacity and management of coastal fihseries, both artisanal (i.e., Pajas Blancas and Santa Catalina) and industrial fleets, in the RdlP are:

3.2.3 Artisanal fishery

River flow: affect species availability in the fishing areas.

Weather (winds): limiting fishing trips.

Extreme events: affect bottom sediments (fishing zone).

3.2.4 Industrial fishery (coastal zone untill 50 m depth; not analyzed in detail here):

Two objetive species: "croaker" and "sea trout".

Change in spatio-temporal distribution.

- Weather (frontal periods - winds): affect spatio - temporal resource availability.
- time of search (higher economic cost).

In order to understand fisheries vulnerability it must be taken into acocunt risk and uncertainty, and it's sources in both environmental and management conditions (*Hilborn & Peterman, 1996*).

3.2.5 Risk and Uncertainty: sources, environmental and management conditions.

- variability in abiotic factors have an important impact on the abundance and spatio-temporal distribution of fish resources .
- effects of ecological interdependencies.
- fluctuations in costs and product prices that determine changes in exploitation intensity and in the quantity demanded.

Variations in:

fishing effort determined by different fishing power and type of gear.

- variability in the behavior of policy makers due to value judgments when taking management decisions.

- in the estimates of fish abundance.
- in future environmental conditions.
- in the response of users to regulations.
- in future management objectives.
- in economical, political and social conditions.

Environmental conditions show systematic patterns, e.g., periodic or linear trends. Thus, the prediction of environmental future conditions is required, especially for resources sensitive to an extreme degree to environmental changes.

Fig. 19: Typical artisanal fishing unit of Pajas Blancas CFS settlement (from Sención, 2003).

3.2.6 Pathways of response of human and natural systems to global environmental change.

Main pathways of response of both human and natural systems of the coastal fishery system and the livelihood vulnerability are presented in figures 20 and 21 respectively.

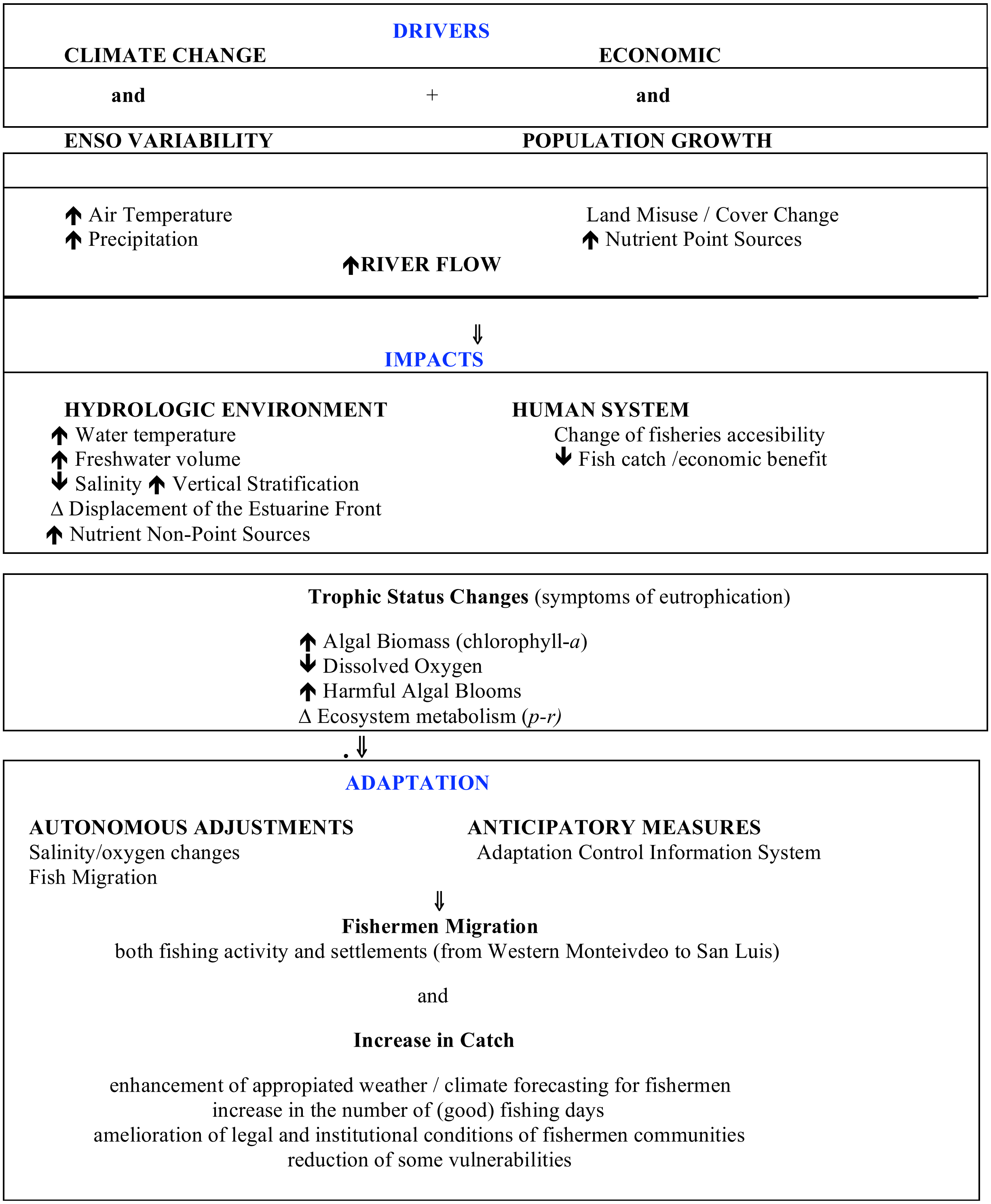


Fig. 20: Pathways of response of fishermen (human system) and eutrophication (natural system) to combined climate change, ENSO-related variability, and human drivers (modified from Nagy et al., 2003).

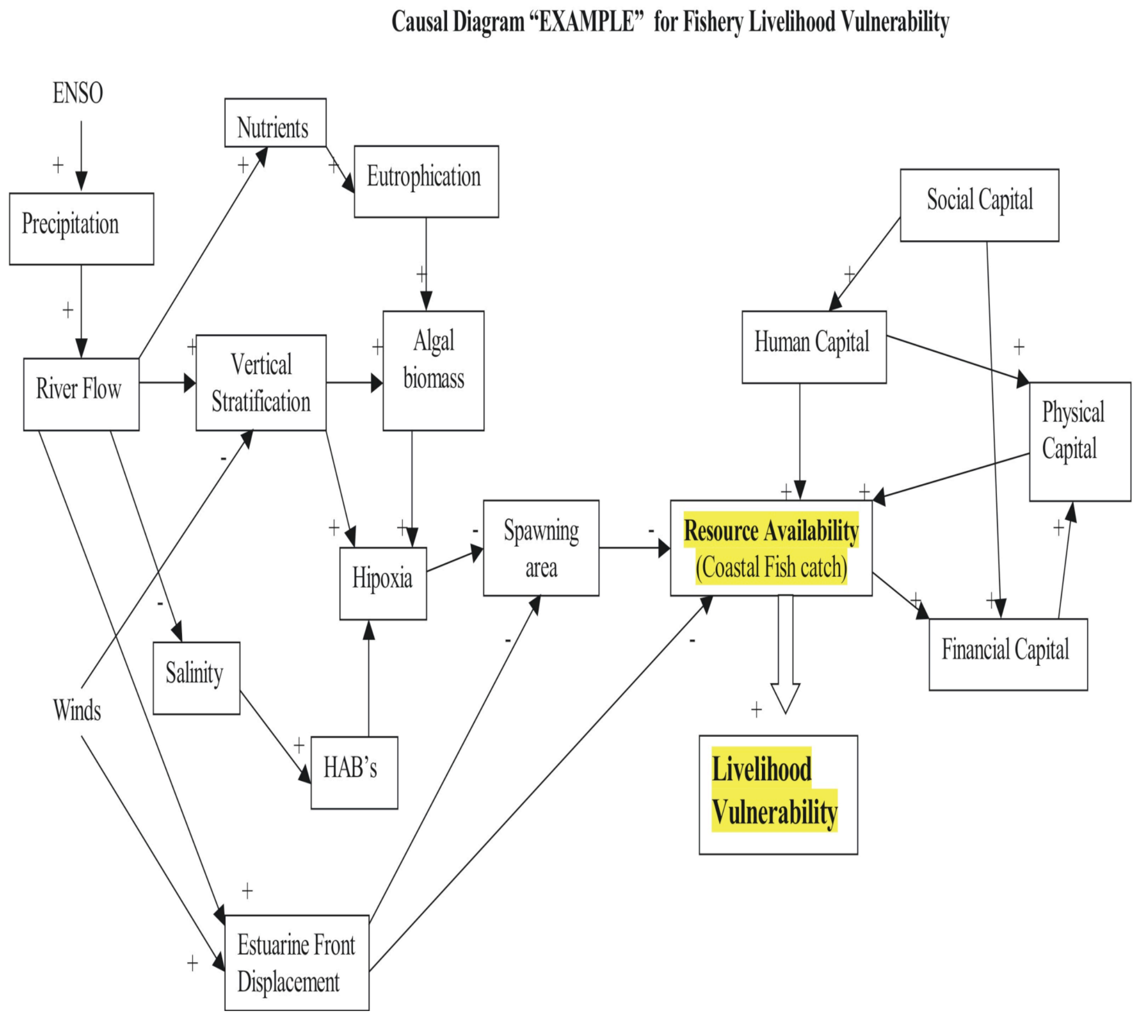


Fig. 21: Causal diagram loop of the coastal fishery system livelihood vulnerability (from Ponce, 2004)

3.2.7 Sensitivity and vulnerability of coastal fisheries

We estimated proxy variables - classified and valued respectively as low (1), moderate (2) and high (3) - in order to assess social, economic, environmental and legal indicators of sensitivity of the Pajas Blancas fishermen's community. The sum of all indicators (*non-weighted index of vulnerability)* suggest that the community is subject to moderate to high vulnerabilities (Table 6) but it seems to be resilient. Determinant factors of vulnerability are strongly interrelated with the adaptive capacity, autonomous fishermen's adaptation and planned management options, which ultimately reduce vulnerability.

Up to date, autonomous adaptation, good fishing skills and management practices have been the key for the sustainability of the CFS under the current climatic, weather, environmental and economic baselines (30-y trends). If vulnerabilities shown in table 3 are realistic, the CFS should be more vulnerable under changing conditions in any of them. Main climate and non-climate conditions shown below seem to be the main threaten to the sustainability of fishermen's community.

ENSO effect: warm phase/cold phase: rainy / dry

Δ Precipitation and Δ River flow

- Sea level rise and storm surges
- South Atlantic Anticyclonic Southward displacement and ncrease in eastearly (E-SE) winds (spring and summer).
- Increase in fuel prize
- Lack of social and legal organization
- Regulations (Directorate of Aquatic Resources and Navy Coast Guard)
- Lack of refrigeration
- Conflicts with industrial fleet

Proxy variable		**Vulnerability**	
Social	**High (3)**	**Moderate (2)**	**Low (1)**
Family		X	
Education		X	
Housing		X	
Employment		X	
Health		X	
Social organization	X		
Sub-total: 2.2/3			
Economic			
Boats		X	
Engines		X	
Fishing gears			X
Communications		X	
Refrigeration	X		
Catch		X	
Prices		X	
Net income		X	
Sub-total: 2.0/3			
Environmental			
Climate - ENSO	X		
Winds	X		
Storm surges / Flooding		X	
Eutrophication		X	
Habitat loss			X
Sub-total: 2.2/3			
Legal / Institutional			
Laws		X	
Territorial planning		X	
Coast Guard controls	X		
Conflicts with industrial fleet	X		
Conflicts with neighbours		X	
Legal organization	X		
Sub-total: 2.5/3			

Table 4: Assessment of the Vulnerability of the Coastal Fishermen Community. (Modified from Nagy et al., 2003 and Norbis et al., 2004). Unweighted total Index of Vulnerability (IV) = 2.2 (scale 1-3).

3.2.8 Integrated climatic, economic and enviromental assessment, scenarios and models

Only those strong ENSO events which effects last during the peak of the fishing period (i .e., El Niño 1992, 1997, 2002 and La Niña 1989, 1999), seem actually impact fishing activity and net income. Therefore, about one third of the peak fishing periods are bad in economic terms, when the net income of fishermen is estimated to be reduced by ~60% with regard to normal years (Figure 22, *Nagy et al.*, 2003; *Norbis et al.* 2004).

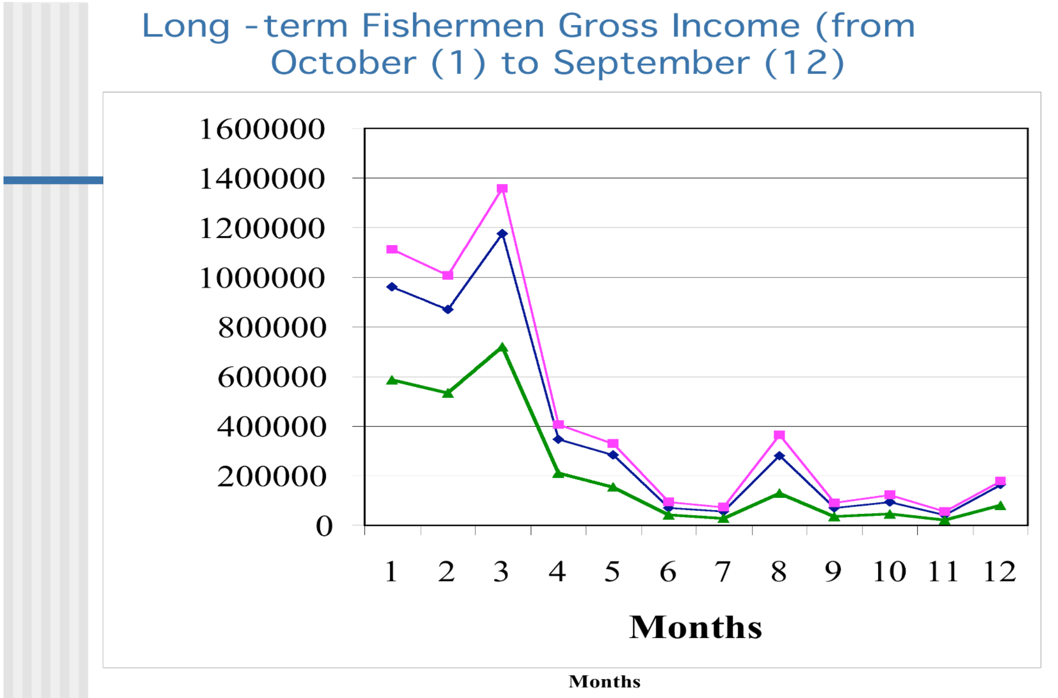


Fig. 22: Long-term fishing activity and net income (From Nagy et al., 2003).

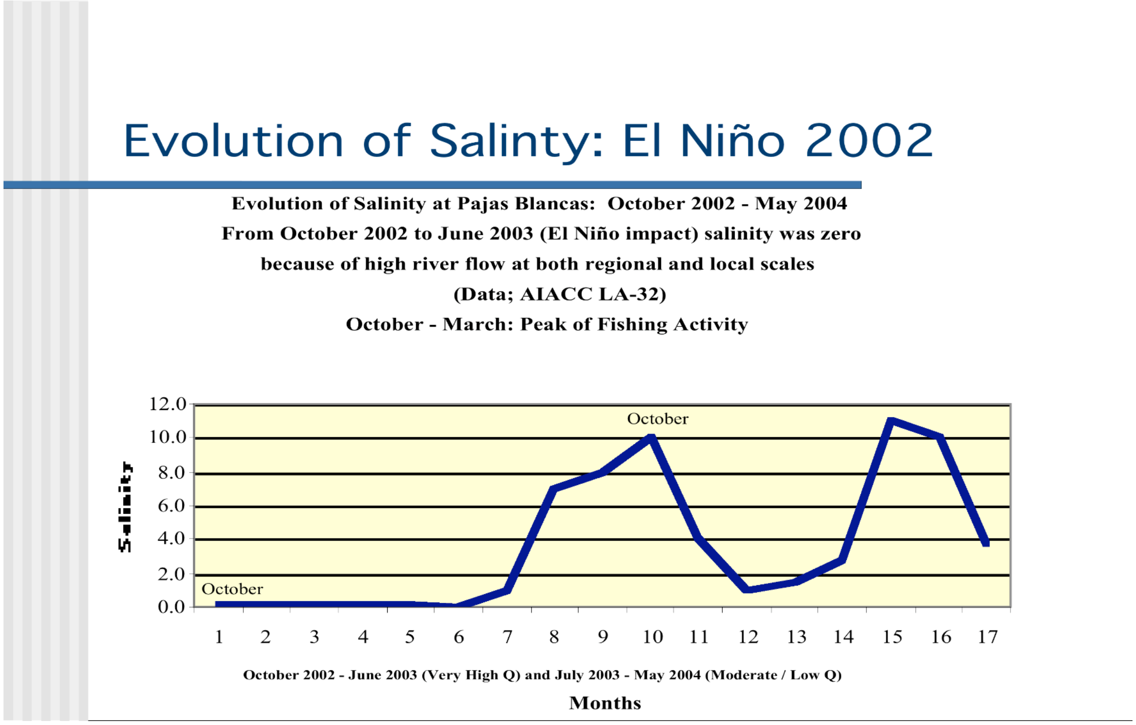
The question addressed about the sustainability of coastal fisheries was thus empirically answered because the fishing activity remains sustainable regardless of their (estimated) high vulnerability. We suggest that their resiliency is (or was) due to:

- the combination of planned and reactive adaptation measures to hydroclimatic variability (i.e. migration),
- good to very good fishing performance of most fishermen and
- their (dominant) cautious behaviour (to avoid weather-related risks in spite of economic losses), all of which reduced their vulnerability to remaining sustainable.

However, will they have the adaptive capacity to persist under increasing climatic and economic pressures such as those occurred in 2002?

- economic crisis,

- increase in fuel prize,
- a moderate El Niño year which decreased surface salinity at Pajas Blancas to close to zero Figure 23 because of the seaward displacement of EF (Figure 24), and
- increase in the occurrence of non-favorable wind conditions for fishing activity (> 8 m/s) as presented in Figure 25 (Nagy et al., 2003; Norbis et al., 2004).


Evolution of Salinty: El Niño 2002

Evolution of Salinity at Pajas Blancas: October 2002 - May 2004
From October 2002 to June 2003 (El Niño impact) salinity was zero
because of high river flow at both regional and local scales
(Data; AIACC LA-32)
October - March: Peak of Fishing Activity

Fig. 23: Evolution of salinity at Pajas Blancas (October 2002 - May 2004). During 2002 salinity was zero during the fishing period whereas during 2003 it was normal (from Norbis et al., 2004).

