Monitoring in Nuevo Gulf (Argentina): analysis of oceanographic data by geographic information systems (GIS)

Solis, Miriam Edith

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Monitoring in Nuevo Gulf (Argentina): Analysis of oceanographic data by geographic information systems (GIS)

Miriam Solis

Examination comittee:
Prof. Dr. P. Denny
Dr. E.D. de Ruyter van Steveninck
Dr. A.G. Dekker

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ABSTRACT

As a consequence of the human activities in coastal areas, the demand for goods and services from renewable and non-renewable marine resources is enlarged. However, generally, the production of these goods and services may affect and also be affected by the deterioration of the quality of marine waters.

The Nuevo Gulf is a semi-enclosed basin located on the Patagonian coast of Argentina. This area is not heavily populated (about 50,000 inhabitants) but suffers from the common problems of coastal areas under the increasing pressure of human activities. A water quality assessment programme has become relevant to maintain the natural value of the place and to ensure the sustainability of growing economic activities, such as for example, tourism. Therefore, it is necessary to know the characteristics of the waterbody and its seasonal and spatial variability, in order to set up future monitoring programmes for assessment.

In this work, a seasonal and spatial analysis of an oceanographic data set (dissolved oxygen, nitrate, nitrite and phosphate, chlorophyll "a", temperature and salinity) collected in the Gulf during 1982-1983, has been carried out. The aim was to characterize the waterbody and to define spatial and seasonal patterns to be applied to the selection of sites and frequencies of samplings, respectively. The analysis was mainly carried out by using a geographic information system (GIS).

From the analysis, the system was characterized as temperate. Different vertical and horizontal patterns were observed in each season. In the vertical dimension, winter is represented by homogeneous distribution of the variables, summer by stratified conditions and autumn and spring, by transitional stages towards vertical homogenization and build up of a thermocline, respectively. From the horizontal distributions, it was observed that in the western and northwestern coast, lower nutrient levels are observed in most seasons.

Sites and frequencies of samplings, are suggested for the design of a network for background monitoring or evaluation of present and future eutrophication. It is recommended to set water quality standards for the Gulf, to use GIS and remote sensing images to learn more about the system and to improve the monitoring efforts. Finally, the monitoring should not be seen as an end in itself but as a dynamic and practical means to test and adjust management decisions.

Key words: enclosed seas - nutrients - monitoring - GIS - seasonal - Nuevo gulf - Patagonia.

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to Lidia and Santo,

my parents

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CHAPTER 1

INTRODUCTION

1.1 - Background

The oceans and the seas, but in particular coastal zones are under the increasing pressure of population growth and economic development. At the Rio Earth Summit, in 1992, it was predicted that, by the year 2000, 60 per cent of the human race would be living at no more than 60 km from a coast, a figure that is expected to climb to 75 per cent by 2025 [Hanneberg, 1997].

The coastal plains and the coastal oceans occupy only 3% and 5% respectively of the earth's surface but account perhaps for 25% of the global biological production and include the most productive ecosystems on earth. These ecosystems are threatened by the combined effects of variation in the climate, the rise in sea level, and human disturbance [Bernal et al., 1992]. Human activities increase the land and sea-based activities and as a consequence enlarge the demand for goods and services from renewable and non-renewable marine resources, resulting in competition between conflicting activities for limited space, conservation, pollution and over exploitation of resources. The geomorphological, hydrological, ecological and social phenomena derived from coastal problems [Viles et al, 1995], are issues related to marine resources management.

The objective of marine resources management is to produce an optimal mix of goods and services from a specific marine resource region [Koudstaal, 1987]. This production depends, among other factors, on the quality of the waterbody. As a consequence, marine resources management is related to the process of water quality assessment[1].

Meybeck et al. (b)[1996] give strategies for water quality assessment and list basic rules for the successful of assessment programmes. In one of this rules, they state that:

"the type and nature of the water body must be fully understood, particularly the spatial and temporal variability within the whole waterbody".

When the time and space variability of the quality of the aquatic environment has to be determined, sampling stations and frequencies, have to be selected, thus this statement is in connection with the monitoring design, and an assessment programme is achieved principally through the monitoring activities [Meybeck et al.(b), 1996].

Due to the large list of variables to describe the status of waterbodies in quantitative terms [Meybeck et al.(a), 1996], it is complex to choose the variables to determine the spatial and temporal

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1- Water quality assessment: the overall process of evaluation of the physical, chemical and biological nature of water, in relation to natural quality, humnan effects, intended uses, particularly uses which may affect human health and the health of aquatic system itself [Meybeck et al. (a), 1996] variability. One criterion may be, to select them based on the perceived importance of problems for the aquatic environment, for example, eutrophication problems are considered through variables like dissolved oxygen, nitrogen, phosphorous, and chlorophyll "a".

1.2 - The case of Nuevo Gulf in the Argentinean coast

The Nuevo Gulf is a semi-enclosed basin located on the Patagonian coast of Argentina. This area is not heavily populated (about 50,000 inhabitants) but suffers from the common problems of coastal areas under the increasing pressure of human activities (tourism, maritime transport, eutrophication, conflicts of interest, lack of planning, of policies, etc.). At present, is likely that the problems are relatively localized; however, this does not exclude them from having trigger effects on larger areas, in the future. Therefore, a water quality assessment programme has become relevant for the area, to maintain the natural value of the place and to ensure the sustainability of growing economic activities, such as, for example, tourism.

1.3 - Objective of this study

There are chemical (dissolved oxygen, nitrate, nitrite and phosphate), biological (chlorophyll "a") and physical (temperature and salinity) data collected during oceanographic campaigns carried out during 1982-1983, in Nuevo Gulf, covering a seasonal cycle. Since those years, there has been no other complete seasonal research campaign, and it is doubtful whether any was carried out before that date either. Because in the dynamic of marine ecosystems, physical process create conditions for many biological process [Mann et al., 1996], the whole set of data is suitable to perform an analysis of spatial and temporal variability of the Nuevo Gulf, in order to get preliminary information on natural processes, which may be applied to a future water quality assessment programme of the area.

The main objective of this study is to carried out a spatial and temporal analysis of a set of oceanographic data of Nuevo Gulf, collected during 1982-1983, in order to:
- characterize the system;
- define spatial patterns that can be applied to the selection of sampling sites; and
- define seasonal patterns that can be applied to set the frequency of sampling.

Because natural compounds like nitrate, phosphate, chlorophyll "a" and dissolved oxygen, are included in the set of data, the selection of the sampling sites and the frequency of sampling will give information for the design of a network for background monitoring[2] or evaluation of present and future problems of eutrophication, etc.

2- Background monitoring: monitoring performed, principally in unpolluted areas, for studying natural process used as reference point for pollution and impact assessment [Meybeck et al.,(b),1996].

In addition, due to the data were collected at the time that human influence was supposed, in most of the places, still null or lower than at present, the spatial and seasonal patterns may be also applied to the identification of sensitive areas to present or future pollution problems and of background concentration of natural compounds[3] that can be taken as points of reference to set water quality guidelines for the area.

The spatial and temporal analysis of the data, is mainly carried out by a geographic information system (GIS). Since the data available is seasonal, the temporal variation is analysed at the seasonal time scale. Additional information was obtained from a TM Landsat remote sensing image and remote sensing images downloaded via Internet.

1.4 - Structure of this report

In the next chapter, concepts about primary production in the marine ecosystems, the seasonal variability of the seas and basic topics and applications of GIS are presented. In chapter three, the study area is described, as well as some information got from collected reports referring to that ecosystem. Chapter four deals with the materials and methodology applied. The results and discussion are presented in chapter five. In chapter six, the conclusions emerging from the work are presented. Recommendations are listed in chapter seven and additional information is presented in the references and annexes.

3- The background concentration of natural compounds is defined as the concentration that could be found in the environment in absence of any human activity [Laane,1992].

CHAPTER 2

LITERATURE REVIEW

2.1- Primary production in marine ecosystems

Marine primary production is mainly based on the contribution of phytoplankton species but attached single-celled algae, larger multicellular algae, and vascular plants also make considerable contribution in shallow coastal waters. The factors affecting the primary production depend on a complex combination of physical, chemical and biological conditions in the marine environment. Light and nutrients can be identified as two of the major factors that control the process, but temperature, grazing, the sinking of dead organisms, the motions of the water masses and meteorological conditions are also variables that interact and exert influence [Valiela, 1995].

In the sea, light fluctuates in quantity and quality depending on the daily, seasonally or annual changes, latitude, depth, weather conditions and its angular distribution. These changes may originate not only at the surface, but also results from factors within the waters, like the presence of suspended particles [Parsons, 1988].

Nitrogen and phosphorous are the most important nutrients, but some organisms like diatoms, also require silica. Fe, Mn, Cu, Zn, Co, Mo and vitamins are also essential, but it is believed that, with exception of Fe and Mn, they do not limit phytoplankton growth [Millero et al., 1992]. Nutrients are more abundant in coastal waters and estuaries than in the open ocean. They are linked to ecological processes, mainly because of the role of limiting factor for producers, consumers and decomposers and of electron donors for microbial decomposers. Although concentration of nutrients varies in the different parts of the oceans, the vertical profiles of oceanic waters, generally have a marked decrease of nutrients near the surface, due to the uptake by phytoplankton, in the photic zone[1] [Valiela, 1995].

In the marine phytoplankton, the N:P ratio is about 10 or 20:1 and comparable to the known Redfield value of 16:1, used by algae and plants during growth. In the oceanic waters, this relationship is in general constant but it is lower in coastal areas [Millero et al., 1992]. Field observations and experiments show that in most coastal marine environments, nitrogen is the principal limiting element, probably due to remineralization of organic matter in the sediments and subsequent loss of regenerated nitrogen by denitrification [Valiela, 1995].