For this scenario, the assessment of vulnerabilities shown in table 3 seems to be more realistic, suggesting the need to put more weight on climatic indicators because fishermen cannot cope with them.

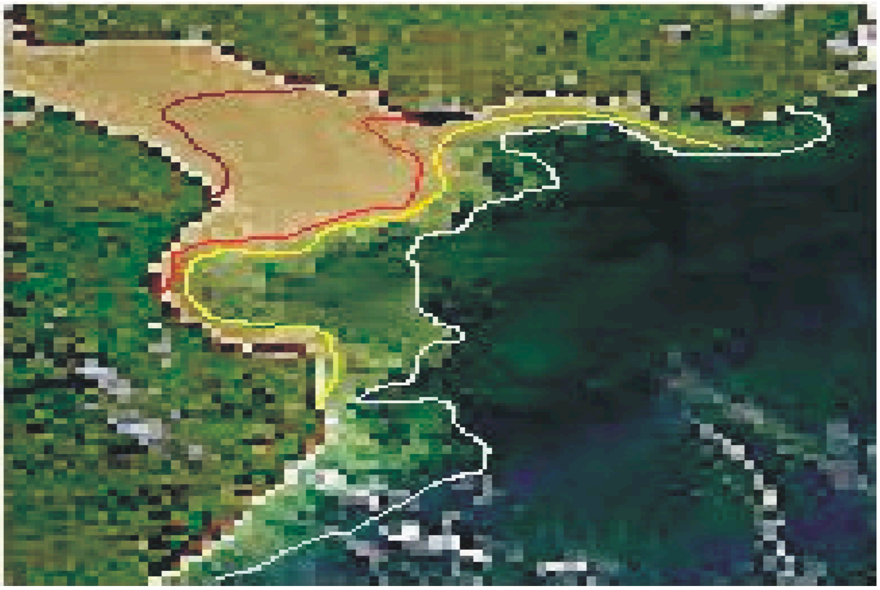
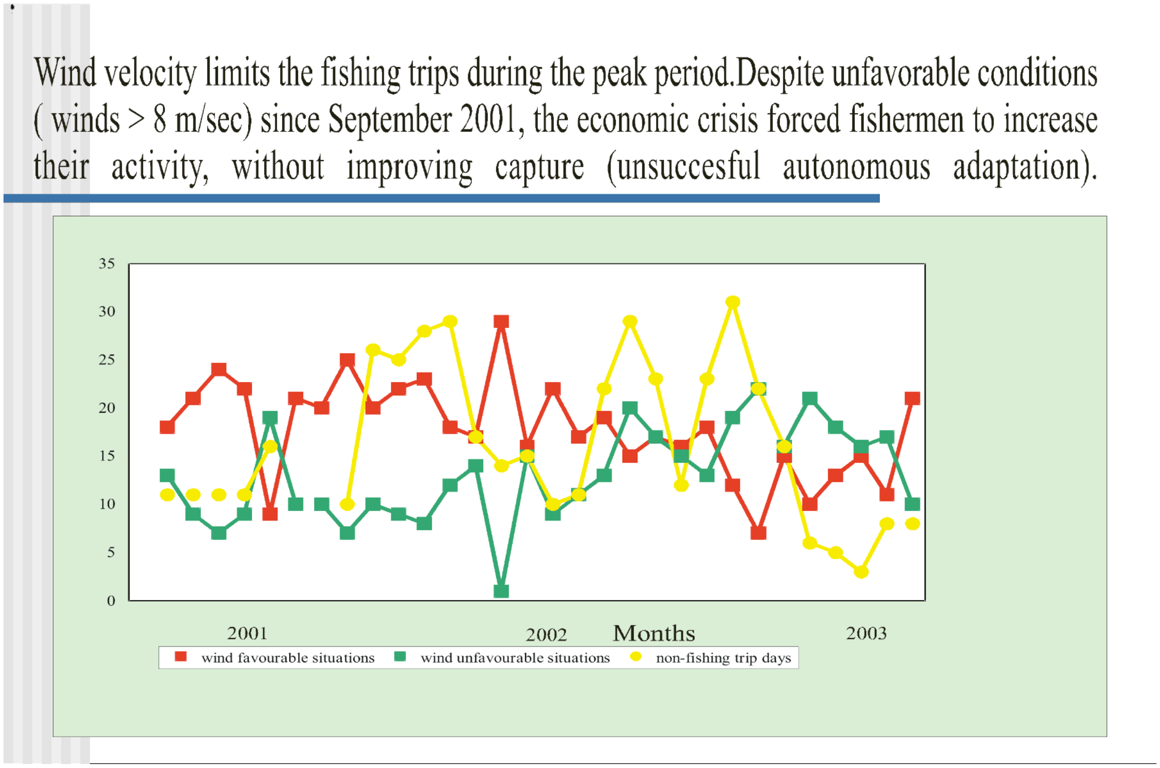


Fig. 24: Extreme seaward location of the estuarine front (red and yellow lines during El Niño event (September-October 2002) (from Severov et al., 2004).

Figure 25 shows the occurrence of favorable and non-favorable wind conditions for fishing activities from 2001 to 2003 (*Nagy et al., 2003*), according to the criteria established by *Norbis* (1995) and *Norbis et al.* (2003) who demonstrated that Southern winds (SW to SE) > 8m/s are non-favorable for fishing and most fishermen prefer not to risk fishing even at the beginning of the set up of favorable conditions, usually losing one favorable day. Average wind speed in the region is 5-6 m/s but it increases to > 6 m/s during spring and summer time due to the prevailing SE winds (*Nagy et al., 1997; Escobar et al., 2004*). It means that fishermen are both highly exposed and resilient to develop their activity within a wind range close to the limit of 8 m/s. However, the overall conditions during 2002 forced fishermen to change their no-risk behavior (*Nagy et al., 2003; Norbis et al., 2004*).



Wind velocity limits the fishing trips during the peak period.Despite unfavorable conditions (winds > 8 m/sec) since September 2001, the economic crisis forced fishermen to increase their activity, without improving capture (unsuccesful autonomous adaptation).

Fig. 25: Frequency of wind favorable and unfavorable conditions and non-fishing days for the period September 2001 – March 2003 (from Nagy et al., 2003).

An economic estimation of fishing units capital and costs per year (boats, crew, engine, gears, investment, maintenance and operation costs) was performed in order to build scenarios and simple economic models of fishing activity at pajas Blancas (table 5).

	U$D	**N^b**
N^b of fishing units		~31
Investment capital	7500	
Maintenance cost / year	500	
Operational cost / year	4000	
Chief boat salary / month	218	
Crew salary / month	109	

Table 5: Economic estimation of fishing unit (from Sención, 2003).

The analysis of the fishing activity for the period 1998-1999 shows that the number of fishing boats and capture increase during favorable days (Figure 26), when the number of daily sorties was 26-31 and capture per boat reached 40 boxes, suggesting that there is no resource limitation and that the community follows the best fishermen.

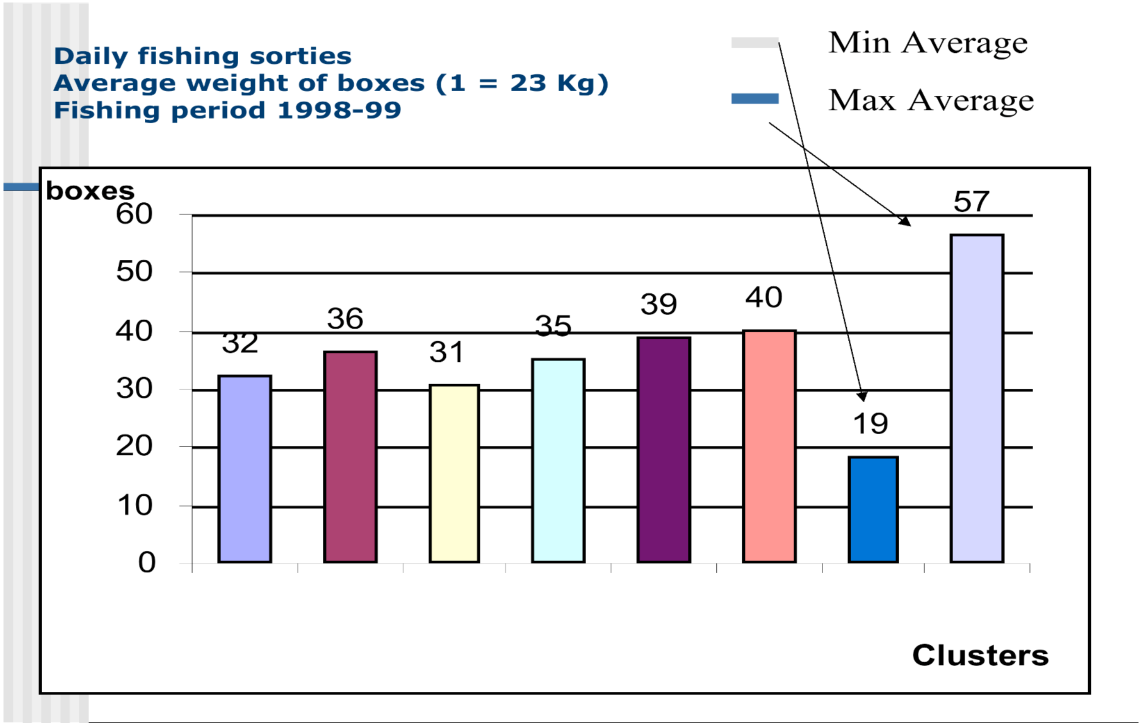
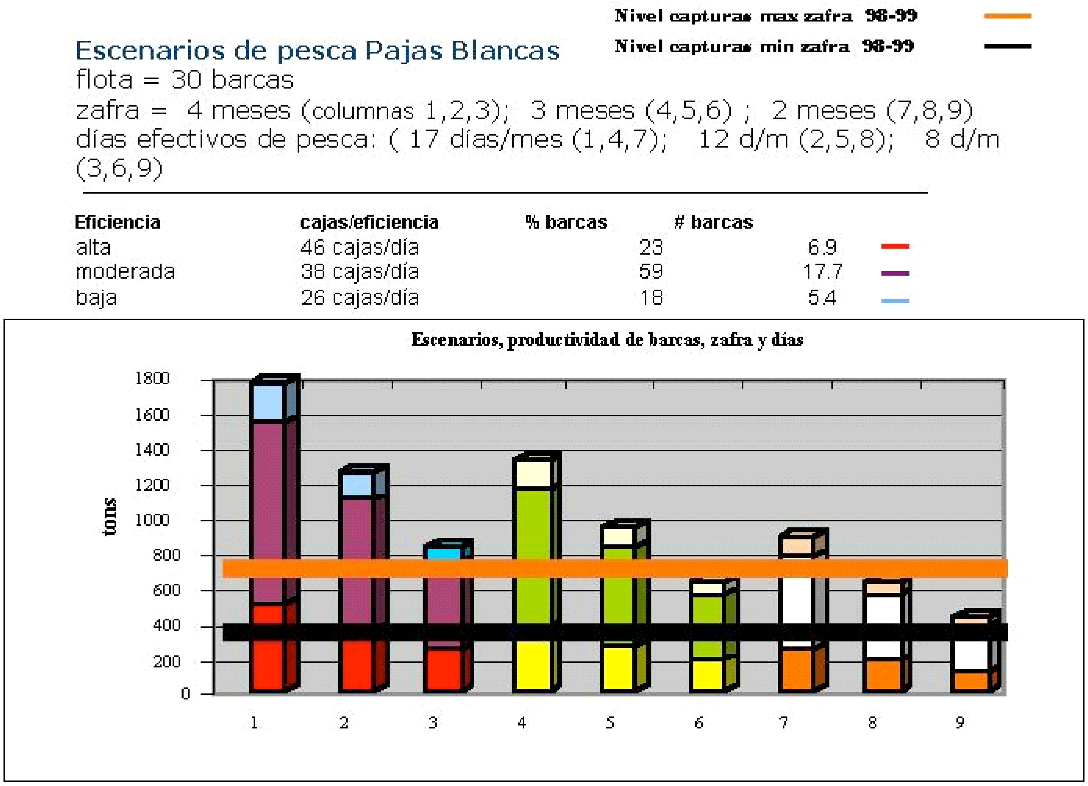


Fig. 26: Clusters of number of fishing sorties, capture (Nb of boxes), and minimum and maximum Nb of boxes during the fishing period 1998-1999.

Figure 27 shows an empirical scenario of fishing activity and productivity based upon the data used to estimate the long-term yearly fishing activity gross income (see Figure 22) and the fishing period 1998-1999 (a typical year) according to the data and results presented by *Norbis and Verocai* (2003) and *Norbis et al.* (2003). This economic scenario was built for:

- thirty fishing boats (artisanal fleet during the high fishing period), three durations of the fishing period, three monthly number of fishing days, and three daily number of fish boxes (~23 kg each one) which represents the variability observed on both the long-term since 1988 and for the 1998-1999 fishing periods activity (*Norbis et al., 2004*). This empirical scenario is compared with the minimum (black line) and maximum (red line) captures observed during the fishing period 1998-1999.



Nivel capturas max zafra 98-99 🟧

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Escenarios de pesca Pajas Blancas

flota = 30 barcas

zafra = 4 meses (columnas 1,2,3); 3 meses (4,5,6) ; 2 meses (7,8,9)

días efectivos de pesca: (17 días/mes (1,4,7); 12 d/m (2,5,8); 8 d/m (3,6,9)

Eficiencia	cajas/eficiencia	% barcas	# barcas	
alta	46 cajas/día	23	6.9	🟥
moderada	38 cajas/día	59	17.7	🟪
baja	26 cajas/día	18	5.4	🟦

Fig. 27: Fishing activity and productivity scenario of Pajas Blancas coastal fishermen community (from Norbis et al., 2004).

Summarizing, the variables considered in the empirical scenario are:

– 30 boats in each case and

- fishing period (2, 3 and 4 months),
- monthly fishing days (8, 14 and 17 days)
- efficiency of fishing units (26, 38 and 46 boxes)

Thus, nine different combinations of i), ii) and iii) – or empirical scenarios – were built which represent maximum (1) and minimum (9) fishing activity within the range of observed conditions since 1988 – especially during 1998 /1999 – for each variable.

Six scenarios give captures greater than the maximum observed in 1998-99 and the most performant are those based upon four and three months performant fishing activity: maximum fishing days and boxes. It must be noted that these scenarios do not include captures during the low fishing activity period (from February to September) as presented in Figure 22, when many fishermen migrate seaward the estuarine front to San Luis (see Figures 1 and 17).

Both, the observations and the economic scenario suggest:

The longer the peak of the fishing period the greater the capture, which depends mainly on hydroclimatic conditions (i.e. ENSO-induced EF location).

The number of fishing days per month is crucial and this is highly dependent on the occurrence of Southern winds (wind-induced EF location and mixing *status*).

The sustainability of the fishing activity depends on several factors or the combination of them, for which thresholds have been estimated: a) fishing activity must be) ≥ 15 days/month, b) fishing period must be >2 months.

The number of boxes per boat / day does not seem to be a key factor. It is related to individual performance and net income rather than the sustainability of fishermen's community.

In case of an increase in climatic constraints only performant fishermen should mantain present income.

Sea level rise and storm surges are a threat to fishermen coastal settlements.

It will be necessary to continue this analysis for at least two more years (from the past and/or future) with different climatic, environmental and socio-economic conditions, as well as to incorporate anthropological research.

3.2.9 Key findings

- wind speed and rotations affect the artisanal fishery activity
- limiting fishing trips. Favorable conditions during the peak fishing period (October to March) are: winds of sectors N, NE and E and speed minor than 8,0 m/sec.
- between October 1998 and March 2003 the favorable and unfavorable conditions showed different trends with an increase of unfavorable conditions from September 2001. Non-fishing periods less than 15 days (threshold value) affect the economic subsistence of artisanal fishermen.
- performant fishermen (especially at Pajas Blancas site) have already adapted to past / current climate variability in spite of bad years during El Niño and La Niña..
- some fishermen communities (i.e. Santa Catalina community) and / or less performant fishermen at Pajas Blancas community are highly vulnerable and their activity should be unsustainable under increasing climatic, economic and environmental constraints if adaptation strategies are not developed.

3.3 Impacts, Vulnerability and Coping Capacity of Trophic State Changes (TSC)

3.3.1 Goal

To assess current and future vulnerability of the estuarine waters to express symptoms of eutrophication.

3.3.2 Problem

The Rio de la Plata shows increasing symptoms of eutrophication (nutrient excess, increase in algal biomass, hypoxia and increase in the occurrence of HABs) since the early 1980s.

3.3.3 Trophic state

Trophic state (TS) is the state of the ecosystem metabolism (system level Production minus Respiration of organic matter) as a function of all organic material (CH20) inputs, both allochtonous and autochtonous, usually based on Phytoplankton Primary Productivity (P), which is usually limited by the turbidity gradient and nutrient availability in estuarine ecosystems (NCR, 2000; Pinckney et al., 2004).

- Allochtonous inputs: Derived from outside the estuary and transported into by rivers, sewage,

atmosphere. They are divided into point-sources (i.e., sewage outfalls) and non-point sources (i.e., runoff and atmospheric deposition).
- Autochtonous inputs: Generated within the estuary by primary producers, benthic regeneration and microbial processes.

Trophic states are usually divided into four categories, according to the load of CH20 to the system (presssure and state) and /or according to the level of expression of the symptoms of eutrophication (primary variables of response).

- Oligotrophic
- Mesotrophic
- Eutrophic
- Hypertrophic

3.3.4 The overload of nutrients: An environmental change on a global scale

Human activity seems to have doubled the quantity of nitrogen recycled in the biosphere, and more than doubled the rate of transfer of phosphorous to the ocean (*Schlessinger, 1997; Rabalais and Nixon, 2002*).

The primary causes (pressures) of over-enrichment in Nitrogen (Q_N) and Phosphorous (Q_P) are population increase, the use of synthetic fertilizers, and of the depositing of atmospheric N used in the production of food and energy (Seitzinger et al., 2002). Nutrient flux is associated with three drivers: landscape biogeochmistry, human intervention, and runoff (V_Q), whereas the delivery of nutrients to the ocean is associated with three variables: runoff, basin area and population (Smith et al., 2003).

Most of these changes have occurred over the last thirty years. Many estuarine ecosystems receive more nutrients than they can assimilate, but at the same time they are still the habitat of large fisheries, and have other economic and aesthetic benefits. This is why the quantification of the relations of the load of nutrients to coastal ecological processes is a scientific challenge (*Rabalais and Nixon, 2002; De Jonge et al., 2002*).

There are present and future differences on the regional and latitudinal scale. The subtropical and temperate zones of the southern hemisphere (20-45ºS) have a comparatively low percentage of the area of hydrographic basins (~9 x 10^6 km^2), of the contribution of fertilizers, of sources and of the export of Dissolved Inorganic Nitrogen (DIN), and the Rio de la Plata is the main source of DIN. When it comes to considering continents, the export scenario for South America for the year 2050 (Business As Usual Scenario) would be nearly three times greater, exceeded only by Asia; on the other hand, the export of Dissolved Inorganic Phosphorous (DIP) could decrease because of the retentive effect of particles in reservoirs. Generically, the temperate regions export less than half the N with respect to their total anthropogenic sources than do tropical regions, a phenomenon which is not only explained by the distribution of the sources of N and the area of river basin, but also in part by lower precipitation (*Seitzinger et al., 2002*), a factor which is not well represented in the models.

3.3.5 Eutrophication and organic metabolism (P-R)

Eutrophication is the process by which a body of water is enriched with organic material when this causes changes in that system. It is a cumulative global environmental change associated with Nitrogen (N) and Phosphorus (P) excess, the drivers of which are the increase in population and economic activities (e.g. the use of synthetic fertilizers; *Seitzinger et al., 2002*).

The excess of N and P from direct (point-sources) or diffuse (rivers and atmosphere) sources stimulates *in situ* production of organic material (P) and the autotrophy - heterotrophy balance (P-R) to harmful levels. This organic metabolism approximately follows Redfield's stoichiometric ratio (*Gordon et al., 1996*; eq. 1):

$$\text{eq (1): } -/+C_{106}:-/+N_{16}:-/+P_{1}: \Leftrightarrow +/-O_{138}$$

Rates of limiting nutrients inputs usually determine eutrophication and trophic state. Nitrogen is usually the limiting nutrient, whereas phosphates and silicates (Si) may also be limiting in some estuaries or at different times of the year. Therefore, estuarine ecosystems are impacted and respond to external (extra-systemic) physical and human forcings such as increases in river flow (Q_V) and temperature, land-use changes, fertilizer application, damming, sewage outfalls, and nutrient loadings, by expressing symptoms of eutrophication

The occurrence of eutrophication effects or symptoms (excess algal biomass: chlorophyll-*a*, hypoxia and harmful algal blooms-HABs) indicates when the system cannot cope with the available internal and or external nutrient inputs (*NCR, 2000; De Jonge et al., 2002*). Organic metabolism of CH_20 (P-R) dictates the magnitude and direction of air/sea flux of bioactive elements (*Gordon et al., 1996*). The greater the buoyancy (vertical stability) the greater are P (*Lucas et al. 1999*) and R (*Rabalais et al., 1999; Nagy et al., 2002b*).. The assessment of the vulnerability of estuarine systems to TSC is under development (*NCR, 2000*). The main factors in the expression of symptoms of eutrophication are:

- flushing time (ft),
- turbidity gradient (tg),
- nutrient inputs (N_I or Q_N) and
- mixing state (stratification-destratification cycle: s-d) (*De Jonge et al., 2002; Nagy et al., 2002b*).

3.3.6 Susceptibility

The susceptibility to express symptoms of eutrohication depend on both N_I (*NCR, 2000; De Jonge et al., 2002*) and the balance between Q_V and wind stress, which determine mixing state and transport processes (*EPA, 2001; Nagy, 2003, 2004*). The susceptibility of estuarine systems to TSC depends on the sensitivity and resiliency of the system as well as on climatic conditions which govern the balance between buoyancy and mixing forces (Figure 28).

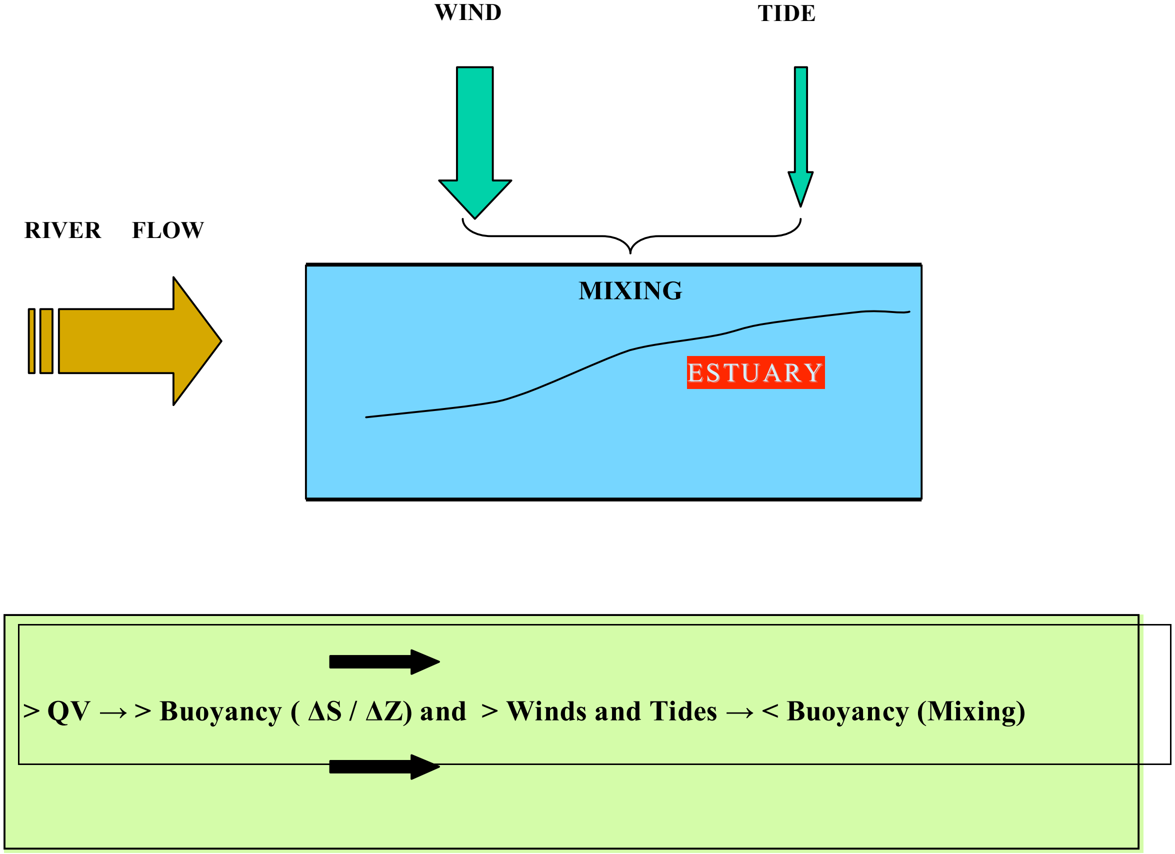


Fig. 28: Physical control factors of the susceptibility of estuarine systems to express symptoms of trophic state change (Nagy 2003).

3.3.7 Eutrophication pressures and trophic status in the Rio de la Plata

The Rio de la Plata is a large (3.1 x 10^6 km^2; 3.6 x 10^9 m^3), microtidal (amplitude -A < 2.0 m) coastal plain system, which is rich in nutrients and trophically based on phytoplankton (*López Laborde and Nagy, 1999; Gómez-Erache et al., 2000; Nagy, 2000; Nagy et al., 2002c*).

Because of its extension and morphological and environmental diversity, the RdlP can be divided into tidal river and estuarine regions, which in turn can be sub-divided into a number of sub-systems (*Nagy et al., 2002c*) with different depth, mixing state, trophic state, clarity and water exchange. In the second half of the 20th century the basin was subject to an increase in human and climatic pressures: nutrification, changes of use and erosion of the soils, increase in air and water temperatures ~0.8-1.0° C), precipitation and river flows (Q_V) respectively (~20 to 35%), attributable to global warming and to the increase in ENSO variability (*García and Vargas, 1998; Nagy et al., 2002b; Menéndez y Re, 2005*) and the displacement towards the south of the subtropical Atlantic anticyclone (Escobar, 2004). These changes have been greater during the last two decades (*Bidegain and Renom, 1998; Nagy et al., 2002d*).

The tidal river is characterized by a moderate heterotrophy (source of $C0_2$): an excess of DIN, especially ammonium of urban origin (mainly from Buenos Aires metropolitan area), and high denitrification rate (*Pizarro and Orlando, 1985; CARP, 1990; Bazán et al., 1996; Gómez-Erache et al., 2000; Nagy et al., 2002c*), with a concentration greater (> 20%) than the world average of 16%, slight oxic deficit (<90% saturation) and cyanobacteria blooms. However, the expression of the symptoms of eutrophication is limited by the turbidity gradient of the water (*Pizarro and Orlando, 1985; CARP, 1990; Bazán et al., 1996; EcoPlata, 2000; Meybeck, 1982; Nagy et al., 2002c*).

The estuarine region is globally autotrophic (sink of $C0_2$) and its nutrification is typical of non impacted subtropical systems; however, it shows several symptoms of eutrophication: i) oxygen deficit in the bottom layer (subclinal) in conditions of prolonged stratification (see Table 2), ii) frequent HAB blooms in summer, and iii) high biomass, as well as high rate of denitrification (*Gómez-erache et al., 2000; Nagy et al., 2002c*). The N/P ratio diminishes from >20 near the sources to <15 further down, and <5 at the marine zone, due to dilution and losses of NH_4^+ due to assimilation and /or adsorption) and of $N0_3^{1-}$ due to assimilation and / or denitrificaton (*Nagy et al., 1997; Nagy, 2000; Nagy et al., 2002c*), that is to say, an evolution of the limitation of P by N (Table 6).

	Q_N	DIN	Q_P	N / P	Si / N	Area (S) mM m^2 a^{-1} X 10^9	1-V_F 2-V_E mM m^3 y^{-1} x 10^{10}	Q_N / S	Q_N /V	C	B	O	FAN
Tidal River	2,3	20-45	1	> 20	5-7	15	1-7	1500	330	2	1	1	3
Frontal Zone	2,0	5-20		< 10	6-9	6	2-3	3300	470	1	2	2	2
Canal Oriental		<6		< 10	3-6								
Marine Zone	1,2	<5		< 5	5-9	16	2-1	750	120	1	1	2	3

Table 6: Loads, concentrations and ratios of typical nutrients, and degree of expression (1=light, 2= moderate, 3= high) of trophic indicators (C,B,O, HAB) in the Rio de la Plata: fluvial, frontal, Canal Oriental and Marine (modified from Nagy 2002 and 2005).

During AIACC project we have conducted fieldwork at the Canal Oriental, the Frontal zone and the Santa Lucía river estuary. We emphasized on some theoretical aspects such as the role of climatic forcings and mixing state, which are known to control the expression of symptoms of eutrophication (*NCR 2000; De Jonge et al., 2002*).

Recent researches (*Smith et al., 2003; Calliari et al. 2005; Huret et al., 2004; Lappo et al., 2005; Nagy, 2005; López y Nagy, 2005; Ponce,* unpublished report) suggest that TS indicators have increased (i.e increase in typical nitrate and chlorophyll-a concentrations, and occurrence of cyanobacterial blooms-Cyano-HABs) with regard to current baselines (1980-1989).

The RP shows an increasing trend of pressure indicators of TSC since the mid 1940s, and a shift of state indicators during the 1980s (*Nagy et al., 2003b; López and Nagy, 2005; Calliari et al., in press*). For example, eutrophic concentrations of nitrate (> 50 µM) and chlorophyll (>20 µg/L) are found during extreme floods (e.g., during El Niño 1983 or La Niña 1999 respectively; *Nagy et al. 2002a,b*). Human and climatic drivers have indirectly altered TS by modifying the physical environment (e.g., residence time, local warming), and / or stimulated the development of new symptoms (i.e. bottom water hypoxia under prolonged stratification periods and HABs), and these drivers are expected to increase in the next few decades. Therefore, an increase in Q_V should increase the vulnerability.

3.3.8 Indicators of susceptibility, impact and vulnerability

We are in need to develop indicators of susceptibility (e.g. f_t, residence time of water-RT, buoyancy and mixing *status*) and TS for both cross-system and long-term comparisons as well as for the assessment of the impact of the degree of nutrient excess in estuaries (*NCR, 2000; De Jonge et al., 2002: EPA, 2001*). Some indicators were developed for fresh and estuarine waters of the Uruguayan coastal zone and watersheds (*Nagy et al., 2002b, 2004; Nagy, 2003; Nagy and Ferrari, 2003)* as presented in Figure 29. The main variables considered are:

- susceptibility (e.g. f_t, RT, buoyancy and mixing *status*).
- drivers (population density, fertilizer use, point sources and river flow).
- pressure (N, P, and Si load and gradients).

- state or causal variables (e.g. [N, P]).
- response / impacts or symptoms (Chl-a), $[0_2]$HABs occurrence, □ nutrient ratios (N/P and N/Si) and species change (Officer and Ryther, 1980; Turner, 2002).

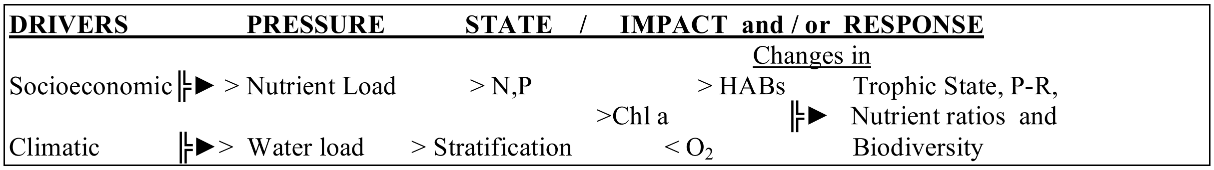


Fig. 29: d-PSI Framework (modifed from Nagy, 2003).

3.3.9 Causes and symtpoms of eutrophication in the Rio de la Plata

Even if nutrient inputs to the Rio de la Plata are well below the figures for developed countries, estimated by *Nagy* (2003) as being ~330 and 120 mM m^3 y^{-1} for the tidal river and marine zone repectively (based on data from *Pizarro and Orlando 1985, Nagy 2000, Menéndez et al 2002*), they are higher than they were in the past (e.g. estimated for 1950) because of:

Increase in population and agricultural intensificaton (sewage, fertilization, irrigation, □ land-use, soil erosion, leaching) (*López and Nagy 2005*)

Increases in precipitation and river flow (> 30%).

Persistent stratificacion (over several tidal cycles to weeks during fall) (*Nagy et al 2002b*) and

Low tidal mixing and (horizontal) excursion (*Nagy, 2000*) determining the development of symptoms of eutrophication (as defined by *Bricker et al. 1999; 2003, NCR 2000, EPA 2001*):

Low dissolved oxygen concentration in bottom waters (subclinal environment).

Supraclinal eutrophic levels of chlorophyll-a (e.g. > 20 □g l-1).

HABs occur since at least 1980, showing an increase in frequence during the last decade.

Eutrophic nitrate levels (e.g. > 50 μM) during severe/extreme floods (e.g. El Niño 1983, *Nagy et al. 2002a,b*), and an increase in typical mesoeutrophic values over the last few years.

Summarizing, the Rio de la Plata is highly susceptible to express symptoms of eutrophication because of low tidal mixing and mixing *status* (mix is driven by winds) and high RT, and moderately eutrophied because of nutrient load (N_I), N_I / estuary volume ratios, total normalized nitrogen load-TNNL (= N input x Area x mixed layer depth / RT, expressed as μM), internal sources (remineralization and low dissolved oxygen concentrations in bottom waters). Redfield stoichiometry varyies from 6 to 10 (*Nagy et al. 2002b*), and denitrification (sink of N) reduces eutrophication danger provided that present oxygen levels be mantained; *Nagy et al 2002a,b*).

3.3.10 Harmful algal blooms (HABs)

Harmful and Noxious Algal Bloms (HABs) events have a great economic impact because they affect the commercialization of mollusks and fish, and tourism in Uruguay. The first episodes of toxic HABs on both the Argentine and Uruguayan coasts occurred in 1980 (*Yentsch 1982*). Since that year they have occurred every spring on the Argentina platform, while on the Uruguayan coast they recurred in 1991, and every year since up the present time (*Carreto et al. 1998; Ferrari 2002*).

The Paralytic Shellfish Poisoning (PSP) producing species are *Gymnodinium catenatum* and *Alexandrium tamarense.* The former is registered in summer and the fall (*Méndez and Ferrari 2002*) and the latter at the beginning of spring (*Méndez et al. 1996; Brazeiro et al 1997*). *Gymnodinium catenatum* was noted for the first time in the area in the summer of 1992, and since then every summer-fall its presence and toxicity has appeared. The greatest development of the blooms of this species occurs in the warm waters of summer, and given the presence of cysts in the sediment (*Méndez 1995*), the start is attributed to the re-suspension of cysts in the sediment and to these temperature conditions. *A. tamarense* develops in the south and is associated with subantarctic waters of the Argentine platform, and it is carried by the currents to Uruguayan waters depending on the reduction in the discharge of the tributaries of the Rio de la Plata (*Méndez et al. 1996)*, particularly of the Uruguay River *(Nagy et al 2002b*).

The first diarrheic intoxications in Uruguay occurred in 1990; they were due to the presence of *Dinophysis acuminata*, and then diarrheic episodes also occurred in 1992, 1994 and 1996. However, the presence of *Dinophysis* is variable in all seasons of the year (*Ferrari et al., 2000*).

The diatoms of the genus *Pseudo-nitzschia*, present on the coasts but never associated with toxic episodes, manifested it in December 2001, causing a peak below the limit level of amnesic toxin (*Medina et al., 2002*).

Cyanobacteria have multiplied in recent years, although their presence had been recorded for a number of years before; the first appearance of *Microcystis aeruginosa* in the Rio de la Plata was in 1982 (*CARP, 1990*). This species is very persistent in the summer months, especially on the coasts of Montevideo and Colonia, and its bloom produces extensive green stains which dye the water as if they were paint. Toxic blooms occurred in 1997 and 1999 (*De León and Yunes, 2001*). In the summer of 2001, the massive bloom all along the whole coast of the Rio de la Plata was accompanied by other species of *Microcystis* which had not been noted before (*Ferrari and Sienra, 2002*).

Diatom *Aulacoseira granulata* and the cyanobacteria *Microcystis aeruginosa*, both associated with river discharge, are indicators of two coexistent trophic *status* on different time and geographic scales (*López and Nagy, 2005*):

(1) alternated mesoeutrophic and

2) persistent eutrophic, related to combined lotic-lentic communities, the former being typical of the annual cycle and the latter of the warm period (late spring to early autumn).

This distribution pattern covers the lower basin and the north coast of the Rio de la Plata, especially associated to River Negro and Uruguay discharges (*O'Farrell and Izaguirre, 1994; Bonilla, 1997*). To be able to understand and predict the HAB blooms, it will be necessary to carry out connected studies of climatic events on a macro scale, of ENSO events, the discharge of the Paraná and Uruguay rivers, the location of the frontal zone of the Rio de la Plata and of the subtropical convergence front (*Ferrari, 2003*).