In seawater, nitrate is the primary form of inorganic nitrogen. Concentrations, in general, do not exceed 1.0 µg-at NO_3^--N.l^{-1} and are rarely higher than 25 µg-at NO_3^--N.l^{-1} [Valiela, 1995]. Nitrogen also exists as other inorganic salts, such as nitrite and ammonium, as molecular nitrogen and as dissolved organic nitrogen. The organic form, resistant to decomposers, is usually present

1- Photic zone: layer where daily rates of photosynthesis are sufficient to compensate the daily rates of respiration. The lower limit of the photic zone is called compensation depth and is located where approximately 1 % of surface light is found [Steeman Nielsen, 1975].

in larger quantities than the inorganic form. Nitrite concentration is low and varies between 0.01 and 5.0 μg-at NO_2^--N.l^{-1}. Ammonium concentrations are between 0.1 and 5 μg-at NH_4^+N.l^{-1} [Parsons, 1988]. In the interstitial water of sediments, the concentration of nitrogen compounds is much higher than in water due to degradation of the large concentration of organic matter, low rates of percolation and the presence of active exchange surfaces [Valiela, 1995].

Nitrate is taken up by algae, bacteria and plants, in aerobic environments. Under anaerobic conditions, this anion is reduced to NO_2^-, then to NO and N_2O, and to N_2 gas, in the dissimilatory process of denitrification. On the other hand, nitrate also may be reduced by denitrifiers organisms to ammonium, but this is probably not such an important source of ammonium as the degradation of organic matter is. Ammonium is also taken up by plants, algae and bacteria. In general, it is more abundant in productive shallow areas and peaks when microbial degradation of organic matter is favoured by temperature increase. By nitrification process, ammonium may be oxidized to nitrite by nitrosomona bacteria and by further oxidation to nitrate, by nitrobacters. The rate of this process is often limited by the oxygen supply but some nitrate is produced even at low oxygen levels, in sediments and water [Valiela, 1995]. Certain bacteria, including blue-greens are able to fix gaseous nitrogen. It is an anaerobic process and not a significant source of nitrogen in marine environments [Millero et al., 1991].

Ammonium and nitrate uptake is highly dependant on light and it is restricted to the photic zone [Dugdale, 1976]. Ammonium is usually preferred [Millero et al., 1992]. Nitrate uptake is suppressed by ammonium and the degree of suppression depends on the concentration of ammonium present [Dugdale, 1976].

Dugdale et al, [1967] states that in marine environments production is driven by two sorts of nitrogen inputs, one of them via nitrate and N_2, which are called new production, and the other via ammonium, urea and aminoacids, identified as regenerated production. The principal sources of new nitrogen are upwelling process and diffusion of nutrients from deeper rich water into the photic zone. Secondary sources are the inputs due to run off, rivers, wastewaters, atmospheric deposition and nitrogen fixation. Regenerated nitrogen is derived from excretory activities of animals and the metabolism of heterotropic microorganisms [Eppley et al, 1979].

In seawater, phosphorus is present in living organisms or in the aquatic environment as dissolved inorganic phosphorus, dissolved organic phosphorus and particulate phosphorus [Valiela, 1995]. The sources of dissolved organic phosphorous are the breakdowns of cellular materials and the release of organic phosphorous from plants and animals [Parsons, 1988]. In contrast to organic nitrogen, which requires exchange of energy for the fixation, reduction and oxidation process, phosphorus is readily hydrolysed from organic compounds. In aerobic conditions, inorganic phosphorus is mainly found as ortho-phosphate [Valiela, 1995].

Phosphorous requirements are principally satisfied by direct assimilation of dissolved inorganic phosphorus (orthophosphate ion), and in less proporcion, utilizing the dissolved organic form [Valiela, 1995]. Sometimes, phosphorus may be in very low concentration, to define the phytoplankton growth rate, but due to the readily remineralization rate of this compound, especially when zooplankton is present, results generally available [Parsons, 1988]. According to Millero et al.[1991], the maximum excretion of phosphorous by zooplankton is reached when phytoplankton is scarce, because when these cells are abundant, zooplankton use phospholipids for storage and egg production. When phosphate concentration is compared to that of nitrate, which is highly soluble in water, it is generally lower, due to the easy adsorption onto particles or to the capacity to form insoluble compounds with certain metals. In sediments, the phosphorus concentration is quite variable and influenced by the redox conditions [Valiela, 1995].

2.2 Seasonal cycles in the sea

Parsons [1988] states that regions in the hydrosphere are not defined only by latitude because "warm or cold currents may cross such imaginary lines". Due to water temperatures, the principal regions to be considered are: a) tropical (water temperatures above 25 °C all the year); b) subtropical (*ca.*15-30 °C); c) subpolar (*ca.* 5-15 °C) and d) polar (*ca.* 0-5 °C). The combination of subtropical and subpolar waters is defined as the temperate region [Parsons, 1988].

Tropical and subtropical waters are seasonally stable waters, but in temperate and polar waters, seasonal changes are evident. In temperate waters, at the end of summer, the water column may be described by an upper mixed layer[2], warmer, lighter, with a very low nutrient level, especially of nitrate, and a lower layer, cooler, heavier and with a higher nutrient level. Both layers are separated by a region of rapid change of temperature and density, known as the thermocline [Mann et al., 1996].

After summer a net loss of heat energy starts, surface water temperatures decrease; wind turbulence disrupts the thermocline until conditions are reached at the end of winter [Pickard, 1970]. The deepening of cooled surface water produces a progressive increase of the mixed layer depth, nutrients are brought into the photic zone, but phytoplankton cells are carried deeper by mixing and spend large time at depths were photosynthesis does not occur. Critical depth[3] becomes shallower than the mixed layer and there is no net growth [Mann et al., 1996].

In spring, light increases and surface waters warms. The mixed layer becomes shallower than the critical depth and the net growth is possible [Eppley, 1988]. Cells trapped above the thermocline spend more time in the photic zone and the spring bloom occurs. As the thermocline presents a barrier to the vertical transport, supply of nutrients from low layers is blocked and exhausted towards the end of summer [Mann et al., 1996]. In temperate systems, a fall bloom is also described [Valiela, 1995; Eppley, 1988], probably due to renewed input of nutrients by thermocline disruption or relaxation of zooplankton grazing intensity [Eppley, 1988].

The same seasonal cycles described for temperate oceans are also observed in coastal waters, but the process is more complex because of factors like shallowness, tidal currents, coastal morphology [Mann et al., 1996], and human activities, which may introduce or enhance

2- Mixed layer: is the stirred, upper layer, where temperature remains constant with depth. Sometimes, it is also called "surface" or "upper mixed layer", to distinguish it from homogeneous layers in the interior or at the bottom [Mann et al.,1996].

3- Critical depth: depth at which photosynthesis for the water column is equals to respiration for the water column [Valiela,1995].

conditions that destabilize the natural balance, like for example the discharge from polluted rivers and run-off or wastewater discharges.

As can be observed, seasonal cycles result from a subtle relationship between physical and biological processes. Reference was made above to the role of the physical variable temperature, in the vertical seasonal pattern. Horizontal changes may also be observed, but they are much smaller than the vertical ones in the same distance. Another important physical variable is salinity, but in contrast to temperature, its vertical distribution cannot be easily summarized. Temperature and salinity are identified as "conservative properties", because below the surface their changes can only be based on the mixing process. At the surface, temperature changes may be mainly due to absorption of solar energy, loss by evaporation and heat transfer by currents. Salinity may be influenced by evaporation or precipitation. Both variables can be related by density, which is another conservative property. Density is, in general, called "Sigma T" (σ_t , where σ= density and t= temperature). This physical variable helps in the identification of water bodies and of water masses in equilibrium (less dense at top and more dense at bottom). Frequently the effect of temperature on density overrides the salinity effect and as a consequence, more saline waters can be found at upper layers as a result of lighter density due to water warming [Pickard, 1970].

2.3 Geographic information systems

Burrough [1986] has defined a geographic information system (GIS) as a "set of tools developed for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes". Many disciplines, uses, data and users may be involved in a GIS. When the use is in connection to environmental and natural resource management, a GIS may have a role in: documenting natural conditions and the suitability of resources for various uses, exposing conflicts, and revealing cause-effect relationships [Bernhardsen, 1992].

In particular, as regards application of GIS to coastal areas, several examples have been found in the literature. The objectives cover a wide variety of targets. Some of them are: to define ecological zones (Gulf of Mexico) [Zarate Lomeli et al., 1997]; to identify places to be evaluated for preservation and restoration (Florida, USA) [Leary T.J. et al., 1997]; to analyse factors that influence the migration movements of right whales (Florida-Georgia, USA) [Ward L.I., 1997]; to predict water pollution risk from human activities on coastal areas (Arno Valley, Italy) [Jemma et al., 1994]; to map eutrophication sensitive zones (France) [Urvois et al., 1994]; to pre-select areas of submerged oyster culture (France) [Durant et al., 1994].

A GIS is integrated by the spatial database and its management, the geostatistical software, the table operations and digital image processing for remote sensing data. The spatial (or geographical) data has three major components: a) the geographic position, b) the attributes or non-spatial data and c) the time. The last component is included because of the importance of referring data to a time or period of time, but it does not imply that a GIS led itself to time-varying studies, because there is no explicit representation of time in the data structure [Meijerink et al., 1994]. The spatial data can be represented by points, lines or areas and a label that can be incorporated into any of these entities for identification. The digital representation of the produced maps can be done by vector or raster models. In the vector model, data are described by a set of lines with starting and end points that define vectors; in the raster model, data representation is given by a set of points on a grid (Fig 2.1).