Table 7 shows an example of impact matrix of HABs occurrence developed by *Ferrari and Nagy* (2003) for the Uruguyan coastal zone of RP for the decade 1991-2000. Four indicators were estimated and aggregated: i) intensity of HABs (cells/L), ii) persistance (months), iii) extension along the coast (% of coverage) and iv) toxicity (toxin concentration from low to very high). Both freshwater (cyanobacteria HABs) and estuarine/marine species were considered. HAB Index = Toxic Species Index + Noxious Species Index

			Prevailing		**Extreme**
Indicators	**0**	**1**	**2**	**3**	**4**
Intensity (cells/liter)	0	10^2	10^3	10^4	10^5
Persistance (months)	0	0.25	0.75	1-6	>6
Extension (% of coverage)	0	10	25	50-75	>75
Toxicity (concentration)	0	low	moderate	high	very high

Table 7: Aggregated impact matrix of HABs (both fesh-and estuarine waters) in the Uruguayan coastal zone of the Rio de la Plata for the period 1991-2000 (from Ferrari and Nagy, 2003).

A second aggregated impact matrix was then built in order to take into account the occurrence of the four main HAB species weighted from absence (0) to very high (4) according to the criteria defined in table 1. Weights of the HAB species were summed and ranked and ranked from 0 to 100 or very low to very high, respectively. Weighting criteria were based on both the literature (EPA, 2001) and local occurrence according to expert judgement of the authors (Table 8). The SST 3.4 index – which is well correlated with Q_U - is reported on annual basis (from March to February).

Year	**SST 3.4**	***1 Alexandrum tamarense***	***2 Gymnodium catenatum***	***3 Dinophysis acuminata***	***4 Mycrocistis aeruginosa***	**Σ**	**Index 0-100**	**Impact**
1990-91	0.3	3	0	0	0	3	21	Low
1991-92	1.0	2	3	2	2	9	64	High
1992-93	0.4	2.75	2.75	0	0	5.5	39	Low
1993-94	0.4	1.25	2.25	1.5	2.75	7.75	55	Médium
1994-95	0.6	2	2.25	0	0	4.25	30	Low
1995-96	-0.4	3	2.25	1.5	0	7	50	Médium
1996-97	-0.3	1.25	1.5	0	3	6	43	Medium
1997-98	1.8	0	2	0	0	2	14	Very low
1998-99	-0.7	1.25	1.25	0	2	4.5	32	Low
1999-00	-1.3	1.0	1	0	0	2	14	Very low
Average	**0.2**	**1.75**	**1.83**	**0.5**	**0.98**	**4.7**	**36**	**Low /medium**

Table 8: Aggregated impact index of HABs for the Rio de la Plata (1991-2000; from Ferrari and Nagy, 2003).

Finally, these indicators were weighted taking into account their impacts on three sectors: i) Human Health (H), ii) Economic activity (Ec) specifically mollusks consumption, and iii) Environmental Health (Ev) according to the expert judgement of the authors. Coefficient weights were 0.75, 0.50 and 0.25 for H, Ec and Ev respectively, which were multiplied by the values reported in table 5. Thus, a weighted aggregated impact index of persistence /extension /toxicity (IPET) was built (Table 9). An impact coefficient was assigned for each of the four species. Relative impact of each indicator (IPET from 0 to 1) is shown for each species and sector. Extreme values are toxicity of Gymnodinium for H and intensity of Dinophysis for Ev.

Weighted Index for each sector (0-1)

Species	**Health: 0.75**	**Economic activity: 0,50**	**Environment: 0.25**
Gymnodinium 0.50	T: 0.37	T: 0.25	P: 0.13
Alexandrum 0.42	E: 0.32	P: 0.21	E: 0.11
Microcystis 0.33	P: 0.25	E: 0.17	T: 0.08
Dinophysis 0.22	I: 0.19	I: 0.13	I: 0.06

Table 9: Weighted aggregated impact index of HABs (IPET) for each species and sector in the Northern coast of the Rio de la Plata (1991-2000; from Ferrari and Nagy, 2003).

The overall impact of HABs occurrence during the studied period was low to medium, with only one high impact year (1992) and two very low impact years (1998 and 2000), which coincide with strong ENSO events (1997-98 and 1999-2000 respectively). However, the only one species that reached high values in 1991 and 1993 (the highly toxic Alexandrium *tamarense*) was related to both the northward displacement of Malvinas current – where Alexandrum is present – and low Q_V (*Méndez et al., 2001*); especially because of extreme low Q_U (Nagy et al., 2002b), as well as in 1996 - when Q_U was very low-. Usually, both drivers are associated with El Niño and La Niña years respectively, which reduces the vulnerabilty of RP to suffer the presence of Alexandrium blooms. Up to date they have occurred during early spring time – when Malvinas current often reaches the mouth of the RP advecting cold waters and Alexandrium into the estuary if Q_V is low- but should be potentially dangeorus to H if they should occur during summer time.

3.3.11 Coping capacity and resiliency to trophic state changes

Even if there is not a clear pattern of HABs occurrence with ENSO ST 3.4 index, some examples such as the occurence of Alexandrum in 1991, 1993 and 1996, the relatively high index of El Niño multiyear event (1991-94), and extreme events of the years 1998 and 2000 suggest some hydroclimatic control. Recent years (2001 and 2003, not shown here) have shown a marked increase in Cyano-HABs (*López and Nagy,2005*) at intensities higher (> 3) than those found during the past decade and this seem to be the main problem for future years. Strong ENSO years coud stimulate cyano-blooms in the RP, the former by advecting freshwaters (from River Uruguay) and the latter by decreasing the ft of water and particles. The coping capacity thresholds for TSC as a function of Q_V extremes associated with El Niño (>32 x 10^3 m^3/s) and La Niña (<16 x 10^3 m^3/s) are synthesized in table 10 and Figure 30.

River Flow thresholds	**x 10^3 m^3 s^{-1}**	**State**	**x 10^3 m^3 s^{-1}**	**State**	**Impacts**
Q_V	< 16	Eutrophic	> 35	Eutrophic	[Chl-*a*], Cyano-HABs
Q_U	< 2	Eutrophic	> 12	Eutrophic	[Chl-*a*], Cyano-HABs
Wind-related thresholds	**m s^{-1}**		**m s^{-1}**		
	>10	Mixing of shallow water column (< ~10 m)	< 6	Prolonged stratification of shallow water column	> *p-r*
	>13	Mixing of bottom waters (> ~17 m)	< 8	Prolonged stratification of deep water column	Hypoxia Remineralization of N,P Denitrification
			>8-10		< Fishing activity Displacement of EF

*Table 10: Coping capacity, resiliency, ecosystem state and impacts as a function of river flow and wind thresholds (Y: A*X* functions); (based upon data from Norbis, 1995; Nagy et al., 2001; Nagy et al., 2002c; Nagy et al., submitted).*

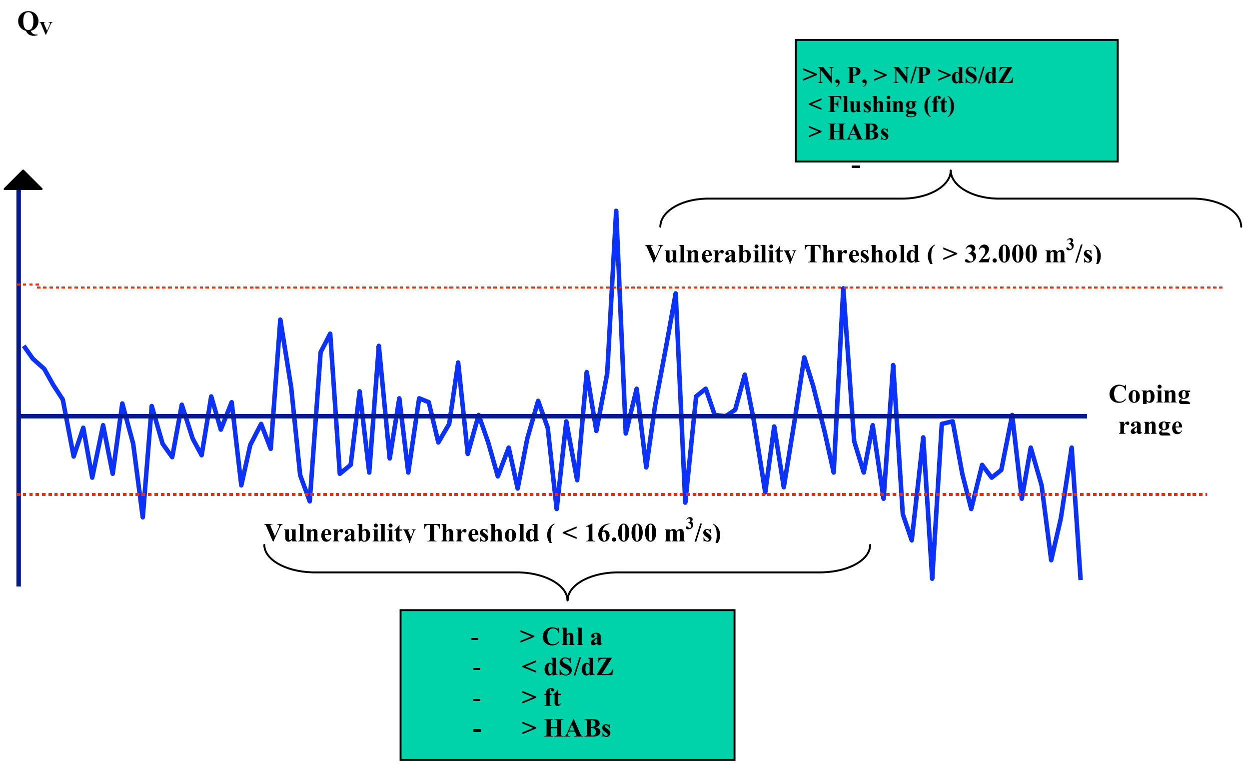


Fig. 30: Conceptual coping range of trophic state changes (□ N, P, N/P, buoyancy, flushing time, HAB5s, Chl-a) as a function of river flow variability (modified from Nagy, 2003).

3.3.12 Susceptibility in microtidal systems

The processes of mixing and transport in coastal plain systems are dominated by the tide (A), river flow (Q_V) and winds (W) as presented in Figure 30 and Tables 3 and 11. The balance between these forces and morphology determines the spatial salinity and turbidity gradients, and mixing state, determining factors of organic metabolism (P -R) and the degree of expression of the symptoms of eutrophication to the load of nutrients (Table 11). Microtidal systems have a low capacity to mix, which depends on the wind, and in them Q_V is the "master variable" which controls buoyancy (dS/dZ), nutrification, RT, stratification and gravitational circulation, and salinity (*EPA, 2001; Monismith et al., 1996*); at similar Q_N these systems present values of B, *p* and *r* greater than in macrotidal systems (*EPA, 2001*).

Type	Mixing forces	Mixing energy	Width / Depth Ratio	Salinity gradient	Mixing index	Turbidity	Bottom Stability	P	Example
A	Q_F	Low	Low	Long/Vert	> 1	Very High	Low	Low	Mississippi
B	Q_F, A	Medium	Medium	Long/Vert	<1/10	Medium	Good	Very High	Chesapeake
C	A, W	High	High	Long/Lat	<1/20	High	Fair	High	Delaware

D	A, W	Very High	Very High	Lateral	?	High	Poor	Medium	
A	Q_F , W, A	High	High	no	<1/10	High	Poor	Low	RP FM
B,A	Q_F , W, A	Medium	Very High	Lo/Ver/Lat	<1/10	Medium	Medium	Very High	RP Front
A	Q_F , W,	Low	Medium	Long/Vert	<1/20	Low/Med	Good	High	RP Plume
B	W, Q_F	Medium	Very High	Lo/Ver/Lat	< 1/10	Low	Medium	High	RP Ext

Table 11: Characteristics of the classification of coastal plain estuaries (EPA, 2001) and it's appliccation to the study of trophic state of the Rio de la Plata.

3.3.13 Summary of determinant factors on the susceptibility to expres symptoms of eutrophication and current trophic state scenario of the Rio de la Plata.

The comparative study of microtidal systems indicates that there are three main factors which affect susceptibility (*EPA, 2001; Bricker et al., 2003*), all of which are very dependent on flow (Q_V).

1- dilution (Q/V) and residence time (RT) of the fresh water ($Q/V_{\text{ESTUARINE WATER}}$).

2- the ratio of the nutrient load Q_N by area (S) and volume (V).

3- the stratification-destratification cycle (*López Laborde and Nagy, 1999;EPA, 2001;*).

Dilution (Q/V), residence time (RT) and the Q_N /S and Q_N /V ratios are proxy variables of the capacity of the system to receive and assimilate nutrients. They are very useful in low volume (V) and vertically mixed systems, and can be well applied in the tidal river (Table 10). In stratified systems, it is better to use suprapicnoclinal volume ($V_{\text{ESTUARINE WATER}}$, EPA, 2001).

Mixing state is controlled by Q_V, the wind (W) and the tide (A); the greater the ratio Q/V, the greater the river predominance, e.g. the tidal river and the Canal Oriental of the Rio de la Plata (*Nagy et al., 2002c*). Stratified systems are susceptible to subclinal oxic stress (Rabalais et al., 1999) due to the fact that the downward transport of oxygen, nutrients and plankton is limited (>R*)*, determining greater RT in the euphotic zone (usually in the supraclinal environment), greater algal development, productivity and assimilation of nutrients (>P) (*EPA, 2201; Rabalais et al., 1999; Cloern, 2001*).

Oxic stress is not only due to metabolic increase but also to the vertical stratification of density (> ΔS and / or > ΔTemperature), long RT, low tidal mix, and a high ratio of the area of the basin (B_A) to the volume of the estuary (*Cloern, 2001*); the first two factors controlled by Q_V, are to a greater or lesser extent applicable to the Rio de la Plata. If stratification persists through a number of tide cycles (*Simpson et al., 1990*) the organic metabolism diminishes, regulated by the turbulent mix introduced by the wind in function of its intensity and duration, by buoyancy (dS/dZ) and by depth. Therefore, deep regions (> ~15m) are more susceptible than the shallows (< ~10m) as the subclinal layer remains for weeks without mixing completely. This condition is typical of the end of the fall and the start of winter (April-August), when the wind is less intense, the Q_V is greater, and the salinity front is located down-river at greater depth (*Nagy, 2000; Guerrero et al., 1997; Simionato et al., 2001; Nagy et al.,* submitted).

In late spring and the start of summer (November-February) trophic susceptibility is controlled by the increase in temperature and solar radiation, and consequently of B and P – *R*, a lower Q_V (except in the El Niño years) and the predominance of onshore winds (E-S); as these are the ones which have the greatest effect (*Nagy et al., 1997; Guerrero et al., 1997; Simionato et al., 2001*). All this favors the move up-river of the salinity front (to less depth), and less vertical difference in density, facilitating the upward flow of nutrients. On the interannual scale, a combination of these seasonal conditions would predominate, with interaction of buoyancy and the mix, which have increased due to the increase in Q_F, temperature and of the frequency of onshore winds in the last three decades respectively (*Nagy, 2000; Bishcoff, 2002; Escobar, 2004*). This balance would also control the source of "new" nutrients from the subclinal environment, autotrophy (*p*) in the euphotic layer, and, probably, the ratios of nutrients. Although neither these balances nor their effects have been quantified, the increase in HAB blooms in the Canal Oriental could be connected with the development of these indicators.

3.3.14 Reflections on the use and application of trophic indicators in the Rio de la Plata

The use of trophic indicators is complex and ambiguous. It depends on time-scales, e.g. phytoplankton responds to changes in nutrient concentrations (Δc) in hours to days while the recycling of bioamss (B) in nutrients takes days to weeks. Besides, nutrification associated with greater Q_V might not develop the expression of symptoms of eutrophication in the system due to the lower RT and the greater export of nutrients (*EPA, 2001*). Two indicators which combine many of these concepts for systems limited by N are:

i) the export rate (E_N), or percentage of N which leaves the system without *in situ* losses (*EPA, 2001*).

ii) the total normalized load of nitrogen-Qn_N (*EPA, 2001*).

The export rate (in %) or delivery is estimated from input (Q_N) and output values and / or dilution curves (plot of salinity Vs nutrients). Residence time is a control factor for this rate: the greater the RT the less E (> *in situ* losses); if RT is lesser than one day the symptoms of eutrophication are not expressed since the phytoplankton does not double independently of nutrification (*EPA, 2001*). E_N varied in the Rio de la Plata between 5 and 20 % for a RT of around 1 month (2 to 6 weeks; *Nagy, 2000*).

The normalized total nitrogen load is an index of the potential for eutrophication expressed as c (uM), and is estimated from Q_N, S, Z and RT ($Qn_N = Q_N \times S \times Z/RT$); in stratified systems supraclinal Z is used. Table 14 shows Qn_N for the subsystems considered.

(sub) System	**Area**	**Z**	**Q_{DIN}**	**RT**	**oxic status**	**Mixing *status***	**E (%)**	**QNn**	**DIN** uM
Name	10^3 km	m	mM m^{-2}	months	OK-H-A			uM	
Baltic	374	55	217	250	Hypo/Anoxia	Stratified	-	81	
Chesapeake	11	6	938	8	Anoxia	Stratified	-	98	
Gulf of Mexico	20	30	6500	6	Hypo/Anoxia	Stratified	-	107	
Tidal River-RP	15	5	1500	0.9	OK	Homogeneous	≥ 80	22	30-45
Frontal Zone-RP	6	8	2700	0.3	OK/Hypoxia	Stratified	≥ 80	25	5-20
Canal Oriental-R	5	17	800	0.5	OK/Hypoxia	Highly stratified			
Marine Zone-RP	14	14	1800	0.6	OK/Hypoxia	Stratified	>70	13	<5

Table 12: Nitrogen load, rate of export, mixing status *and subclinal oxic* status *(OK, Anoxia-A, Hypoxia-H) of subsystems of the Rio de la Plata and other stratified estuarine systems (based on EPA, 2001; Nagy et al., 2002c).*

The estimates of QnN are comparable with the mean concentrations of the four subsystems (*Nagy et al., 2003c*), in particular for the tidal river and the frontal zone, while they are underestimated and overestimated in the Canal Oriental and marine zone respectively. This seems to be due to greater uncertainty in the estimating of input and of RT. These values suggest a mesoeutrophic system. In the stratified sub-systems, the internal source of new nitrates come from the subclinal reservoir (*Nagy et al., 2002c*), estimated, for the Canal Oriental, as being of the same order of magnitude of the supraclinal. Compared with an empirical model of the fractions exported aa a function of time of residence in world's estuaries, a similar behavior in the tidal river (<1 month and E ~0.75) can be seen, while in the estuarine region (RT ~0.3-0.5 month) it is somewhat less (E≤0.6) than the model (> 0.7), which would be explained by losses through denitrification and the temporal accumulation in the subclinal reservoir (*Gómez-Erache et al., 2000; Nagy et al., 2002c*).

3.3.15 Oxic status and vulnerability of the fish habitat

Oxic deficit affects the habitat of fish and their reproductive location; therefore, it is preferable to consider the concentrations which cause biological stress in fish as hypoxia, that is to say ≤50% of oxygen saturation (*Breitburg, 2002*). These concentrations do not prevail in the shallow zones of the Frontal Zone (*Nagy et al., 2002c*) where its main resource, the white croaker spawns in spring-summer (*Vizziano, 2003; Vizziano et al., 2003*) and its frequent occurrence in the present scenario does not seem plausible.

3.4 Sea Level Rise and Coastal Vulnerability of the Western Coast of Montevideo

3.4.1 Introduction

The western coastline of Montevideo (~80 km including fishermen settlements, Santa Lucía river estuary and mouth, beaches and wetlands) was previously defined by several qualitative assessments as one of the most vulnerable of the country to sea level rise-SLR (Table 13).

This coast is unique because it is subject to fluvial, estuarine and marine forcings (tides, storm surges, river flow, drift currents and changes in salinity) due to its location within the transition from fresh- to estuarine waters (*Nagy et al. 2004*). The soleley long-term tide-gauge record in Uruguay is located within this coastal section of Punta Lobos (Figure 31). The rate of increase was 0.11 mm/y (within the world range, IPCC, 2001). During the last 15 years this rate was ≥3 mm/y and the extremes were associated with strong La Niña-1989 and El Niño-1998 respectively (from Nagy et al., 2004a).

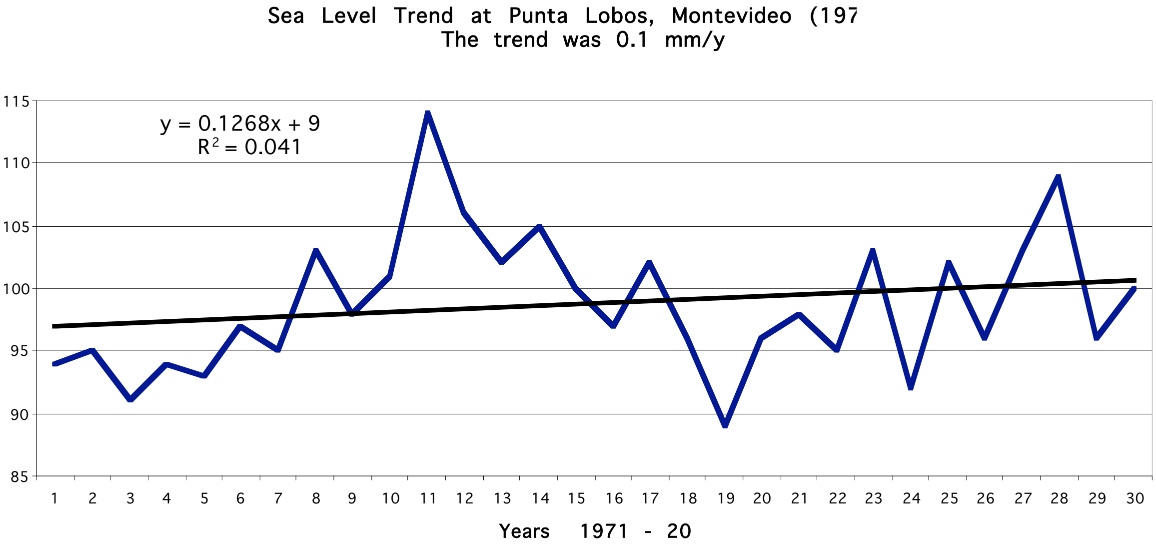


Fig. 31: Sea level rise in Montevideo during the period 1971-2000 (from Nagy et al., 2004a).

Sector	Low	Moderate	High
People affected		X	
People at risk	X		
Biodiversity (e.g., wetlands, bird habitat)			X
Capital at risk / Infrastructure	X		
Coastal Fisheries		X	
Tourism		X	

Table 13: Synthesis of previous cualitative assessments of the vulnerability of people, sectors, and systems in the western coast of Montevideo (from Kokot et al., 2004, based on Saizar, 1997; Nicholls and Mimura, 1998; EcoPlata, 2000; OECD, 2004; UCC, 2004).

3.4.2 Dynamical factors that increase vulnerability to SLR are:

Southern winds (especially those from the WSW to the SSE) increase observed amplitude (1.0 m) and produce storm surges and floodings (3.0 - 4.0 m) which when combined ravage the coast (*Lorenzo and Texeira, 1997; Pshennilkov et al., 2003; Nagy et al., 2004b*). An example of this occurred in February 1993.

Strong ENSO-related observed fluctuations of Q_U and Q_P (regional factor) and Q_{SL} (local factor) that increase or decrease observed amplitude (+/-10 cm) on annual basis (*Nagy et al., 2004b*).

The former is common to most world’s coastlines and the latter is a particularity of the coasts of the RP due to its river-dominated regime (controlled by winds over synoptic timescale).

3.4.3 Factors of vulnerability

We used a quantitative index of vulnerability (*Gornitz, 1990, Gornitz et al., 1997; Shaw 1998*) which is built on 7 indicators shown below where vulnerability decrease to the right.

- Height: from –0.5 m to 5 m: low lying areas (-0.5 m) are highly vulnerable to
- moderate SLR (0.3 m) and storm surges. Of particular concern are wetlands.
- Lithology: Hard rocks / Sedimentary rocks / Sediments / Unconsolidated
- sediments
- Geoforms: cliffs, wetlands, sandy beaches, rocky shores.
- SLR: Over the past 100 years SLR was 9 cm, below both world average (15 cm) and Buenos Aires (17 cm; *Barros, 2003*). However it shows an increasing rate since 1971 (Figure 22).
- Coastal retreat: stable / low / moderate
- Tidal amplitude: 0.5 m (or 1.0 m due to wind).
- Wave energy: ~2.0 m (estimated).

Thus the vulnerability was objectivley classified as low, moderate and high for 24 boxes along the coastline (Table 14 and Figure 32). The western sector and wetlands are highly vulnerable to SLR and SSE - WSW storm surges.

	COASTAL VULNERABILITY				
	Very low	**Low**	**Moderate**	**High**	**Very high**
VARIABLES	**1**	**2**	**3**	**4**	**5**
1. Height (m)	>30	21-30	11-20	6-10	0-5
2. Type of Rock	High grade plutonic, Volcanic and high grade metam. rocks.	Metamor rocks	Majority of Sedimentar rocks	Sedimentary rocks Not very Consolidated sediments	Unconsoli-dated sediments
3. Geoform	Fiords, high cliffs	Interm. and low cliffs	Beaches, Beaches on littoral platform	Barriers, deltas, tombolos	Tidal plains, marshes , wetlands
4. Sea level (cm / 100 y)	> -50	-50 – 20	-19 +20	+21 - +40	> +40
5. Displacement of coastline (m/y)	>+0.1 accretion	0 stable	-0.1 –0.5 erosion	-0.6 –1.0 erosion	>1.0 erosion
6. Tidal range (m)	<0.50	0.5 – 1.9	2.0 – 4.0	4 -6	>6.0
7. Maximum height of wave in a year (m)	0-2.9	3.0-4.9	5.0-5.9	6.0-6.9	

Table 14: Coastal vulnerability matrix for the western coast of Montevideo (from Kokot et al., 2004).

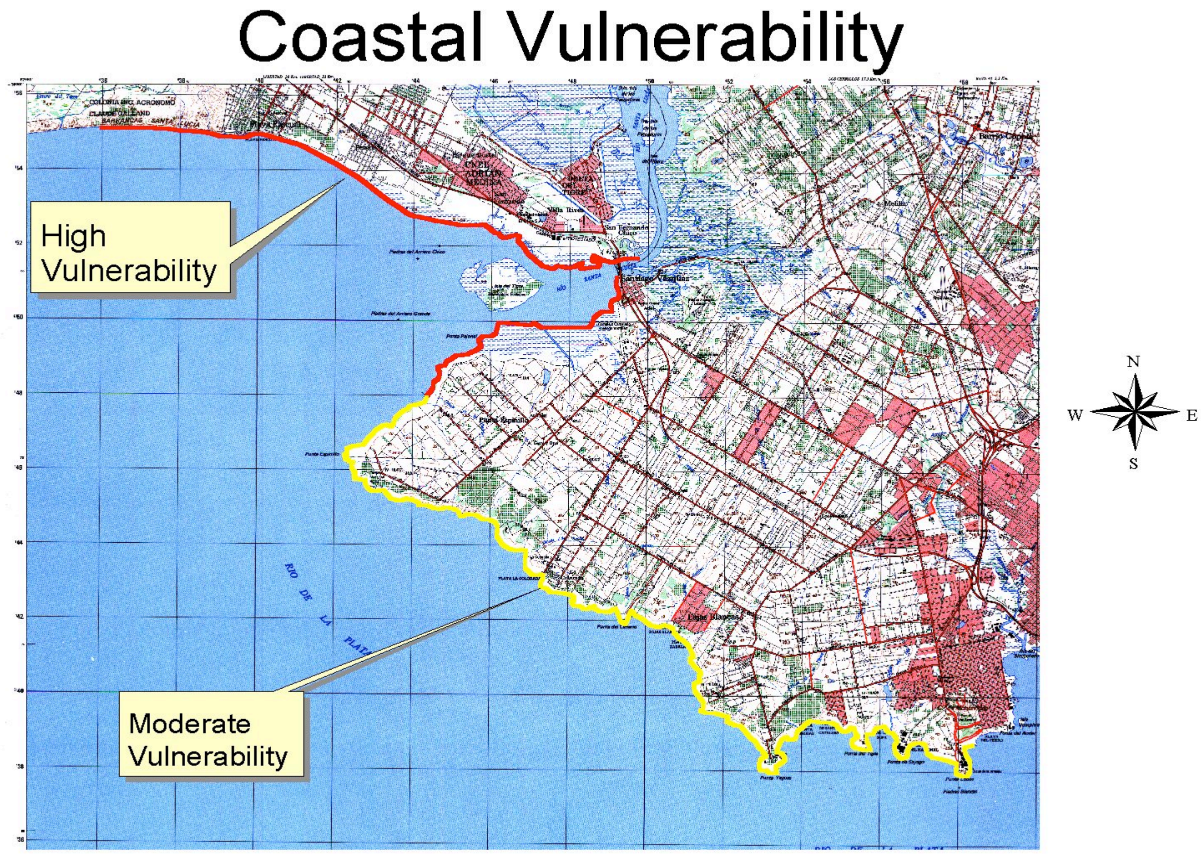


*Fig. 32: Coastal vulnerability of western Montevideo and Santa Lucia coastal zone. Red colored low-lying area is a continuum of sandy beaches (from Kokot et al., 2004)***.**

3.5 Santa Lucía River Estuary

3.5.1 Hydrology

The Santa Lucía river estuary and coastal zone (SL) is the main low-lying coastal subsystem of the Rio de la Plata's northern coast (Figure 33). This system is highly nutrified (mostly N from fertilizer application) and rich in biodiversity (associated with sandy beaches, salt marshes and wetlands, *EcoPlata, 2000; Caffera et al., 2004; Nagy et al., 2004*) and supplies most of drinking water to Montevideo and surroundings. The mouth (estuarine zone), located close to the estuarine front, is a subsystem of the RP, from where it receives salt water a few months of the year.

Fig. 33: Main Santa Lucía River basin, southern Uruguay, and the estuarine front.

Interannual variability of river discharge (Q_{SL}<0.02 to >1.8 10^3 m^3s^{-1}, average: ~0.10 x 10^3 m^3s^{-1}) as presented in Figure 34 is ENSO-related in the middle basin from August to February, especially from October to December, which coincides with the peak of fishing capture in the adjacent EF. Nevertheless, this relationship was not not clear on yearly basis for two of the strongest events (El Niño 1997 and La Niña 1999 respectively), when the influence was very strong on seasonal basis. Both an increasing trend (> 25%) and a relationship with ENSO-related variability (El Niño: 1983, 1993 and La Niña 1989, 1996, 2000) are observed.

During floods Q_{SL} decreases the salinity and increses both the nutrification and stratification (buoyancy) of adjacent waters of the Rio de la Plata (Caffera et al., 2004) close to the EF, which should favor $C0_2$ fixation (P) via photosynthesis. The historical daily maximum was 4.1 x 10^3 m^3s^{-1}.

Such as a strong relationship with ENSO was not expected because previous works (Bidegain and Caffera, 1989) indicated that it's signal was relatively weak in southern Uruguay. River flow at the middle basin follows yearly precipitations at Florida city a few tens of km upstream. Monthly precipitations at Florida (1990-2003) are shown in Figure 35. Both precipitations and Q_{SL} are greater than the average from February to April and from October to December (when ENSO influence is maximum) and decrease from June to August (austral winter). Average yearly precipitation during recent years (1997-2003) is 7% greater than the climatic reference (1961-1990).

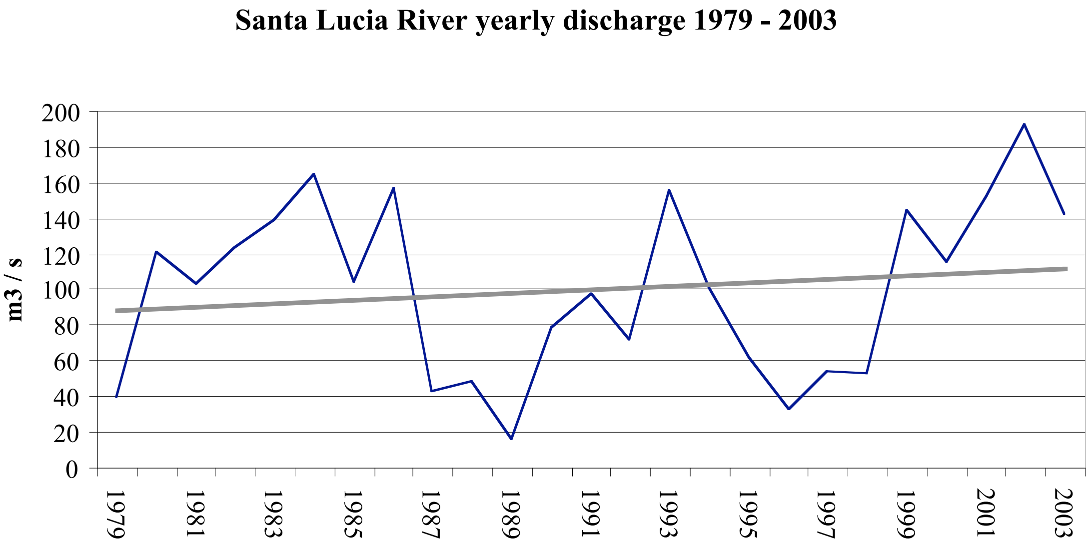


Fig. 34: Santa Lucía River yearly discharge (1979-2003).

The influence of El Niño is strong in October - November and weak in February (Table 15 and Figure 36), whereas La Niña influence is strong in October and February, and weak in January.

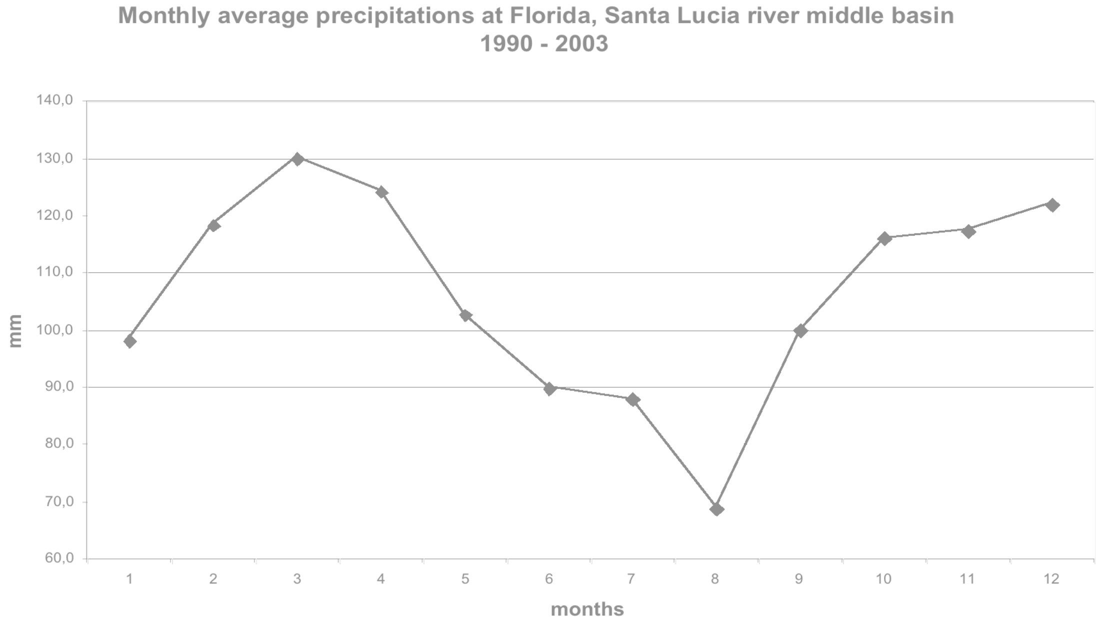


Fig. 35: Monthly average precipitations at Florida in the middle Santa Lucia basin.

ENSO phase	**Month**	**DHR > 0.75**	**DHR > 0.50**	**DHR < 0.25**
El Niño (EN)	October	0.33	**0.68**	0.12
Neutral (N)	October	0.28	**0.55**	0.17
La Niña (LN)	October	**0.03**	**0.08**	**0.69**
El Niño	November	**0.52**	**0.68**	0.09
Neutral	November	0.36	**0.52**	0.21
La Niña	November	0.13	0.22	**0.52**
El Niño	December	0.38	**0.67**	**0.04**
Neutral	December	0.24	**0.45**	0.16
La Niña	December	0.12	0.16	**0.28**
El Niño	January	0.19	**0.54**	0.07
Neutral	January	0.24	**0.46**	0.24
La Niña	January	0.37	**0.48**	0.20
El Niño	February	0.08	**0.45**	0.14
Neutral	February	0.28	**0.57**	0.18
La Niña	February	0.37	0.32	**0.62**
EN average		**0.30**	**0.60**	**0.09**
N average		0.28	**0.51**	0.19
LN average		0.20	0.25	**0.46**
	Maximum	**EN-November**	**EN-Oct/November**	**LN Oct/February**
	Minimum	**LN- December**	**LN-October**	**EN-December**

Table 15: Daily river heights (DRH) during ENSO (October/December) and ENSO +1 (January/ February) years (1979-2003) in the middle Santa Lucia Basin (modified from Caffera et al., 2004).