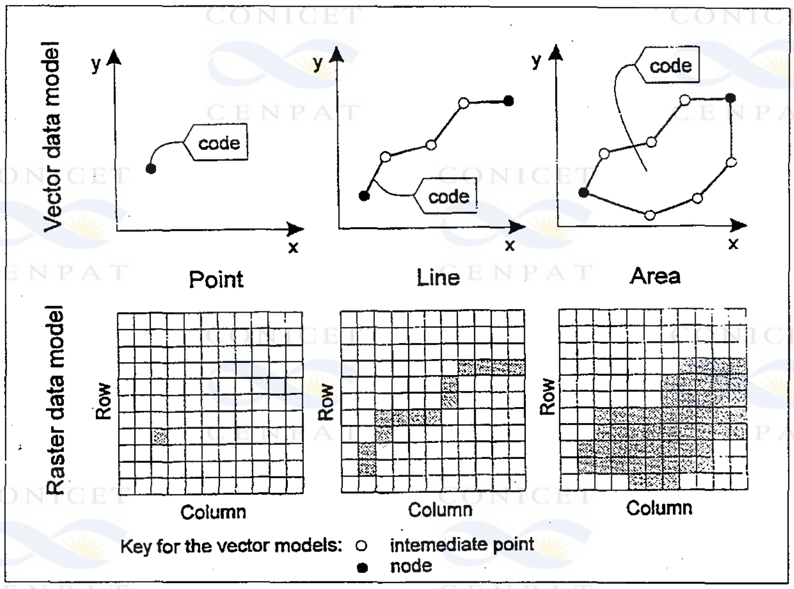


Fig. 2.1 - Vector and raster representation of data (from *Ilwis 2.1 for Windows-User's guide*)

At the beginning of GIS development, the users had to choose between working with raster models, that allowed an easy spatial analysis but required huge storage space and produced ugly maps, or working with vector models, that provided a database of reasonable size and elegant graphics, but difficult spatial analysis. Nowadays, the technology has solved the problem and both structures are interconvertible by valid methods. The simplest conversion is that achieved from vector to raster maps, nevertheless the rasterising process is not error-free. The most frequent error perhaps occurs because only a single value of an attribute can to be assigned to each cell, when a polygon vector map has to be approximated by a grid [Burrough, 1986].

Some of the advantages of raster models are:
- the simple data structure,
- the easy overlay and combination of mapped data with remote sensed data and
- the easy spatial analysis.

They are also seen as generally well suited when the geographic information of interest is the spatial variability of a phenomenon [Meijerink et al., 1994]. Because the objective of this work is related to spatial analysis, only the raster models are described in the next paragraphs.

The simplest raster model structure consists of an array of grid cells (also termed pixels or pictures elements) referenced by a row and a column number and a value for the attribute being mapped. In this way the geographical data are represented on a two-dimensional surface in a "quantized" way, which can result in a loss of precision mainly when the estimation of length and areas is carried out by pixel size larger than the features to be represented [Burrough, 1986]. Several flat cartesian surfaces representing the geographical space and associated attributes can be "overlayed" or "stacked" by arithmetic, logical or conditional operations giving as a result new information also presented as a raster representation.

A GIS is a georeferenced technological information resource that allows to creation of a model of the real world to study a process, to analyse the results of trends or the results of a planning decision. Nevertheless any of these objectives can only be reached satisfactorily if the data collected, entered, stored and processed are sufficiently reliable and error-free for the proposed target. Some errors may be obvious and easy to check, e.g.: age of the data, density of observations; others can be detected only when working intimately with the data, e.g.: the positional accuracy; but others are more difficult to identify because they require a deep knowledge of the data structure and the algorithms used [Burrough, 1986].

When the objective of study is to identify spatial patterns or spatial combinations from spatial point data of a GIS, the process of converting the discrete information into areal data is achieved by mathematical methods of interpolation. In this way from the observations carried out in visited point data, regularly or irregularly spaced, the properties of the unvisited points can be estimated. To find an interpolation technique that best suit to the data is not a simple task; the domain of application and the weakness and strength of each method should be known and evaluated.

Interpolation methods can be grouped into deterministic or non-stochastic schemes, and statistical or stochastic schemes. In the deterministic models, mathematical functions of various types and complexity are used to fit a surface through the set of sampled "z" values at known x, y coordinates. When it is achieved, the " z_0 "values can be determined for any coordinate position (e.g.: polynomial interpolation, linear interpolation, moving average, Thiessen polygons). In the statistical methods, the approach depends on whether or not the spatial data set may be considered as having random variation. If it does not happen, the "z" estimation may be done in terms of probability (e.g.: Fourier series, trend surface) [Meijerink et al., 1994].

The interpolation methods can also be grouped into discrete techniques (e.g.: Thiesen polygons) or techniques that provide models with continuous spatial changes which can be described by a smooth mathematically defined surface (e.g.: moving average, trend surface, B-splines). On the other hand, models are classified into models of global techniques (e.g.: Fourier series) or models of local fitting techniques (e.g.: moving averages). The former are those models constructed from all the observations of the property of interest at all points of the study area. The latter are models created only by the values from the neighbouring points [Burough, 1986].

In this work, the ILWIS software gives the possibility of selecting between the Thiessen polygon, the moving average, the trend surface or the moving surface method. For this work the moving average method was chosen because, according to Burrough [1986], it is a deterministic method that results in a model of gradual spatial change, appropriate for quick contour plots of moderately smooth data. The computing load is moderate and the output structure is on a raster map generated by local fitting technique.

In the moving average interpolation method, an average value is calculated for a central point within a local neighbourhood or "window" from "m" reference points encountered in the window. Then the window is moved in Δx and the procedure is repeated. Apart from that, a "weight" step can be also introduced in order to consider that the weight of an observation point, in the interpolation scheme, diminishes when the distance from the point increases. This effect is computed by a weighted moving average function. One of the most common expressions, according to Meijerink et al.[1994] are given by the equation 2.1:

$$6 = \frac{\sum_{k=1}^{m} w_k \cdot z_{lk}}{\sum_{k=1}^{m} w_k} \qquad \text{(Equation 2.1)}$$

where 6 = average value generated by the interpolation,
w_k = weight function
z_{lk} =observation value
m = reference points in the window

CHAPTER 3

DESCRIPTION OF THE AREA OF STUDY

3.1 - Geographical position and morphology of Nuevo Gulf

The Nuevo Gulf (Fig. 3.1) is located on the Patagonian coast of Argentina (Fig. 3.2) and limited by the coordinates S 42° 29' to S 43° and W 65° 03' to W 64° 03'. The surface area is approximately 2,400 km^2 and the volume is about 250 km^3. It is a semi-enclosed basin of approximately 70 km long and 60 km width. More than one third is deeper than 120 m and the maximum depth is 180 m, in the central area. It is connected to the Atlantic Ocean through a shallow sill of an average depth of 44 m and a length of 16 km [Rivas et al.,, 1989].

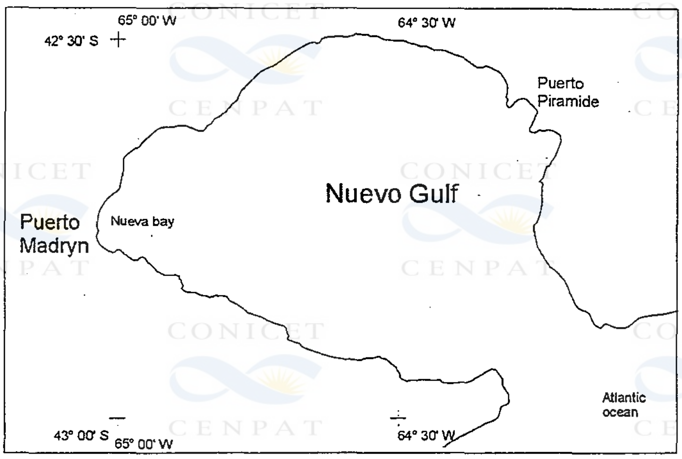


Fig. 3.1 - Nuevo gulf

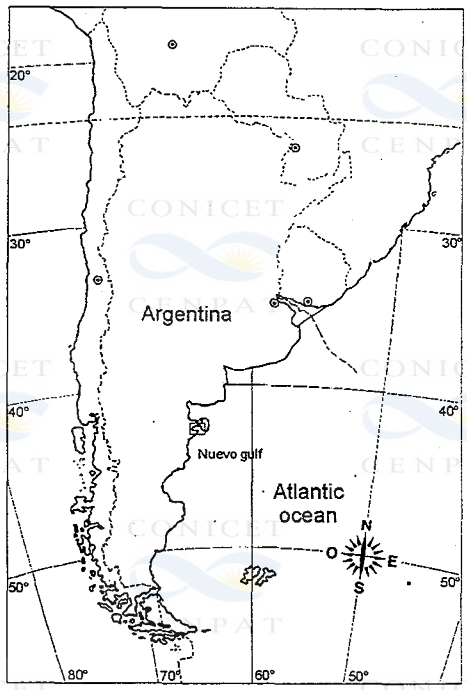


Fig. 3.2 - Geographical position of Nuevo gulf

Based on the morphology and sedimentary character, the Gulf has two regions: the peripheral region, extending like a crown, from the coast to 100 m depth and the central region, below 100 m depth, which totally surrounds the former region (Fig 3.3). The peripheral region has an irregular floor with submarine valleys, ridges and a canyon in the strait of entrance. The slopes are deep, with gradients between 1:16 and 1:100. This bottom area is covered by coarse sediments (sand, gravel and shell fragments) with outcrops of base rock (Tertiary marine and continental sediments) at some places. The central region has gentle slopes with gradients around 1:300, covered by clayey sediments occasionally interrupted by sandy stratified layers and gravel in a sandy matrix [Mouzo et al., 1978]. The tide is semidiurnal with an average amplitude of 1.9 m [Rivas & et al., 1989].

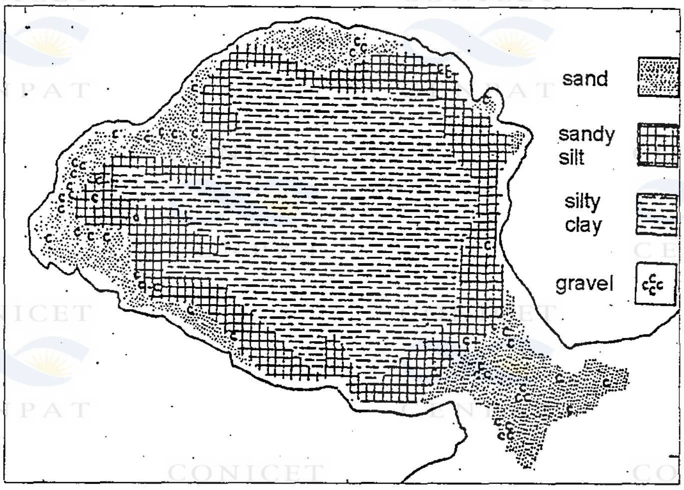


Fig 3.3 - Sedimentology of Nuevo Gulf (from Mouzo et.al.,1978)

3.2 - Features of the surrounding coast

The surrounding area is dominated by the typical steppe tableland of the Patagonian region of about 100 m height, which, in some places, ends on the coast in active cliffs which may be separated from the sea by narrow coastal plains. The coast is in general shaped by processes of marine erosion and marine accretion. It is irregular, with several small bays where sandy or gravel beaches are found.

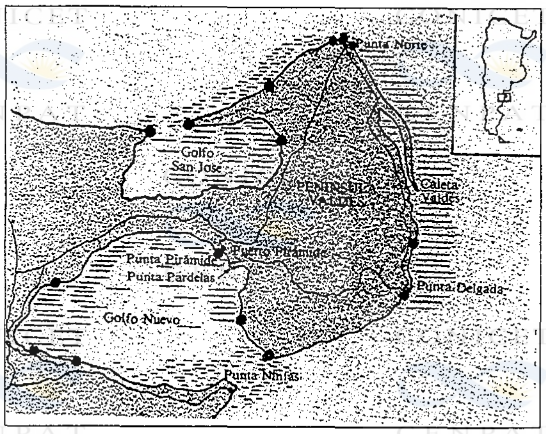
3.3 - Climate

The climate of the region is semi-arid. The annual mean precipitation is 200 mm and evenly distributed throughout the year. The annual mean air temperature is 13 °C with a maximum mean of 20.5 °C in January and a minimum mean of 6.5 °C in July. The most frequent wind blows from the west with intensities higher than 20 km/hr. The southwest and north winds, with similar intensities, are the next in frequency. The calm periods are about 16% [Vallejo et al., 1994].

3.4 - Other natural features

The vegetation is scarce and the soil is easily exposed to wind and rain erosion. The northern coast of Nuevo Gulf is one of the boundaries of the wildlife reserve of Peninsula Valdés. On the coast, there are southern sea lions rookeries (*Otaria flavences*), at Morro Nuevo, Punta Loma and Punta Piramide (Fig.3.4) which is mainly an area where pups are born. There are also other places only occupied during the winter by non reproductive animals [Crespo et al., 1991]

During winter and spring the right whales (*Eubalaena australis*) arrive at Peninsula Valdés, San Jose and Nuevo Gulf. Figure 3.4 shows the distribution of the right whales according to aerial and coastal censuses. It is believed that it is not an important area for feeding



----- Whale observation areas ● Sea lion rookeries

Fig 3.4 Sea lion rookeries and whale observation areas in Nuevo Gulf (after Harris et al.,1990)

and that location of the mammals in this area is due to their need for calm seas for rearing pups. It has been proved that mothers with pups try to settle in waters of 5 m depth [Harris et al., 1990].

The "manila" silverside (*Odontesthes smitti*) and the "Patagonian blenny" (*Eleginops maclovinus*) have been reported as the most important catches in Nuevo Gulf during an artisanal shore seine fisheries evaluation carried out during 1987 and 1989, representing 83% and 7% of the total biomass, respectively [Elías et al. 1997].

3.5 - Human settlements

Most of the coasts of the gulf are inhabited. Human activities are concentrated in Puerto Madryn City and in the small village of Puerto Piramide (Fig. 3.1).

Puerto Madryn city is located in the Nueva Bay area. The origin of the city is related to the arrival of Welsh pioneers in 1865, but the settlement was effective since 1886. In the last census, the city had 45,000 inhabitants (1991)[1] and at present about 60,000 inhabitants. The population was tripled in ten years after the building of an aluminum plant, the construction of the Storni pier and other industrial settlements, started in the '70's. The most important economical activities are concentrated in the aluminum and the fish processing plants, the port and in tourism. This activity is especially based on ecotourism and is rapidly expanding[2].

Puerto Piramide is located on the north eastern coast. The origin of this place is registered around 1900 with the settlement of the first pioneers dedicated to sheep raising in the surrounding area and the exploitation of the salines in Valdés Peninsula. Now, it is a small village with a stable population of approximatelly 200 people in winter and about 2,500 people

1- Mean age: 25 years old.
2- Tourist arrival during summer: 25,000 people (1993); 69,000 people (1997).
(Data from the Municipal Tourism Secretary of Puerto Madryn city)

in summer. Some years ago the economy of the few inhabitants was mainly supported by basic commercial activities from people living in the rural area and from regional tourism during the summer. Since the 80's, this place has become nationally and internationally known because of the whale watching tours[3]. In the surrounding area, sheep ranches are placed in sheltered canyons.

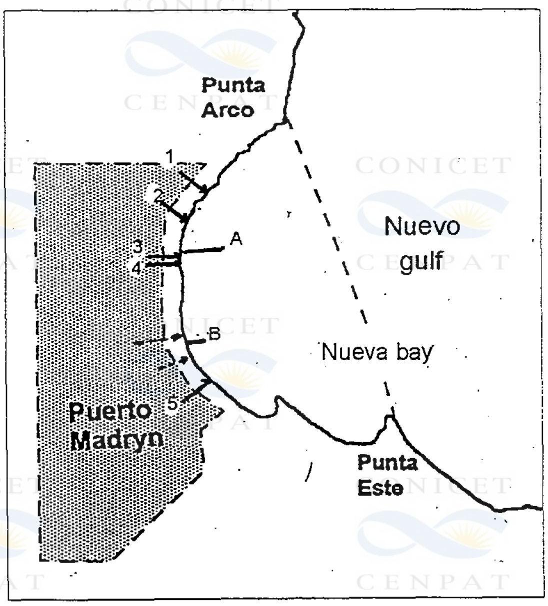
3.6 - Freshwater resources

There are no surface freshwater sources in the area. The groundwater available for human consumption is reduced to wells at 10-20 m depth, of low efficiency. Most of the wells have no suitable water for human or animal consumption because of the high concentration of sulfate, carbonate and chloride [Haller, 1981].

Puerto Madryn city receives drinking water from the Chubut river by a 70 km pipe line system. In Puerto Piramide the activities and development of the village are limited by the lack of water. Drinking water is supplied from a reverse osmosis plant and by tanks transported by trucks from Puerto Madryn city (80 km.) and Trelew city (150 km).

3.7 - Discharges entering the Gulf

The main discharges entering the Gulf come from Puerto Madryn city in the area of Nueva Bay (Fig. 3.5). No exact figures are available but the total domestic and industrial discharges to the bay are about 10,000 m^3/day [Esteves et al, 1997].



A: Storni pier
B: Piedrabuena pier

Discharges:
1 & 2: fishery plants
3: aluminium plant
4: aeration ponds
5: Moreno pluvial
-----> temporary discharges

Fig. 3.5 - Discharges from Puerto Madryn city (from Esteves et al., 1997)

3- Whale watching tours: 5,200 people (1987); 53,000 people (1996).
(Data from the Municipal Tourism Secretary of Puerto Madryn city)

The fish processing plant, discharging at point 1, has fish food and fish flavour processes. At point 2, two fish food plants are discharging. The waste waters are treated in each plant before discharging to the beach, but many times it has been observed that effluents do not receive efficient treatment [Esteves et al., 1997]. The aluminium plant, located in front of the Storni pier, includes a system for recycling fluoride gases. The wastewater is reused in forestation located close to the plant and the discharge to the sea is generally dry [Esteves et al., 1997]. The activities in the Storni pier (next be enlarged) are based on the transport of raw materials for the aluminium plant, aluminium, wool and fruit exportation as well as summer stages of big tourism ships. The Piedrabuena pier concentrates on the fishery activities. During 1997 an increase in the maritime activity has been registered especially in connection with charge operations outside the piers and frequent leakages of fuel have been observed close to the city.

The city has a sewerage system only for domestic wastewater collection. The network covers about 50% of the city but it is probable that less of the population is connected to the system. The wastewater is treated in aerated lagoons that discharge directly to the beach. The efficiency of the treatment is not optimal because the plant capacity has been overloaded by population growth. People not connected to the sewerage system or living outside of the network area have septic tanks dug in the ground. In some places this system percolates towards the beach during ebb tides [Esteves et al, 1997]. On the west side, the city is bordered by the "bardas", a typical Patagonian formation at about 100-150 m height. The runoff of this area and that from the urban sector is collected in most of the city by the pluvial system and discharges directly to the beach. These pipes also may transport occasional or permanent streams that reach the sea during dry weather.

Nueva Bay, as well as some other areas of the Gulf, also receive increasing volumes of solid wastes (mainly plastics) transported by tides and winds from the land activities (eg: tourism on the beaches) and from sea activities (eg: litter from the ships).

3. 8 - Legislation

No water quality standards exist for Nuevo Gulf. The Provincial Law 1,503 of The Atmosphere and Water Protection regulates only some compounds in the effluents (nitrogen and phosphorous are not included) and gives norms of water quality for receptor bodies of industrial and urban discharges according to water body uses (irrigation, aquatic life, recreation, drinking water with treatment, etc.) but no distinction is made between loads discharged to closed bays, open sea, etc. and some admissible maxima indicated for the receptor bodies are extremely high when compared with natural conditions (eg. nitrate in sea water).

3. 9 - Background of the area of study

On the next paragraphs, a review of information from reports of the study area, related to the aim of this work, is presented.

3.9.1. - Analysis based on temperature and salinity of Nuevo Gulf

Based on temperature and salinity, Barros et al., [1978] have characterized the annual evolution of the Nuevo Gulf as mainly influenced by atmospheric conditions which results in a seasonal cycle with higher variations than that produced by interannual fluctuations. In summer and autumn, these authors describe the Gulf as a dilution basin with lower surface water density inside than outside the area and surface water going out through the north side of the mouth. In winter, the water body evolves towards a concentration basin with higher surface water density inside than outside the Gulf, flowing out again by the north side of the mouth, but from the bottom. This autumn pattern has been also reported by Romaña [1970]. The summer and autumn density condition is explained by seasonal water warming and low evaporation due to a stable saturated atmospheric layer giving high relative humidity at sea. In contrast, the winter condition is the result of surface water cooling and evaporation increase produced by the instability of the lower atmospheric layers with low relative humidity at sea.