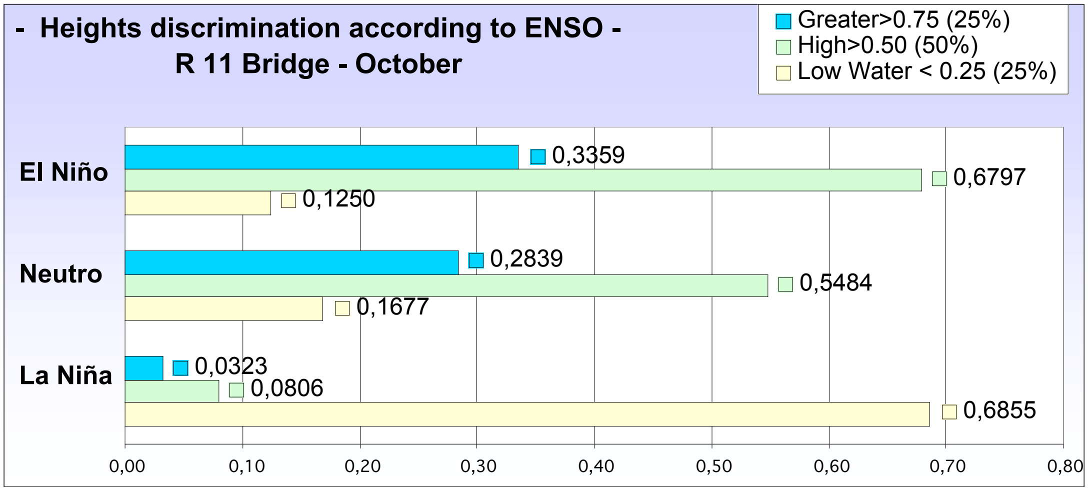


Fig. 36: Level of discrimination of river water height in the Santa Lucia middle basin during October and February for the period 1979-2003 (from Caffera et al., 2004).

3.5.2 Trophic state

The evolution of the trophic state (TS) in the Santa Lucía river estuary showed a strong relationship with both Q_U and Q_{SL} during the period October 2002 and May 2004. We selected one state / impact variable of TS, chlorophyll-*a*, (Figure 38) to show this relationship, as well as the coping capacity and vulnerability of the ecosystem to ENSO-related climate variability. During the studied period the temperature control on TSC was moderately high (correlation-r T vs Chl-*a*: 0.44) but was almost blocked during the peak of river flow – of both Q_U and Q_{SL}- from October 2002 to May 2003. Both, the increases in freshwater in the RP and Q_{SL} enhanced physical controls on TSC other than temperature: decrease in ft of water and plankton, increase in turbulence, and supression of the estuarine circulation and stratification regime. This control blocked the expression of TS symptoms when salinity was 1< and chl-a varied from 0 to 7 μg/L in the estuarine zone (Sgo. Vázquez) and from 0 to 8 μg/L at the river - estuary boundary (Delta del Tigre). Once both Q_V and Q_{SL} were within the coping range since October 2003, salinity increased to 4-7 as well as chl-*a* did up to eutrophic levels (18-28 μg/L) at both stations.

Some concluding remarks of these observations are: i) during normal years the system expresses symptoms of TSC which agree well with nitrate excess (30 - 70 μM), ii) during El Niño years the system does not develop symptoms of TSC and deliver nutrients to the RP, and iii) during La Niña years the system should be prone to increase TSC, as observed in the RP (*Nagy et al., 2002a,b*).

Summarizing, fluctuations of river flow, which are partially ENSO-controlled, is a strong physical control of biogeochemical processes and TSC of SL inducing enviromental shifts within this system and in the adjacent coastal waters of the EF of the RP.

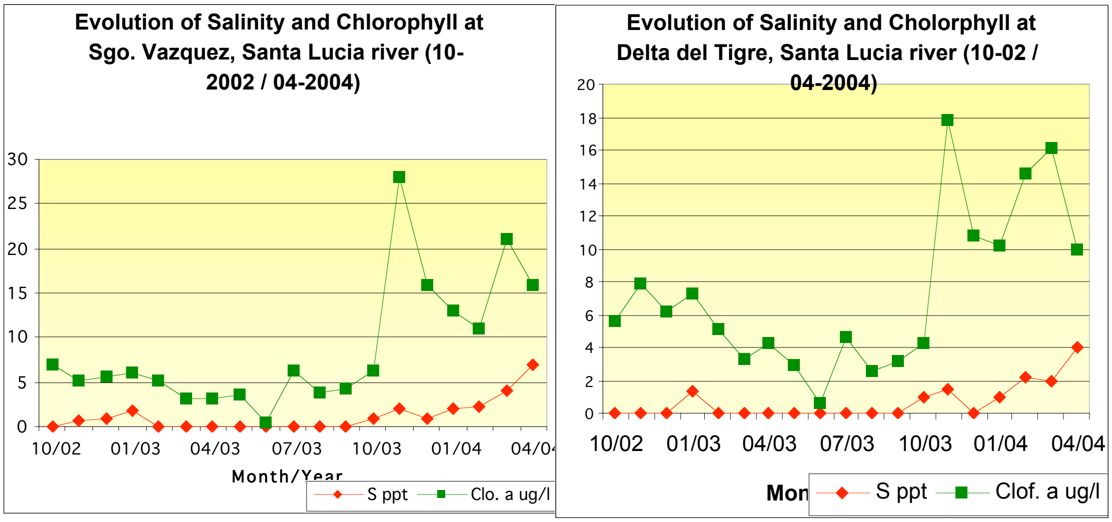


*Fig. 37: Evolution of salinity and chlorophyll-*a *at Santiago Vázquez (estuary, left) and Delta del Tigre (river-estuary boundary, right) from October 2002 to May 2004 (from Caffera et al., 2004).*

3.5.3 An Scenario for 2050

A plausible combined climatic scenario for 2050 could be:

- + 0.20 m SLR,
- increase in SSE wind storm surges and precipitations,
- a strong El Niño year (i.e. October-December), should increase both SLR and DRH, blocking the discharge of Q_{SL}.

This scenario would ravage, erode and impact the coastal ecosystem, infrastructure, tourism, fisheries and agriculture sectors, as well as coastal settlements on both the coast and SL river margins. Thus, the regional vulnerability - coastal zone, water resources, coastal settlements and fisheries livelihood sectors - are related.

4 Adaptation

4.1 Activities Conducted

The aim of this section is to present future adaptation (planned) strategies for the Coastal Fisheries System. Current adaptive capacity and autonomous measures have been explained in the vulnerability section. A deep understanding of the climate, cultural, economic, environmental, legal and social constraints to adaptation would allow to improve the adaptive management and sustainability of fish resources and livelihood of the associated coastal community of fishermen. First of all we define the concept of adaption.

4.2 What is Adaption?

Adaption is the process by which stakeholders involved reduce the adverse effects of climate on their livelihood. This Process involves any passive, reactive or anticipatory adjustment of behavior and economic structure in order to increase sustainability and reduce vulnerability to climate change, variability and weather / climate extremes (modified from *Burton, 1996,1998,2000; Smith et al., 1993; Smit et al., 1999*).

4.3 How Does Adaptation Occur?

Through processes: External forcings (river flow and wind changes) induce displacement of the frontal zone and variations in the location of main resource (Croaker), which ultimatley induced an autonomous adaptation strategy (at the very beginning): seasonal or permanent fishermen migration.

The former option of has being succesful until 2002.

Data used are those analyzed in the vulnerability section (vulnerability indicators and matrix) and economic fishing activity estimation (see Table 5; Figures 26 and 27).

Based on these criteria, we propose an Adaption Control Information System (ACIS).

4.4 Scientific Methods and Data

Our methodological approach was based on: i) framework for vulnerability and adaptation for a second generation assessment (SEI, 2001), ii) multi-level indicator of vulnerability to climate change (Moss, 1999), iii) expert judgement, iv)cost-benefit analysis and regret options, v) Integrated Coastal Zone Management and vi) adaptive management.

Adaptive management leaves scope for decisions to be reviewed, and further decisions implemented at a series of later dates, as improved information becomes available on the nature of the present day and future climate risk (*Hillborn and Sibert, 1988; Hillborn and Peterman, 1996; UKCIP, 2000*).

4.5 Results

4.5.1 Migration adaptation strategy of artisanal fisheries

Spatial changes along the coast reduce the ability of fishermen to catch in other conditions increasing their vulnerability to the vicissitudes of life relocating and finding employment outside of fisheries (i.e. agriculture). However, fishermen don’t notice fluctuations of resources untill they perceive changes of availability as a consecuence of river flow. Thus, extreme events drive adaptive prevention of loss.

This autonomous seasonal migration strategy resulted in a planned definitive adaptation for many fishermen which changed their location of housing and fishing activity (from Western Montevideo and Santa Lucia river mouth to San Luis). These fishermen accepted the permanent loss of benefits in order to avoid uncertainty and risks associated with the displacement of the estuarine front driven by hydroclimatic fluctuations. Thus, accumulated loss over long-periods are minimal regarding to benefits (low regret option).

4.5.2 Industrial Fisheries

The industrial fleet that operates – and compete with – the artisanal fleet is subject to changes in resources and markets (Figure 38). However, because of its capacity to fish in open waters is less dependent on climatic and weather constraints.

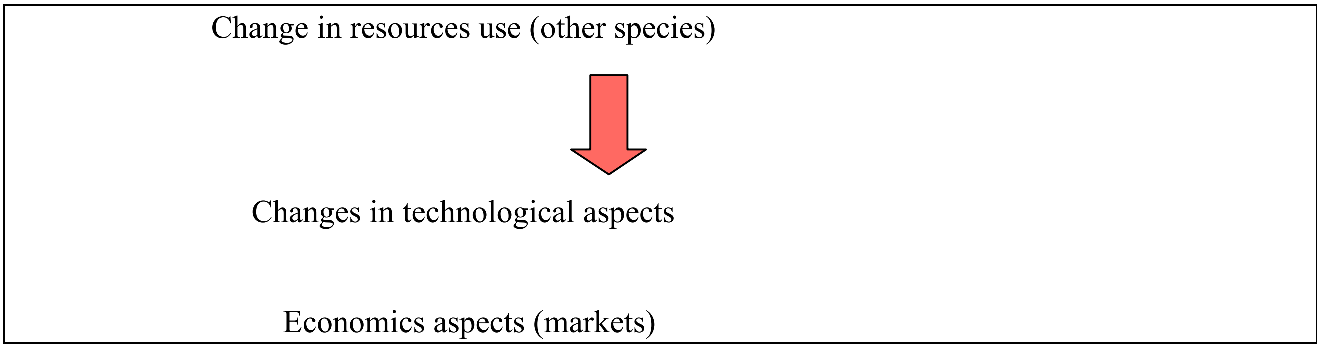


Fig. 38: Environmental, economic and technological adaptive management conditions of industrial fishery (from Norbis, 2003).

4.5.3 Integrated Coastal Zone Management and Adaptation Control Information System

Positive trends (last 30 years) in the Rio de la Plata basin and estuarine system imposes defies and threatens to the CFS. The best options to deal with these trends are the development of an Integrated Coastal Zone Management (ICZM) program which should prioriotize participatory processes, education, weather and climatic forecasting, update of fisheries resources and water quality, real-time information, early warning systems, and adaptive management options. Thus, anticipatory measures are needed, because under strong climatic pressures fishermen are strongly impacted, and reactive measures have poor results or can lead to mis-adaptation (as happened in 2002).

Because of uncertainty, management strategies should be periodically revised and adapted to the dynamic conditions of the stock, environment and resource users, as well as to changes in the intertemporal preferences of the fishing sector (Adaptive management).

Adaption measures will have positive impacts provided communications among stakeholders (fishermen, managers, local authorities and scientists) are improved. Nor the acquired knowledge neither the improve of knowledge, partial relations and communications will be enough until managers and local authorities (i.e., Directorare of Aquatic Resources, Navy Coast Guard, Ministery of Housing, Territorial Planning and Environment) take effective measures, and until fishermen be able of making an effective use of knowledge, information and early warning. An important constraint is the failure of fit between time and space scales between institutions (responsible for management) and Actors (fisheries components). We propose a hierarchical procedure of adaptation control information system (Figure 39) which tales into account most of the above mentioned aspects.

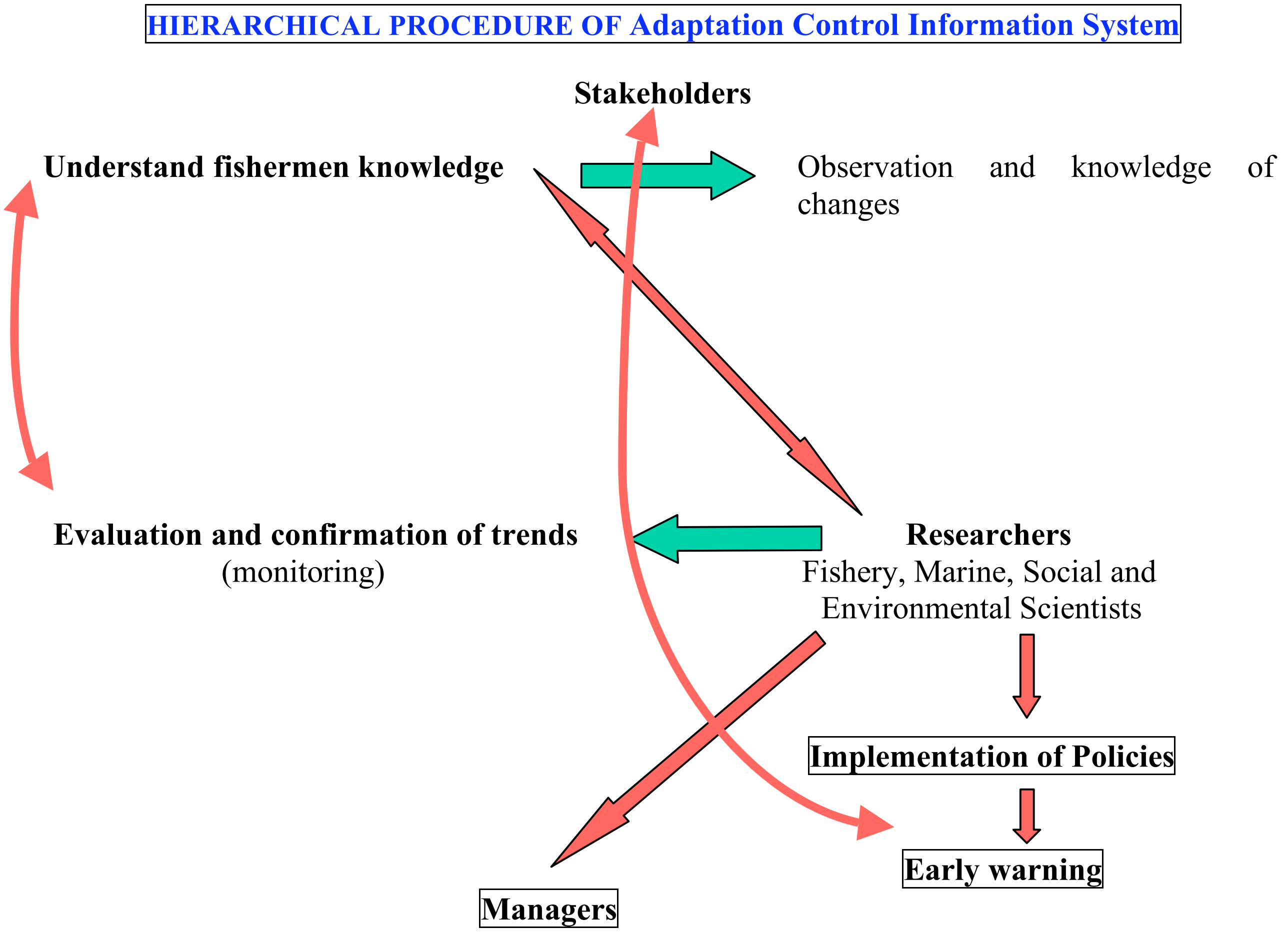
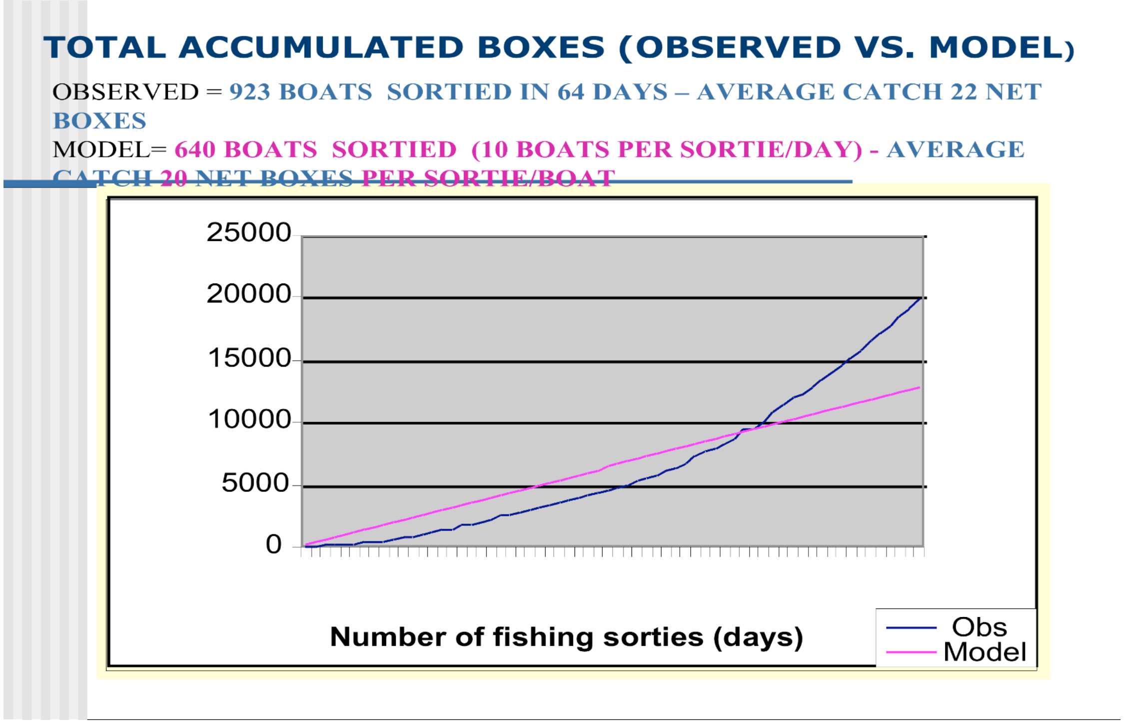


Fig. 39: Hierarchical procedure of the adaption control information system - ACIS (modified from Norbis, 2003).

4.5.4 Scenarios of adaptation and sustainability

We have developed models of fishing activity based on observed data presented in Table 5, and Figures 26 and 27. Observed data are: 923 boats sortied in 64 days with an average catch of 22 boxes. The model consider 640 boats sortied (10 boats per sortie/day) and an average catch of 20 boxes per sortie/day.

Figure 40 shows the comparison between observed Vs modeled total accumulated boxes. Up to ~50 fishing sorties (days), observed capture is greater than modeled capture, whereas for fishing sorties greater than 50 modelled captures are greater. For instance, for 64 sorties, the increase in capture should be about 60%.



TOTAL ACCUMULATED BOXES (OBSERVED VS. MODEL)

OBSERVED = 923 BOATS SORTIED IN 64 DAYS – AVERAGE CATCH 22 NET BOXES

MODEL= 640 BOATS SORTIED (10 BOATS PER SORTIE/DAY) - AVERAGE CATCH 20 NET BOXES PER SORTIE/BOAT

Fig. 40: Figure Comparison between observed Vs modeled total accumulated boxes.

Figure 41 shows three scenarios as a function of sortied days.

- Scenario 1 (blue): 31 average boxes and 15 boats.
- Scenario 2 (pink): Fishing period 1998-199.
- Scenario 3 (yellow): 40 average boxes and 31 boats.

Scenario 3 is the maximum expected capture under ideal – but plausible – conditions. Scenarios 1 and 2 do not give differnet captures for a number of sorties greater than 50.

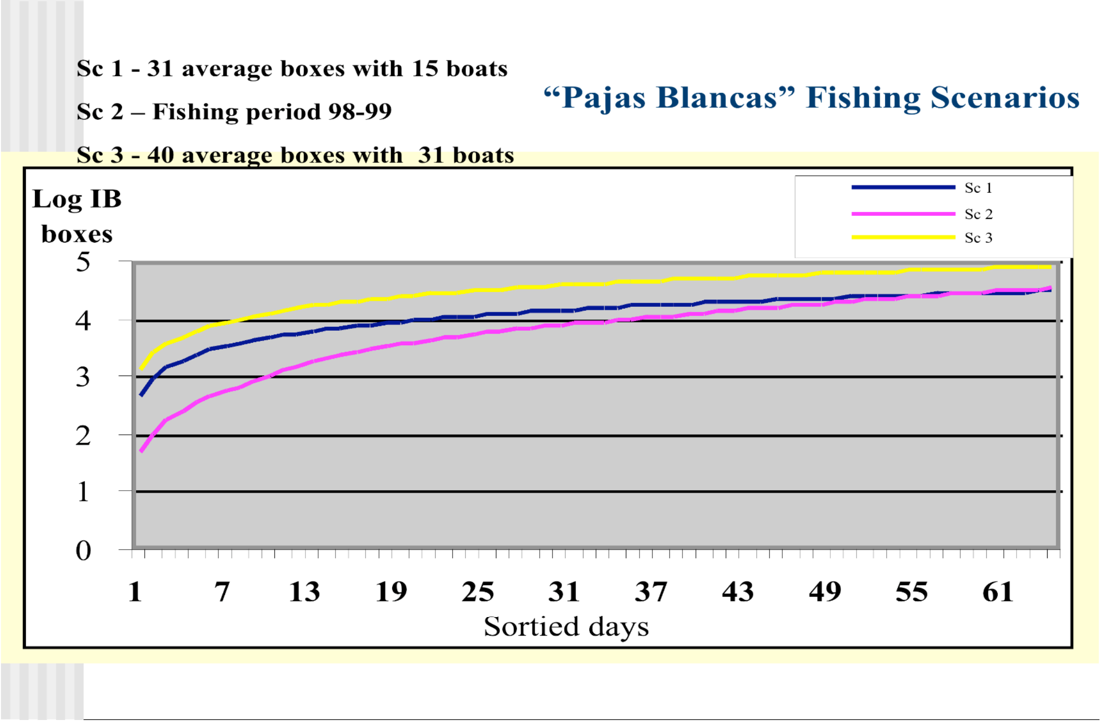


Fig. 41: Fishing scenarios: Capture (log of boxes) as a function of sortied days.

4.6 Conclusions

Modeled scenarios, which take into account cautious numbers of catch per day, suggest that an increase in the number of sorties is the key factor.

Thus, if nor weather neither climate conditions can be managed, real time forecasting and communication with fishermen, which should allow to increase the number of sorties under good fishing conditions, seem to be a good adaptation practice. For this, an increase in security of navigation and relations with the Coast Guard is needed.

Average boxes and sortied days are not independent. Evidence is that when fishing conditions are better, more fishermen decide to fish. Usually a few number of performant fishermen decide to fish, and this number should increase if adaptation measures are taken.

Thus, a plausible combination of an increase in the number of sorites and average box capture should be the most realistic scenario to increase fishermen's net income in order to recover the investment capital.

The hierarchical procedure of Adaption Control Information System is suggested as an example of adaptive management.

Current and future adaptation strategies of coastal fishermen are climate influenced decisions, it is to say that climatic factors prevail over non-climate decisions, taking into acocunt a low regret cost – benefit ratio.

5 Expected future climatic and environmental scenarios, impacts and vulnerability

5.1 Implications for Estuarine Biocomplexity.

The following paragraphs drown from the report: *Summary of Climate Change Assessments: Implications for Estuarine Biocomplexity* (*Boesch, 2002*), seems to be a likely scenario for most temperate estuaries, such as the Rio de la Plata.

"In estuaries and coastal waters experiencing seasonal density stratification, climatic conditions projected for later in the 21st century could bring earlier, longer lasting and stronger stratification affecting nutrient and oxygen dynamics, changes in the dominant phytoplankton competing for available nutrients and subsequent effects on higher trophic levels and microbial remineralization processes"

It stands to reason that a warmer Earth will bring more overall precipitation because rising temperatures will increase evaporation and accelerate the water cycle. However, just as there are deserts and rainforests, this does not mean that precipitation will increase everywhere—if fact, models project that some regions may receive less precipitation. Furthermore, precipitation is more greatly influenced by regional—even local—processes than temperature, reducing the confidence one can assign to projections of changes in precipitation falling on or runoff delivered to a specific estuary.

GCM models often produce widely different projections of changes in precipitation on regional scales and their results should be interpreted with caution. Nonetheless, the models generally agree on two things: changes in precipitation in a specific area are likely (although how much and even the sign of the change may be uncertain) and the frequency of heavy precipitation events is likely to increase.

5.1.1 Temperature

According to the IPCC the following climate changes are very likely over most areas during the 21st century: higher maximum temperatures and more hot days; higher minimum temperatures, fewer cold days and frost days; reduced diurnal temperature range; increase in the heat index (combining temperature and humidity); and more intense recipitation events. Likely changes include: increased summer drying and associated risk of drought. Based on GCM models, the average global temperature is projected to increase by 1.4 to 5.8ºC by the end of the 21st century, with a most probable increase of 2-4ºC. Temperatures are projected to rise more rapidly (IPCC, 2001).

5.1.2 Climate change implications after about 2040.

While a change of a few degrees might not seem like much, it should be remembered that this is an annual and global average. Put in proper context, the projected global mean temperature would greatly exceed the range of variability within the last 1,000 years and the rate of warming is without precedent during the past 10,000 years, based on paleoclimate data.

5.1.3 Climate change implications

The effects of these changes in air temperature on water temperature in estuaries are not straightforward. Water temperatures in east and Gulf coast estuaries that have a small tidal prism (such as the RP) are fairly closely linked with air temperature rather than the temperature of the coastal ocean. Of course, this varies with respect to distance to the mouth of the estuary. In any case, milder winter temperatures and warmer summer temperatures, plus changes in the seasonal timing of temperature would have manifold consequences to estuarine ecosystems, including, but not necessarily limited to (only retained those which could occur in the RP):

- high temperature stress on indigenous biota;
- increased metabolic rates;
- opportunities for invasive species currently limited by minimum temperatures;
- earlier warming and later cooling, with effects on production cycles, seasonal timing;
- lowered summer dissolved oxygen levels because of higher temperatures;
- stronger density stratification, with effects on oxygen, circulation, and biogeochemical processes.

5.2 Future Regional Climate Scenarios and Expected Environmental Impacts and Vulnerability.

5.2.1 Regional climate scenarios for Southeastern South America.

In order to evaluate the differences between the observed climate and the climate simulations with Global Climate Models (GCMs), in the Southeastern South America region, we selected seven available runs from IPCC Distribution Data Center, using socioeconomic SRES-A2 and B2 forcing scenario. The models are: HadCM3, ECHAM4/OPYC3, CGCM2, NCAR-PCM1, GFDL R30, CSIRO Mark 2 and L8-LMD.

We have compared sea level pressure, surface air temperature (Figure 41) and precipitation (Figure 43) from the models, against observed climate fields, trying to estimate regional performance of the control simulations (baseline climate scenarios). We assume that the models that better simulate the current regional climate in their control experiments are likely to be more reliable in their simulations of regional climate under changes of greenhouse gases concentrations.

The comparison between the monthly and annual SLP fields shows that only four models (HADCM3, CSIRO-mk2, ECHAM4, GFDL-R30) have an acceptable agreement with the observed SLP field and are able to represent the position and intensity of the pressure systems and the annual cycle. Comparison for precipitation was performed only for the four models with best agreement in the SLP fields: HADCM3, ECHAM4/OPYC3, CSIRO-mk2 and GFDL-R30. In all cases, precipitation is largely underestimated in the Río de la Plata basin. The comparison between the monthly and annual temperature fields shows that in general all the models have an acceptable agreement with the observed fields.

We used the original spatial resolution of both models: HadCM3 has an horizontal resolution of 2.5° of latitude by 3.75° of longitude. The model ECHAM4 has an horizontal resolution of 2.8° of latitude by 2.8° of longitude. The future climate change scenarios, for precipitation and temperature, over Southern cone of South America were constructed for 2020, 2050 and 2080s. Only as example the figure shows the changes in precipitation for 2050 and 2080 over the south of South America, estimated by HADCM3 model forced by SRES A2 socioeconomic scenario.

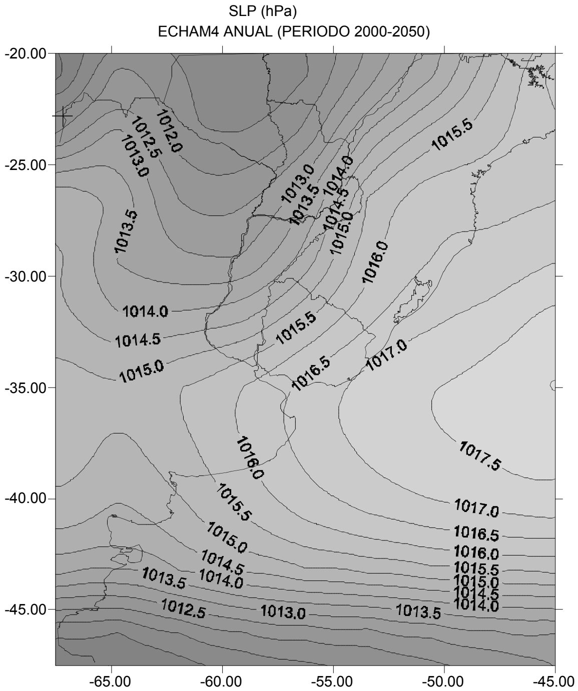
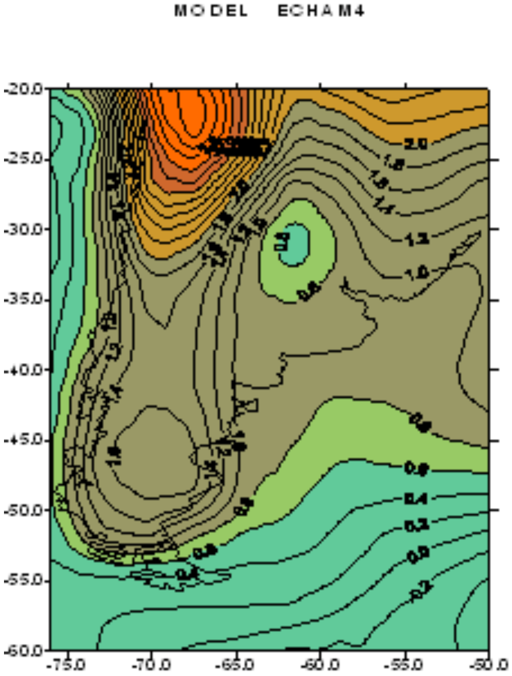
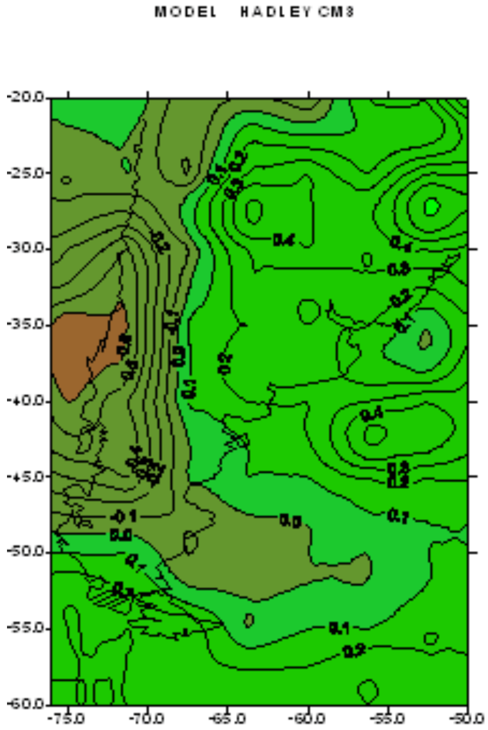


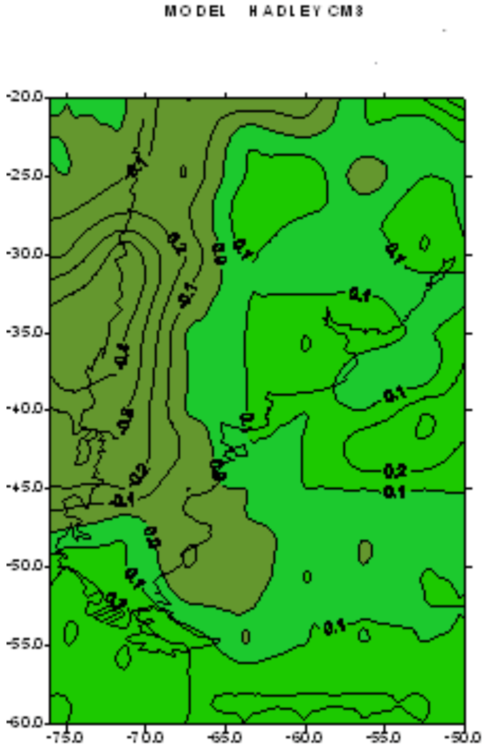
Fig. 42: Future changes (2050) in Sea level pressure (above), and temperature (below) for RPB.





2050 SRES-A2a

Fig. 43: Future scenarios for precipitation (SRES-A2a) for 2050 (above) and 2080 (below).



2080 SRES-A2a

5.2.2 Statistical and dynamical downscaling experiments.

In order to generate precipitation and temperature daily time series based on future climate change scenarios from the Global Climate Models (GCMs) we selected the both statistical and dynamical techniques for downscaling. Because of the coarse resolution of GCMs, downscaling techniques are used to bridge the spatial and temporal resolution gaps between what climate modelers are currently able to provide and what studies impact and vulnerability assessments require. We make use of statistical downscaling technique through the SDSM model (*Wilby et al*, 2001). With the goal of determinate the performance of daily rainfall prediction with SDSM model, we selected predictor variables.

The selected ones for daily precipitation are sea level pressure, zonal and meridian wind components at 850 hPa. This daily variables was selected because their strongly correlation with observed precipitation at surface and are accurately described by the GCMs. The predictor variables came from the reanalysis (*Kalnay, E. et al, 1996*), of National Centers for Environmental Prediction (NCEP. We selected four locations in Southeastern South America during the period 1996 – 2001. The cities are Buenos Aires and Santa Fe in Argentina, and Montevideo and Salto in Uruguay. As final conclusion we have that statistical downscaling SDSM model is a valuable tool and is capable of representing many of the characteristics that existed in the precipitation data of the temperate region of South America.

Another tool used, at the end of AIACC project, to generate future high resolution scenarios over Southeastern South America was PRECIS. This is based on the Hadley Center's regional climate modeling system. It has been ported to run on a PC (under Linux) with a simple user interface, so that experiments can easily be set up over any region. PRECIS was developed in order to help generate high-resolution climate change information for as many regions of the world as possible. The PRECIS was transferred freely to Faculty of Sciences in Uruguay, to help to develop climate-change scenarios at national scale and simultaneously building capacity and drawing on local climatological expertise. These scenarios will be used in impact, vulnerability and adaptation studies, and to aid in the preparation of National Communications behalf Unit of Climate Change (Ministry of Environment).

5.2.3 Some conjectures about future climatic scenarios and associated environmental vulnerability and impacts.

In additon to the scenario developed by *Boesch* (2002) for the Estuaries of the United States, which is generally valid for most temperate estuaries all over the world, we make some assumptions, conjectures, primary conclusions and questions about the RdlP basin, esutary and coast, which as a whole, may be considered as work hypothesis for future research.

Current environmental scenarios (1971-2003) in the Rio de la Plata basin (RPB) and estuary (RP) discussed all along this report are dominated by the following main stresses:

- increases in temperature, precipitation, streamflow and onshore winds.
- increases in population, use of natural resources and export of nutrients.
- increases in economic activities, land use changes, soil erosion and runoff / infiltration ratio, damming.

Current climate and future scenarios (time horizon 2020 - 2050) for the RPB and RP suggest a change in precipitation, temeperature and sea-level rise within the ranges 5% - 10%, +1 to +2°C and + 10-20 cm respectively. During the last few decades these changes have being + 20 - 25% for precipitation, +0.6 - +0.9°C for temperature and 5 cm for sea-level rise, as well as + 25 - 40% for river flows (AIACC LA-32, 2005).

Trends for Q_{Vs} are very difficult to be estimated because of both the uncertainty of regional human drivers (i.e., land-use change and runoff / infiltration ratio) and because of the varied regional scenarios from different GCMs. For precipitation, all of them have systematically underestimated the precipitation over the region, but not necessarily the increase of it. Indeed, during the past few decades the observed increase in precipitation (*Liebmann, 2004*) was associated with the observed increase in riverflow. Moreover, small changes in precipitation are doubled in the streamflow signal (*Berbery and Barros, 2002*). *Tucci and Clarke* (1998) suggested that 1/3 of observed increases in streamflows were attributable to land use changes.