In 1989, the seasonal variation of the termo-haline structure of Nuevo Gulf was analysed by Rivas et al., [1989]. The analysis was based on the temperature and salinity data collected during oceanographic campaigns carried out in 1982-1983. From these data, the authors concluded that the water body evolves from complete mixing in autumn and winter (12 ° and 10 °C at surface and bottom respectively) to stratified conditions in summer (18 °C and 11 °C at surface and bottom respectively). The salinity has a slight horizontal and vertical variation and no clear annual variation, ranging from 33.750 up to 33.825 ups. When sampling sites inside and outside the Gulf were compared, it was seen that during summer the temperature inside the Gulf is higher than in the ocean; this situation is reversed in winter. Salinity is higher inside the Gulf all year round. This temperature and salinity data in addition to the dissolved oxygen, nitrate, nitrite, phosphate and chlorophyll "a" are now analysed in this work.

3.9.2. - Marine currents at Nuevo Gulf and Nueva Bay

In general, the mean current velocity inside the Gulf is not higher than 50 $cm.sec^{-1}$. The exception is the entrance area where speed velocity is highly variable [Lanfredi, 1974] and in the nautical chart H 218 from the National Hydrographic Service, currents up to 150 $cm.sec^{-1}$ are registered. Results observed in the field, about circulation of water masses in the western area, between Punta Flecha and Punta Este has been reported by Lanfredi [1974] and for the area between Punta Arco-Punta Este (Nueva Bay), by Krepper et al., [1979] and Rivas [1983]. The authors agree when they report that current velocities are low and that flow is influenced by the topography, close to the coast. Current meters in the limit of 0.5 $cm.sec^{-1}$ are suggested for future field work [Rivas, 1983]. Experiments performed by Lanfredi [1974] was under no wind influence and found subsystems of circulation mainly related to the topography and shape to the coast rather than to the influence of tides. Krepper et al., [1979] concluded that current velocities decrease with depth and there is no clear pattern of circulation, which in general seems to depend on winds. Rivas [1983] did not find a good current- wind correlationship, but it is not clear if the reason is due to the experimental conditions or to other factors like the necessity of a minimum threshold of wind intensity for starting to exert influence.

3.9.3. - Secchi disk depth at Nuevo gulf

The average extinction coefficient (k), according to the mean Secchi depth showed in Fig. 3.5, is k=0.15, which corresponds to clear coastal waters [Parsons, 1988]; (k=1.7/D; D= Secchi depth in meters [Pickard, 1970]).

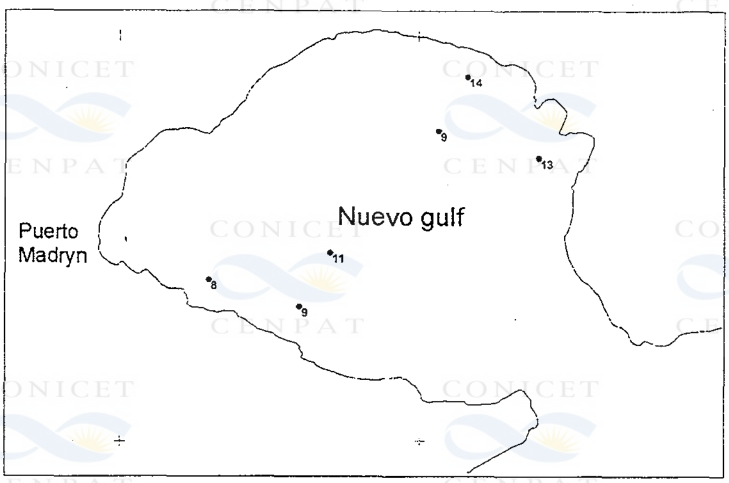


Fig 3.6 - Secchi disk depth (m), in summer '70 [After Rojo et al., 1970]

3.9.4. - Anthropogenic effects on Nueva Bay area

The last report with physical, chemical and biological information from Nueva Bay and the effluents discharged in this area refers to data collected during annual campaigns carried out in 1993, 1994 and 1995 [Esteves et al., 1997]. The impact of the urban and industrial discharges is seen on the coast. The effects of the human activities on the Bay have already been mentioned in 1987 by Esteves. In the 1997 report it was observed that nutrients, particulate organic matter and densities of phytoplankton and zooplankton cells are higher at the sampling points close to the coast and towards the northern part of the Bay than at the external points. In 1993 (December) and 1994 (November), the highest densities of the toxic dinoflagellate producer of paralytic shellfish poison (PSP), *Alexandrium tamarense*, were coincident with the zones of highest nutrient concentration. *Pseudo-nitzschia pseudolicatisima* and *Pseudo-nitzschia australis*, diatoms, producers of amnesia shellfish poison, and *Dynophysis acuminata*, diatom producers of diarrheic shellfish poison have been also mentioned in abundance, in this report. It is not the first time that harmful algae have been identified in Nueva Bay. A toxicity peak of *Alexandrium scavatum* was registered in January 1988. The origin of this bloom was suspected to be an upwelling process, because abnormally low surface water temperature during December 1987 and January 1988 was observed and related to fifteen days of dominant south west winds with an average intensity higher than 20 km/h [Esteves et al., 1992]. Upwelling processes after south west winds of 30 km/h have been also detected because of temperature decrease in January 1978 [Esteves et al., 1980].

The highest chlorophyll “a” concentration has been measured at Storni [Esteves et al., 1981] and Piedrabuena piers [Esteves et al., 1981 and 1997]. In the latter place, the highest chlorophyll concentration has been associated to the highest nutrient concentration for the data collected in 1994.

The tides and the wind exert influence on the accumulation of macroalgae on the shore where the algal layers may reach up to one meter height. The decaying macroalgae produce odours, concentrations of insects and reduce the recreational value of the beaches. There are no systematic observations, but *Ulva sp., Dictyota sp.* and *Codium spp.* seem to be the most abundant species [Eyras et al 1993]. Inhabitants of Puerto Madryn [Piriz, pers. comm.] have mentioned that *Codium spp.* used to be the dominant species on the beaches of the city some years ago. The municipality collects the macroalgae arriving at the coast. According to Eyras et al. [1993], the monthly average wet biomass of algae collected was 1,500 tons, with maximum in spring of 2,700 tons and minimum in winter. Accidental introduction of the exotic algae *Undaria pinnatifida,* by cargo fish or fishing vessels, has been detected in 1992 below the Storni pier and, in 1994, a significant expansion from its original location has been reported [Casas et al., 1996].

In Nueva bay, it has been reported that nitrate seems to be the limiting nutrient for phytoplankton growth, and its seasonal variation is higher than that observed for phosphate. [Esteves et al., 1981]. In this bay, the maximum mean temperature is 17.3 °C (February) and the minimum mean temperature is 9.5 °C (August), according to ten year data series (95% of confidence) [De Vido de Mattio et al., 1978].

CHAPTER 4

MATERIALS AND METHODS

4.1 - Oceanographic data

The oceanographic data for the analysis were obtained during five oceanographic campaigns performed in Nuevo Gulf on board of the oceanographic boat "El Austral" during:

* 15 to 18 April 1982 (Autumn),
* 31 August to 3 September 1982 (Winter),
* 2 to 6 November 1982 (Spring),
* 15 to 19 January of 1983 (Summer) and
* 8 to 12 April 1983 (Autumn).

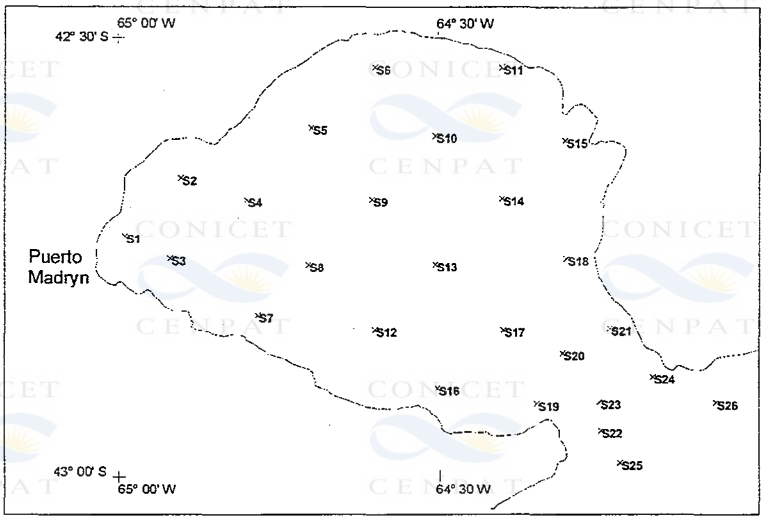


Fig. 4.1 - Sampling points

Samples were collected with Nansen bottles at 26 sampling points (Fig. 4.1) and discrete depths: 0, 5, 10, 20, 30, 50, 75, 100, and below 100 m depth every 10 or 20 m, down to reach the bottom. Temperature was measured with protected Kalhsico thermometers (precision ± 0.02 °C). Seawater samples were analysed for dissolved oxygen, salinity, nutrients (NO_3^--N, NO_2^--N, PO_4^{3-}-P) and chlorophyll "a". Dissolved oxygen was determined on board by the classical Winkler procedure. Salinity and nutrient samples were stored (nutrients previously frozen to -20 °C) and analysed at the end of the campaign at the Central Laboratory of the Centro Nacional Patagónico (Puerto Madryn). Salinity was determined by an inductometric salinometer Plessey-6230 N. Nutrients were analysed by the colorimetric techniques described by Strickland et al. [1972] and a Hitachi-110A Spectrophotometer. For chlorophyll "a" analysis, one litre samples were filtered, on board, through 0.5 μm Millipore membrane and frozen until the analysis by 90% acetone extraction and detection with a Turner 111 fluorometer at the Centro Nacional Patagónico laboratory [Molina et al., 1983, 1984 and 1985]. Precision of the analysis is listed in Table 4.1.

Table 4.1 - Precision of analysis

Variable	Precision
Temperature	± 0.02 °C
Salinity	± 0.003 ‰
Dissolved oxygen	± 0.02 ml.l^{-1} (at the level of 6 ml.l^{-1})
NO_3^--N	± 0.2 µg-at.l^{-1} (at the level of 5 µg-at.l^{-1})
NO_2^--N	± 0.04 µg-at.l^{-1} (at the level of 0.5 µg-at.l^{-1})
PO_4^{3-}-P	± 0.03 µg-at.l^{-1} (at the level of 1 µg-at.l^{-1})

The percentage of oxygen saturation was calculated by the formula for solubility of gases in seawater given by Riley et al. [1975], in function of the dissolved oxygen concentration, the temperature and the salinity. Densities, expressed as Sigma T, were calculated from oceanographic tables [Bialeck, 1966].

Files with the stored oceanographic data [Molina et al., 1983, 1984 and 1985] were retrieved and processed by LOTUS '97 spreadsheet. All the data collected on the field were represented on five sets of Figures (one per campaign), where mean values and standard deviations for each variable are shown as a function of depth from surface to 125 m (Annex A). T-tests were carried out to test significant differences ($p<0.05$) between mean values at the surface, 50 m and 100 m depth, respectively, in each season. The same statistical test, was also performed between the surface, 50 m and 100 m depth mean values, respectively, of autumn'82-winter'82; winter '82-spring'82; spring'82-summer'82; summer '83-autumn'83 and autumn'82-autumn'83.

4.2 - Satellite data

Via Internet [world wide web (1), (2), (3)], a search of remote sensing images of Nuevo Gulf was carried out. As a result, information from images of the satellites Spot (HVR: XS and PAN), Landsat (TM and MSS) and Seawifs were obtained although the availability of images of the area is scarce. As an example, a Landsat TM image (resolution: 30 km) from 19/02/86 was purchased. These search prevented the acquisition of more commercial imagery

Examples of the Spot images, are listed in Annex D. General and zoomed views, as well as a pre-processed temperature image of the purchase TM Landsat image, are included in Annex E. The web Seawifs service allowed the view and download of simulated Seawifs chlorophyll "a" images. The extracted images were built from original images of 4 km of resolution; they are listed in Annex

F. Due to the resolution of these images and to the frequency of dates (16-19-20-21 and 25 of September 1997; 3-6-8 and 22 of October 1997) this information results much more complete than any collected from a sampling programme. From Seawifs, also commercial images of one kilometre resolution can be obtained.

4.3 - Analysis of the data

4.3.1 - Seasonal and spatial analysis of the data

The spatial variation of a parameter, may be observed in the "x" (longitudinal), "y" (transversal) and "z" (depth) dimensions. Through the analysis of the spatial variation in the "z" dimension may be identified vertical patterns; in the "x, y" dimensions may be identified horizontal patterns. The temporal variation may be observed at scales of hours, days, months, seasons, years. In this work, due to the frequency of the data available, only seasonal variations may be analysed.

For the spatial analysis, maps (raster maps) with horizontal distributions of each variable were produced by a geographic information system (GIS). The GIS was chosen not only by the facility of integrating information on maps, but also by the possibility of being completed in the future with remote sensing images of the area and land-use information. The software used was ILWIS 2.1 for Windows (Integrated Land and Water Information system), which has been developed by the International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands.

To produce the maps, the coast line and the 50 and 100 m depth isobath were digitalized from the H218 - Golfo Nuevo chart published by the Naval Hydrographic Service of Argentina (Fig. 4.2).

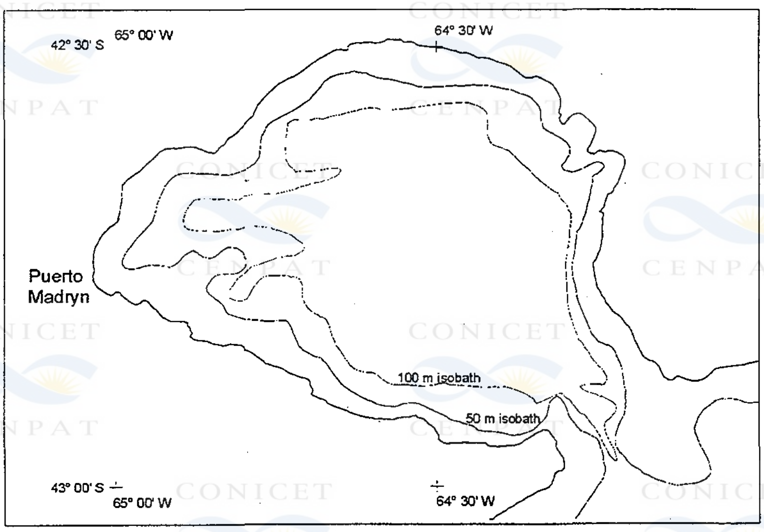


Fig. 4.2 - Contour of the coast and isobaths of 50 and 100 m depth

The input of the sampling point coordinates was done manually. LOTUS data tables were transformed to .DBF extension and imported by ILWIS. Attribute point maps with the georefenced information were created and used as input point maps to produce the raster maps with horizontal representations of the variables, at 0, 50 and 100 m depth. In November, most of the dates were collected at 95 m depth, instead of the 100 m, thus, the 95 m layer was selected. The horizontal maps were obtained by the moving average point interpolation method, which performs a weighted averaging on point values of a point map in such a way that the output pixel value is more influenced by points located close to it than by the values of points that are further away. In other words, the output value for a pixel is calculated as the sum of the products of weights and point values divided by the sum of weights [ILWIS, 1997] (see Chapter 2). For this method, the ILWIS programme expects the user to choose between two weighting functions (inverse or linear distance); to specify the exponent weight and to select the limiting distance for points with weight zero (no influence) on the output pixel value. Some trial raster maps generated at different input conditions were evaluated before selecting the working conditions: Weight function= Inverse distance; Weight exponent = 1 and Limiting distance = 47500. These raster maps, with a pixel size of 100 x 100 m, will be referred in this work as "basic" raster maps (Table 4.2).

Table 4.2 - Basic raster maps obtained by moving average point interpolation

CAMPAIGN	DEPTHS (m)	PARAMETERS	INTERPOLATION PRECISION
April '82 November '82 January '83 April '83	0; 50 and 100	Temperature Salinity Density (Sigma T) Dissolved oxygen NO_3^-N NO_2^-N PO_4^{3-}-P	0.05 °C 0.02 $g.l^{-1}$ 0.02 0.05 $ml.l^{-1}$ 0.5 $\mu g\text{-}at.l^{-1}$ 0.05 $\mu g\text{-}at.l^{-1}$ 0.05 $\mu g\text{-}at.l^{-1}$
August '82	0; 50 and 95	(as above)	(as above)
April '82 August '82 November '82 January '83 April '83	0 and 5 m	Chlorophyll "a"	0.1 $mg.m^{-3}$

Basic raster maps were subsequently classified with the ILWIS tool CLFY function for a better identification of zones. This function classifies values into a number of classes previously defined. The ranges selected for this classification are listed in Table 4.3.

Subsequently, the classified raster maps of temperature, salinity, NO_3^--N, PO_4^{3-}-P and chlorophyll “a”, at the surface, were combined by addition of codes assigned to areas bigger than 0.5 % of total surface area, according to codes listed in tables of Annex C. The ILWIS tools used in this process were: Area numbering and Map Calculation [ILWIS, 1997]. Dissolved oxygen and NO_2^- -N were not included in the combination procedure, because these variables, generally, do not show horizontal pattern to the level of classification applied.

For the presentation of the results and discussion of the Seasonal and spatial analysis, the variables were grouped in:

*physical variables: temperature, salinity and density. The latter calculated from temperature and salinity and expressed through the sigma T.
*chemical (dissolved oxygen (and the calculated percentage of saturation), nitrate, phosphate) and biological variables (chlorophyll "a"),
and analysed in vertical and horizontal way.

Table 4.3 - Ranges used for classification of the basic raster maps

MAP	RANGE USED FOR CLASSIFICATION
Temperature	1 °C
Salinity	0.2 $g.l^{-1}$
Density (Sigma T)	0.2
Dissolved oxygen	1 $ml.l^{-1}$
NO_3^--N	1 and 0.5 $\mu g\text{-}at.l^{-1}$
NO_2^- -N	0.5 $\mu g\text{-}at.l^{-1}$
PO_4^{3-}-P	1 and 0.5 $\mu g\text{-}at.l^{-1}$
Chlorophyll “a”	1.0 $mg.m^{-3}$

4.3.2 - Characterization of the water body

The results of the Seasonal and spatial analysis were subsequently used in the characterization of the water body.

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, the results and discussion are presented in two main topics:

5.1 - Seasonal and spatial analysis, and
5.2 - Characterization of the water body.

The Seasonal and spatial analysis is carried out season by season. In this analysis, the physical variables (temperature, salinity and density), and the chemical (dissolved oxygen, nitrate, phosphate) and biological (chlorophyll "a") variables are analysed in the vertical and the horizontal way. After the Seasonal and spatial analysis, the results are subsequently applied to the characterization of the water body.

Nitrite is not included in the analysis. It is an intermediate compound in the nitrification process and expected to be in low concentration in presence of oxygen. In fact, the values observed in the Gulf are low, mean values are no higher than 0.4 μg-at NO_2^--N.l^{-1}, and inside the range given by the literature reviewed. It is not observed patterns of horizontal distribution, in most of the seasons. The results of this variable, are included in Annex G.

The results for the Seasonal and spatial analysis are presented in Fig. 5.1 and the maps with the horizontal distributions, produced by the GIS. In Fig. 5.1 are represented the mean values of all the variables at the surface, 50 m and 100 m depth, for the five campaigns carried out in the Gulf. Because this Figure covers the analysis of all the seasons, it is included at the end of the Seasonal and spatial analysis. The maps, with the horizontal distributions of the single variables, at the surface, 50 m and 100 m depth are listed at the end of each Seasonal and spatial analysis.