From an environmental point of view, under a future scenario (2020-2050) in which streamflow remains similar or slightly lower (i.e. 0% to -10%) with regard to present values, we do not expect a significative increase in current environmental stresses on the estuarine system (which are already moderately high) <u>with the expection of N inputs and further TSC</u>.

Our concern is about a future scenario where Q_V increases within the range ~ 10-25%, together with projected temperature increases, economic and population growth, for which significative impacts are expected in the estuarine and coastal systems (i.e., increase in the vulnerability to TSC, and air-water and sediment-water gases, and nutrient exchanges) besides changes in the shelf and contour current circulation (i.e., water temperature changes; ocean-driven HABs; see Figure 14).

Thus, the following key question arises:

- Is the increase in both temperature and Q_V plausible under projected changes in temperature (i.e.+ 1-2° C) and precipitation (~5-10%), taking into account the consequent increase in evapotranspiration?

Some assumptions are:

- about 1/3 of Q_V changes may be due to land use changes (*Tucci and Clarke, 1998*).
- observed vs. projected changes are of the same sign in all variables,
- the expected value for temperature change is 2 to 4 times greater than the formerly observed.

SLR rate will accelerate (with regard to the rate prior to 1990).

Main uncertainty is related to the relative amounts of potential and actual evapotranspiration rates in the future, which makes very difficult to establish any coherent scenario about future streamflow, especially if current land-use changes continue increasing the runoff / infiltration ratio (which could reduce the impact of temperature rise on evapotranspiration).

Considering the fact that seasonal temperature, precipitation and streamflow cycles are not superposed, any changes should modify seasonal circulation and mixing *status*, inducing further environmental shifts (i.e. □ gas and nutrient exchanges, Δ P-R, increase in HABs occurrence, with a probable increase in both the degree and occurrence of hypoxic events (estimated to be about - 20%) in deep bottom waters and denitrification (emission of N_2 / N_20 to the atmosphere; *Nagy et al., 2002a,b; 2003*), as well as an increase in the vulnerability of fishermen communities and low-lying areas.

The long-term evolution of salinity (*Nagy et al., 2002a; Bidegain et al., 2004*) and its monthly evolution during the period 1998-2002 (*Nagy et al., 2003; Severov et al, 2004*), as well as the fluctuations of the estuarine fronts location within the RP and adjacent shelf since 1998 (*Severov et al., 2003. 2004; Nagy et al, submitted*) allows to develop a conceptual model - not detailed here - on both yearly and monthly basis (see Figure 12):

- when Q_U was/is 4,000 m^3/s, typical yearly salinities were/are >10-12,
- when Q_U was/is >5,500 m^3/s they are ~7-9 (present average: ~8),
- when Q_U was/is >7,000 m^3/s salinity is <5 on timescales greater than weather development,
- when Q_U is> 10,000 m^3/s freshwater prevail in most of the Uruguayan coast and the EF is displaced tens of miles to the mouth.

Under a hypothetical environmental scenario for 2020 - 2050, based upon climate models outputs, past trends, reference projections and expert judgment, some speculations can be made.

Both long-term and monthly analysis of recent years allow to suggest that a hypothetical increase in Q_U of ~ 20% should reduce average salinity at Montevideo by 2-3 (reaching 5-6) and displace riverward the EF. If these changes are coupled with a plausible increase in onshore winds, especially during spring and early summer months - when ENSO is active and biological processes and goods are in their activity peak period - significant changes in both the structure and location of the several fronts of the RP - as well as of the biological and biogeochemical functions associated, including fish reproduction, fishing activity and gas dynamics, are expected to shift (*Severov et al., 2004; Nagy 2004; Lappo et al., 2005; López and Nagy, 2005; Nagy et al, submitted*).

The export scenario (delivery to the coastal ocean) of N for South America for the year 2050 would increase nearly three times. Generically, the temperate regions export less than half N from total anthropogenic sources than tropical regions do, which is partially explained by lower precipitation (*Seitzinger et al., 2002*). Thus, ENSO variability plays a major role as a control factor of drivers, control and state variables of TSC in the RdlP (*Nagy et al., 2003, 2004*).

Under conditions of a moderate and combined increase in temperature, Q_V, Q_N and p in this period, the occurrence of extreme climatic events (e.g. El Niño 1997-1998; *Nagy et al., 2003a*), could increase the frequency of hypoxia and so affect eggs and larvae, thus increasing the vulnerability of adults to other stress factors and even causing them to move away from the present area of capture, reducing the income of coastal fishing communities.

Some expected impacts and responses under current (1980-1990) and future scenarios (2025-2050) should be an increase in algal biomass, HABs events, changes in nutrient ratios (i.e. > N/P and N/Si) – the three of which have been already observed in the last decade -, hypoxia, a decrease in P-R balance and changes in biodiversity.

Projected or estimated scenarios of human drivers (i.e., + 70-100% population, > ~150-200% N input; *Nagy et al., 2003*) - as well as some further land-use changes - for the URB are to be accounted. Then, significant changes in symptoms of eutrophication and coastal fisheries livelihood are expected. The former should be noxious for both the environmental and human health, as well as for fisheries. The latter should modify the timing and quantities of ecological processes and services and could make unsustainable coastal fisheries by reducing the number of days *per* month and the months favorable for fishing activity.

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Summarizing, eutrophication in the Rio de la Plata system can be thought of as a syndrome (a suite of symptoms) that change with the seasons, years and decades, showing an increasing trend of pressure and state indicators since the mid 1940s, and a shift during the 1970s and 1980s. Natural processes must have been accelerated due to the increase in hydroclimatic means and extremes that led to an increase in soil erosion and diffuse sources of nutrients. These processes, combined with human activities such as damming, which have indirectly altered the trophic *status* by modifying the physical environment (e.g., residence time, local warming), determine that the increase in nutrient load over the last five decades, even if it was well below the figures for developed countries, has altered the natural trophic *status* background and/or stimulated the development of new symptoms, whose drivers are expected to increase (since 1990) in the next few decades (modified from *López and Nagy 2005*).

It must be emphasized that because of the particular dependence of SLR in the RP on non-eustatic factors (sea level pressure, river flow and winds), further changes in the three of them under the minimum SLR projections (i.e. only 0.20-0.30 m), are a potential threat to the coastal system provided past synoptic and climatic extreme events occur simultaneously, which has already happen.

Taking into account the evolution, variability and extremes of temperature, precipitations, sea level rise, winds, river flow and trophic state variables change during the last 30 years over the Rio de la Plata basin and estuary and the acceleration rates of change of most of them during the last 10 years, we are in need to assume a pessimist point of view.

Human drivers (increase in population density, damming and agricultural intensification), and climatic change and variability (CCV) within the lower basin of the Rio de la Plata (shown for Rivers Uruguay, Negro and tidal freshwater of the RdlP) are schamatized in in Tables 16 and 17. Projecting these recent changes through the next 10-30 years, together with a plausible extreme future scenarios for temperature and streamflow, significant environmental changes, shifts and impacts are to be expected (i.e., increase in all symtoms of eutrophication, loss of area and / or function of coastal wetlands, and decrease in coastal fisheries income and sustainability).

Accumulative Changes	Systemic Changes	El Niño / La Niña
? Land Use ⇓ **Soil Erosion and Runoff**	> 0.8° C	➢Frequency ➢Intensity ➢Duration
Damming ⇓	> Onshore winds	➢200-300 mm Precipitations ➢20-35 % m^3 s^{-1} Streamflow
➢N fixation ➢Fertilizer application ➢Point-sources (untreated sewage) ➢Non-Point sources ⇓ **Eutrophication**	⟺	**Increase in:** **Nutrients** **Cyano-Harmful Algal Blooms** **Algal Biomass (Chlorophyll-a)** **Hypoxia**

Table 16: Global accumulative, systemic and ENSO-related climatic and environmental changes in the Rio de la Plata basin and Estuary.

Site/ Period	1- 1925-33	2- 1934-45	3- 1946-1980	4- 1981-2000	5- 2000-2004	6- 2020-2050
Drivers and Trophic status and change	Pristine baseline (low PD, absence of dams and fertilizer application). Oligomesotrophic	Developmentof HDof TSC (Damming) Mesotrophic	Increase in HD (damming, agricultural intensificationand PD) and symptoms of TSC. Mesotrophic	Acce leration of CCV (precipitation, temperature) and of HD of TSC Mesoeutrophic	Consolidation of HD and CCV drivers of TSC and symptoms. C-HABs. Mesoeutrophic to Eutrophic	Moderate increases in PD and temperature, and high increase in N export. Eutrophic
Lower Basin of the RdlP (in River Uruguay)	First records of cyanobacteriae in Uruguay	No data Construction of Rincón del Bonete Dam (1945)	Construction of Baygorria Dam (1962). Strong increase in population and beginning of the use of fertilizers	Construction of Salto Grande-SG R. Uruguay, 1979) and Palmar (R. Negro, 1982) dams. Increase in agricultural intensification .C-HABs in SG Dam	C-HABs in Dam reservoirs of Rivers Negro and Uruguay (M. aeruginosa)	Expected increase in nutrients, chl-a, and C-HABs,
Tidal river and estuarine front of the Rio de la Plata	Absence of C-HABs blooms (Microcystis, Anabaena, Aphanizomenon)	Booms of Microcystisin summer.	Blooms of eutrophic environment diatoms in R.Uruguay and other streams (in the 70s).	Blooms of M.aeruginosa in the tidal river of the RdlP all along the year, and C-HABs during summer and fall	Recurrent yearly Cyano-HABs, especially during summer and fall. Increases in nutrient and algal biomass concentrations	Increaae in all variables of pressures and state, and symptoms of TSC up to eutrophic levels.

Table 17: Past, current and future scenarios of trophic state expressed by Cyanobacterial Harmful Algal Blooms (C-HABs). Six periods are defined, from baseline (1) to a plausible future scenario for 2020-50 (6) (modified from López and Nagy, 2005).

6 Overall Concluding Remarks

The overall vulnerability and associated impacts on estuarine waters, goods, processes and services, and coastal zone of the Uruguayan coast of the Rio de la Plata is primarily associated with ENSO-related climate variability.

In addition, human and climatic changes are drivers of environmental pressure and state variables within the RP basin and sub-basins at different spatial- and time-scales, which produce, stimulate or triggers impacts, ecosystem responses and shifts within the estuarine waters of the RP and its coastal zone.

Increase in precipitation plays a major role in controlling buoyancy and stability, nutrient export, eutrophication and P-R processes, since sensitivity to trophic state changes depends on the balance between river flow and winds.

Streamflow variability of the Santa Lucía River is ENSO-related from August/October to December/February. Therefore, an increase of this variability under a SLR scenario > 0.30 m should seriously impact the system by flooding the lower basin plain, estuary and coastal zone in the short- and mid-term (2020 - 2050). This woul also affect the contiguous estuarine front.

Projected estimated scenarios for 2050: [+ 1-2° C, + 5 - +20% precipitations,+ ~70% inhabitants, + ~200% Nitrogen, + 0.3-0.5 m SLR, + ~15-25% river flow; -2 in surface salinity, + ~100% nutrients, ~-20 % oxygen saturation in bottom waters, - ~25% net income of coastal fisheries], will increase vulnerabilities of the exposed sectors and some of them will be heavily impacted, threatened and/or will be unsustainable (coastal fisheries, low-lying wetlands and beaches, tourism, supply of drinking water).

Further increase in the Santa Lucia river flow could change the river morphology as well as the capacity of its wetlands to retain floodings. This could impact the built infrastructure (i.e. bridges and roads) designed under past hydrological statistics, as well as affect the trophic *status*.

Climatic changes (Q_V and W) should modify the circulation, stratification and mixing *status* inducing further environmental impacts (i.e., Δ P-R, oxygen *status*, HABs, increase in the vulnerability of fishermen and low-lying areas).

Hopefully, recent public initiatives on prospective analysis of coastal systems, including the biophysical and human dimensions of climate change and variability, as well as the 3rd National Communication to the UNFCC could take into account some of these conclusions.

7 Capacity Building Outcomes and Remaining Needs

Capacity building was second to none among AIACC LA-32 priorities. In most cases capacities were applied in specific activities. However, we put the emphasis on long-term development and science-policy linkages.

7.1 Capacity Building

Several junior and senior researchers involved in AIACC LA-32 got acquainted with new knowledge, skills and techniques by attending to workshops and courses, as well as in-hand activities.

For instance:

Mario Bidegain attended to the AIACC workshop on Climate Scenarios in Norwich, UK, 2002.

GJ Nagy, A Ponce and G Seneión attended to the AIACC Workshop on Vulnerability and Adaptation in Trieste, Italy (2002).

Alvaro Ponce and Juan Lagomarsino attended to a GIS and Environmental Analysis course at the University of Buenos Aires, Argentina (2003).

Roberto Silva and Alvaro Ponce attended to courses on Participatory Processes organized by Project Eco-Plata (2004).

Karina Sans and Juan Lagomarsino attended to a Graduate course on Estuarine Systems (2004).

César López attended to a course on Coastal Wetlands Management (2004).

César López attended to a graduate course on Remote Sensing of Oceans at the University of Concepción, Chile (2004).

Mario Bidegain and Juan Lagomarsino attended to the “Precis Training Workshop” in Sao Paulo, Brazil, November, 2004.

Several senior researchers involved in AIACC LA-32 developed lectures, modules and courses for undergraduate and graduate students, as well as for High School teachers.

C Martínez, M Bidegain, GJ Nagy and RM Caffera developed lectures on Global Change for a course on Earth System Science devoted to High School teachers of Earth and Space Sciences.

GJ Nagy and M Bidegain developed lectures on Global Change for a Graduate International course on Ocean Color for Latin American students.

GJ Nagy, M Bidegain, RM Caffera and A Ponce updated the course on Earth System Science and Global Change for the Master of Science in Env. Sciences, Facultad de Ciencias, UdelaR.

RM Caffera, M Bidegain and GJ Nagy presented project’s results in several outreach-type meetings organized by the Ministry of the Environment (2005).

Advice and financial support was given to *Alvaro Ponce* to perform his research on Global Environmental Change of the Santa Catalina coastal site (IIASA-START Grant).

7.2 Remaining Needs

In spite of the above mentioned activities and the continuous learning process associated with research we detect a partial lack of capacitites in some fields such as:

- Vulnerability mapping.

- Integrated climatic, environmental and socioeconomic analysis.
- Quantitative multicriteria assessments of stakeholders perception
- Particpatory processes and stakeholders engagement.

We assume that Integrated climatic, environmental and socioeconomic analysis will be performed by the economist who will participate in the 3rd National Communication in collaboration with our AIACC-team.

8 National Communications, Science-Policy Linkages and Stakeholder Engagement

Capacity Building, Science-Policy Linkages and Stakeholder engagement were mainly directed to strengthen relations with government agencies. AIACC LA-32 was invited by the Unit of Climate Change and GEF-related projects (FREPLATA), to participate in their activities. Outputs of these activities were part of / or complemented the initial goals of AIACC by 2001.

Relevant examples are:

- Researchers from LA 32 AIACC LA 32 participated in the revision of the 2nd National Communication (SNC) Draft under the UNFCC.
- Researchers from LA 32 AIACC LA 32 participated in several workshops (2003-2005) organized by the Ministry of the Environment (i.e,. Synergies of the three international conventions: Biodiversity, Climate Change and Desertification.
- G J Nagy was nomitated by the IPCC to act as a Lead Author of Chapter 13 (Working Group II, Latin America – coasts). He was supported by the Directorate of the Environment of the Uruguayan Ministry of Foreign Affairs, the Unit of Climate Change of the Uruguayan Ministry of the Environment and AIACC.
- Researchers from LA 32 LA 32 participated in a series of 4 Prospective workshops organized by the Minisitry of the Environment: "Reflections on Uruguay 2025" (Coastal Zone + River Uruguay margin Working Group).
- Researchers from LA 32 were engaged by the Ministry of the Environment to update climatic, hydrologic and oceanographic trends in order to prepare the 3rd National Communication (TNC) under the UNFCC.
- GJ Nagy and R. M. Caffera attended to a LA-26 stakeholders meeting in Buenos Aires (July, 2004).
- GJ Nagy was invited to present a draft on coastal systems and to explain to the GEF consultant the capacity to undertake vulnerability and adaptation assessments for the coastal systems, fresh and estuarine waters during the TNC.

9 Policy Implications and Future Directions

AIACC LA-32 was succesful in some subjects that have policy implications: Interaction with government agencies and international projects, outreach and public awareness, supported scientific activities of a memorandum of understanding with the Russian Academy of Sciences. We must emphasize the fact that our team is consulted by some government agencies and journalists on climate variability, change and extremes. Future direction of our team seems to be related to environmental and climatic emergencies, development of early warning systems and adaptation policies.

Some examples are:

- AIACC LA-32 developed cooperation with the Directorates for Water Resources (Min. of Public Works) and Hydrography and Oceanography (Min.of Defence), the Public system of education (elementary, high and technical schools) and the Russian Academy of Sciences (Institute of Oceanology).
- LA 32 team members were invited by CONAMA (Perú) to act as consultatants of the Peruvian Report on Vulnerability to Climate Change (2005).
- LA 32 team members presented – together with other regional AIACC teams - a pre- and full proposal on *Global Change and Sustainable Livelihood in the Rio de la Plata Basin* (IAI CRN-II call).
- LA 32 team members were invited by the Bi-National (Argentina – Uruguay) Uruguay river Management Committee to present regional current and future climate and environmntal scenarios. Agreements and specific activities -some of them associated with adaptation policies- are expected.
- LA 32 team members presented their results to NGOs, journalists and congressmen (Environment Committee) in the Congress Building. We expect this should increase global change awareness among some journalists and elected officials.

10 Published and Submitted Papers

Published

Lappo SS, E Morozov, DN Severov, AV Sokov, AA Kluivitkin, G Nagy (2005). *In Russian*. Frontal Mixing of Fresh and Marine Waters in the Rio de la Plata. *Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Section*, 401 (2): 226-228.

Doklady of RAS, Earth Science Section, 2005, V 401, N2.

http://library.iem.ac.ru/dan/d-es/2-40105.html.

Submitted

Nagy GJ, DN Severov, V Pshennikov, M De los Santos, JJ Lagomarsino, K Sans, EG Morozov (submitted to JASR). Rio de la Plata Estuarine System I: Relationship between River Flow and Frontal Variability, *Journal of Advance in Space Research*, Elsevier.

Submissions Being Processed for Author Gustavo Juan Nagy, PhD

Action	**Manuscript Number**	**Title**	**Initial Date Submitted**	**Status Date**	**Current Status**
View Submission	JASR-D-04-01223	Rio de la Plata System: 1. Relationship between River Flow and Frontal Variability. A2.1-0074-04	04.01.2005	19.07.2005	Under Review

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