5.1 - SEASONAL AND SPATIAL ANALYSIS

5.1.1 - AUTUMN '82

5.1.1.1 - Physical variables

The analysis of the physical variables is based on Figs. 5.1.a; 5.1.b; 5.1.c and horizontal distributions of temperature, salinity and density at 0 m; 50 m and 100 m depth, of April '82 (Figs. 5.A1.1a; 5.A1.1b; 5.A1.1c; 5.A1.2a; 5.A1.2b; 5.A1.2c; 5.A1.3a; 5.A1.3b and 5.A1.3c).

a) Vertical analysis

Mean values of temperature, salinity and density, at the surface, are not significantly different from mean values at 50 m depth, but they are significantly different from mean values at 100 m ($p<0.05$). According to these results and the horizontal distributions of these variables, it can be inferred that there are changes in the physical properties of the water column that occur between the 50 m and the 100 m. These vertical changes, result in colder and less saline waters towards the bottom. Nevertheless the magnitude of the change is expected to be slight, because the mean temperature from surface to bottom, differ in less than 1 °C, and salinity in less than 0.2 ‰, hence, water column is close to no stratified pattern.

b) Horizontal analysis

In the horizontal distributions of the physical variables, it is observed that:
-at the surface, no pattern is observed, temperature differs in less than 1 °C; inside waters are more saline (range: 33.8-34.0 ‰) than oceanic waters. On the western sector, density is lower than in other areas of the Gulf;
-at 50 m depth, the horizontal analysis for the three variables results similarly to that described at the surface;
-at 100 m depth, salinity is in the range of the oceanic waters, at the surface and 50 m depth. A central nucleus, colder and more dense is observed over the deepest area of the basin.

5.1.1.2 - Chemical and biological variables

5.1.1.2.1 - *Vertical and horizontal analysis of dissolved oxygen*

The analysis of dissolved oxygen is based on Figs. 5.1.d and 5.1.e, and the horizontal distributions of dissolved oxygen at 0, 50 and 100 m depth, of April'82 (Figs. 5.A1.4a; 5.A1.4b; 5.A1.4c).

The minimum oxygen concentration is 4.0 $ml.l^{-1}$, in the whole water body. The percentage of saturation is higher than 70 %. Mean oxygen concentration and percentage of saturation, at the surface, are significantly different from mean values at 50 m and 100 m depth ($p<0.05$). The higher mean oxygen levels are found at the surface. In fact, in the horizontal distributions, oxygen concentrations above 5 $ml.l^{-1}$, and up to 6 $ml.l^{-1}$, are found mainly at the surface, and only in the northwestern area, at 50 m.

The higher levels at the surface, are expected to be due to atmospheric diffusion and also probably to photosynthetic production. The decrease towards bottom may be due to low vertical diffusion from the surface waters and consumption in the remineralization process at the sediments.

5.1.1.2.2 - *Vertical and horizontal analysis of nitrate*

The analysis of nitrate is carried out with Fig. 5.1.f and the horizontal distributions of nitrate at 0 m, 50 and 100 m depth, from April '82 (Figs. 5.A1.5a; 5.A1.5b; 5.A1.5c; 5.A1.d; 5.A1.e).

The vertical change in the physical properties observed between 50 m and 100 m depth, is also inferred by the vertical distribution of nitrate. Like temperature, salinity and density, the nitrate mean value, at the surface, is not significantly different from the mean value at 50 m depth, but significantly different from the mean at 100 m depth ($p<0.05$). In the upper layers, nitrate concentration is lower than at the 100 m. The mean value from surface to 100 m decreases about 2 µg-at NO_3^--N.l^{-1}.

In the horizontal analysis it is observed that:
- at the surface, the horizontal nitrate distribution, may be described by three zones, where nitrate decreases from the oceanic waters towards inside of the Gulf. The west and the northwestern coast are the places where nitrate is lower (<1 µg-at NO_3^--N.l^{-1});
- at the 50 m, the three areas above described may be replaced by a main pattern given by only one area in the range of 1-2 µg-at NO_3^--N.l^{-1};
- at 100 m depth, the central area, identified as colder and more dense, has also the higher nitrate concentration.

The vertical nitrate pattern, showing lower nitrate concentration in the upper layers, agrees with the descriptions given by the literature reviewed. The photosynthetic activity of phytoplankton is highly regulated by light and as a consequence, nitrate is generally consumed, at the upper layers. At the bottom, nitrate is generally expected to be higher, not only due to the low or null consumption by phytoplankton but also due to nitrate production by remineralization in the bottom sediments. On the other hand, the slight change described in the physical properties, probably, may reduce the vertical diffusion from bottom to the surface and hence, the replenishment of the nitrate consumed.

The vertical analysis suggests that nitrate input to the upper layers by vertical diffusion, may be limited. But, at the surface, the horizontal pattern suggests an input of nitrate from oceanic waters, which may be produced by horizontal advection. This input is probably enough to replenish the nitrate in the waters close to the entrance, but not enough to reach and recharge the west and northwestern area. It is also possible, that this area is also recharged with the external nitrate but the rate of consumption by phytoplankton is higher in this zone than in other places of the Gulf.

5.1.1.2.3 - *Vertical and horizontal analysis of phosphate*

The phosphate analysis is based on Fig. 5.1.g and the horizontal distributions at 0, 50 m and 100 m depth, of April '82 (Figs. 5.A1.6a; 5.A1.6b; 5.A1.6c and 5.A1.6d).

The mean concentration at the surface is not significantly different from that value at 100 m depth ($p<0.05$). Both mean values are lower than 1.2 µg-at PO_4^{3-}-P.l^{-1}. At the 50 m, the mean concentration is the highest of the column (2.6 µg-at PO_4^{3-}-P.l^{-1}) but not significantly different ($p<0.05$) from the surface value.

In the horizontal distributions it is observed that:
-at the surface, the horizontal distribution of phosphate, may be described by an eastern sector, in the range of 1-2 µg-at.l^{-1}, and the rest of the Gulf, below 1 µg-at.l^{-1}. On the west and northwestern coast, the zone below 1 µg-at.l^{-1}, is partially coincident with the area where the lower nitrate was observed.
-at 50 m depth, the horizontal distribution is influenced by two anomalous results of 15 µg-at PO_4^{3-}-P.l^{-1}, on two sampling points;
-at 100 m depth, the pattern is mainly described by an area in the range of 1-2 µg-at PO_4^{3-}-P.l^{-1}.

Similar to the description given for nitrate, phosphate is expected to be lower in the upper layers. This is in agreement with the estimated results of the surface layer, but not consistent with the values found at 50 m depth. Patterns in the vertical and horizontal dimensions, are not as they were for nitrate. It is probably because phosphate hydrolysis is readily achieved in the water column (see Chapter 2). In the horizontal distribution, the lower concentrations of phosphate, coinciding with the lower nitrate, on the west and northwestern area, infer again, a higher photosynthetic activity in this zone of the Gulf.

5.1.1.2.4 - *Vertical and horizontal analysis of chlorophyll "a"*

The analysis is carried out with Fig. 5.1.h and the horizontal distributions of chlorophyll "a" at 0 and 5 m depth, of April '82 (Figs. 5.A1.7a; 5.A1.7b and 5.A1.7c).

Mean values of chlorophyll "a" at the surface and 5 m depth, are not significantly different ($p<0.05$). The higher concentrations (between 1 and 3 mg. m^{-3}) are on the west and northwestern area, where the lower nitrate and phosphate were observed. On the other hand, in the horizontal analysis of nitrate, it was suggested that in this area, probably the consumption rate of nitrate is higher, but which may be the factors that favour the photosynthetic activity?

Light is one of the major factors that control photosynthetic rate (see Chapter 2). On the Gulf it is supposed that irradiation received by surface waters is the same in the whole area, but perhaps there is a factor within the water, as for example, the turbidity, that may be lower on that area and results in better conditions for photosynthetic activity. Low turbidity may be associated to low water movement and low current velocities in this zone. Unfortunately no transparency data are available and data about current velocities, in spite of being reported as low (see Chapter 3), they are not enough to support or reject this hypothesis.

5.1.1.3 -Horizontal distribution by combination of the physical, chemical and biological variables

A horizontal pattern (spatial variation in the "x, y " dimension) was produced by the combination of physical, chemical and biological horizontal distributions, at the surface. From the horizontal analysis, it was observed, that in general, the surface layer is where most of the horizontal patterns are found and the influence of the oceanic waters observed. The combination of these variables was carried out according to the description given in Chapter 4. In autumn '82, the results are represented in Fig. 5.A1.8a (see Codes in Table C.3 - Annex C)

Fig. 5. A1. 8a - Horizontal distributions of temperature, salinity, nitrate, phosphate and chlorophyll "a" - Autumn '82

From this spatial distribution, six zones can be identified. Nevertheless, because some adjacent areas have similar characteristics, a simplification may be applied, for example, by selecting the areas with the same chemical and biological properties, as unique zones. After this procedure, the following map was obtained:

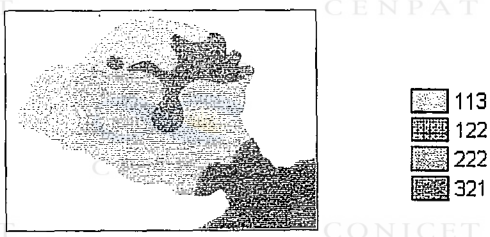
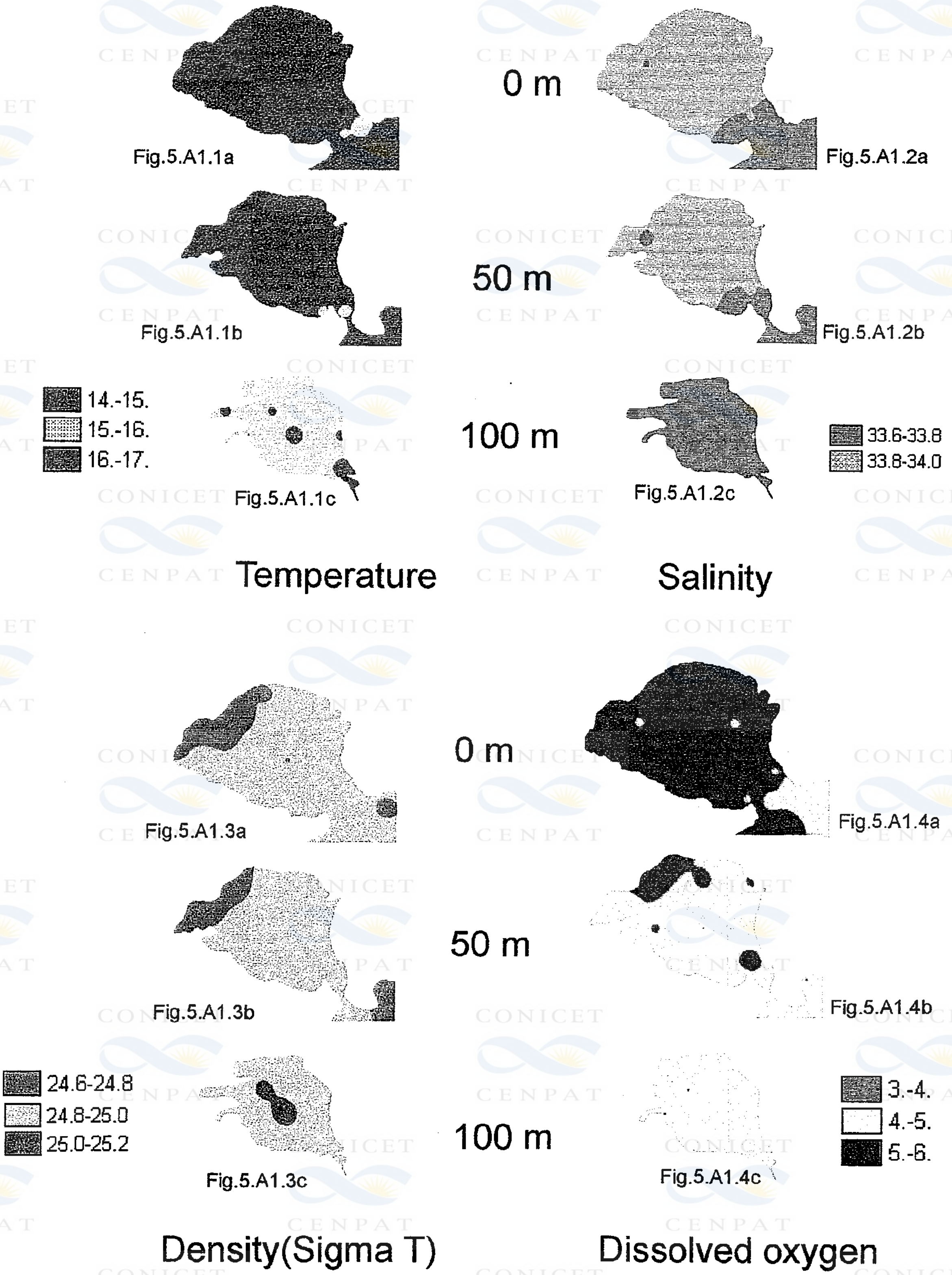


Fig. 5.A1.8b - Horizontal distributions of nitrate, phosphate and chlorophyll "a" - Autumn '82

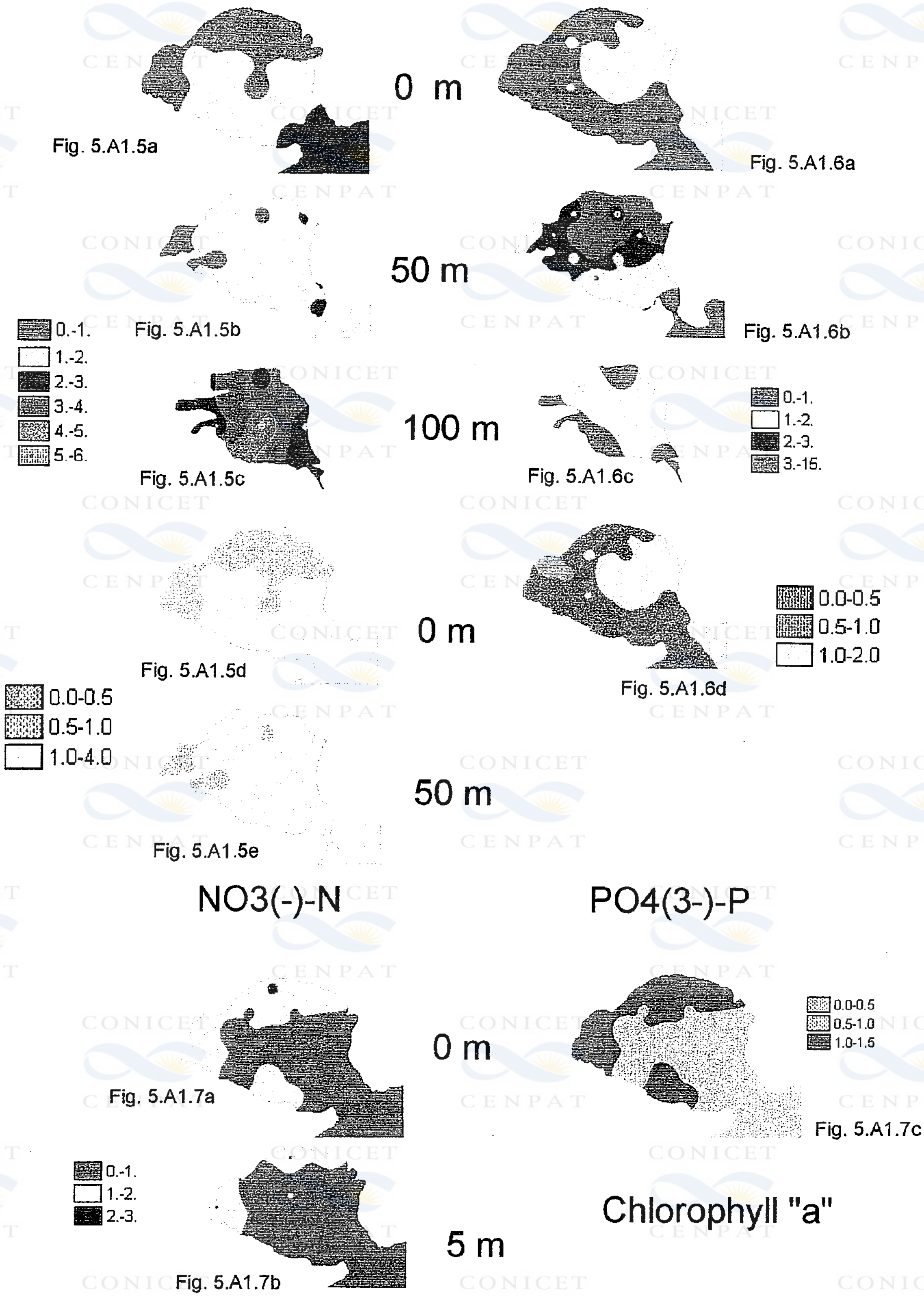
Tabla 5.1 - Codes of Fig. 5.A1.8b

Code	NO_3^--N (µg-at.l^{-1})	PO_4^{3-}-P (µg-at.l^{-1})	Chloroph. (mg.m^{-3})	Temp. (°C)	Salinity (‰)	Observations
113	<=1	<=1	<=3	16-17	33.8-34.0	
122	<=1	1-2	<=2	16-17	33.8-34.0	
222	1-2	<=2	<=2	16-17	33.6-34.0	33.6-33.8 (1)
321	2-3	<=2	<=1	15-17	33.6-33.8	16-17 (2)

(1) salinity in the boundary with area 321.
(2) predominant temperature.



Horizontal distributions - April '82



Horizontal distributions - April '82

5.1.2 - WINTER'82

5.1.2.1 - Physical variables

The analysis of the physical variables is based on Figs 5.1.a; 5.1.b and 5.1.c and horizontal distributions at 0, 50 and 100 m depth, of August '82 (Figs. 5.W.1a; 5.W.1b; 5.W.1c; 5.W.2a; 5.W.2b; 5.W.2c; 5.W.3a; 5.W.3b and 5.W.3c).

a) Vertical analysis

The mean values of temperature, salinity and density, at the surface, are not significantly different from the mean values at 50 m and 100 m depth ($p<0.05$). From these results and figures with horizontal distributions it is observed that the physical properties of the water column are constant above 100 m depth; it is not a stratified water column.

b) Horizontal analysis

In the horizontal distributions it is observed that:
-at the surface and 50 m depth, external waters are colder (range: 9-10°C) and less saline (33.6-33.8 ‰), than inside waters. No horizontal pattern is observed for density. It differs in less than 0.2 units;
-at 100 m depth, the above horizontal pattern is maintained. Colder and less saline waters are on the east of the basin, and density has no horizontal pattern;

5.1.2.2 - Chemical and biological variables

5.1.2.2.1 - *Vertical and horizontal analysis of dissolved oxygen*

The analysis of dissolved oxygen is based on Fig. 5.1.d and 5.1.e, and the horizontal distributions at 0, 50 and 100 m depth of August '82 (Figs. 5.W.4a; 5.W.4b; 5.W.4c).

The minimum oxygen concentration is 6 ml.l-1, in the whole system. The minimum percentage of saturation is 96 %. Mean dissolved oxygen and percentage of saturation, at the surface, are no significantly different from mean value at 50 m depth but significantly different from the 100 m ($p<0.05$). In the horizontal distributions, dissolved oxygen differs in less than 1 ml.l-1 and no pattern is observed.

The homogeneous vertical structure, observed through the physical variables, and now also represented in the homogeneous vertical and horizontal oxygen distributions, infers mixing process in the water column.

1.2.2.2 - *Vertical and horizontal analysis of nitrate*

The analysis of nitrate is carried out with Fig. 5.1.f, and horizontal distributions of nitrate at 0, 50 and 100 m depth of August '82 (Figs. 5.W.5a; 5.W.5b; 5.W.5c).

Nitrate concentration is around 5 µg-at.l^{-1} and almost constant from the surface to the bottom. Like temperature, salinity and density, the mean values at the surface are no significantly different from 50 m and 100 m depth ($p<0.05$).

In the horizontal analysis it is observed that:
-at the surface and the 50 m, nitrate is higher (range: 5- 7 µg-at NO_3^--N.l^{-1}) in the zone of the mouth and the oceanic waters;
-at 100 m depth, the pattern is mainly described by an area in the range of 4-5 µg-at NO_3^--N.l^{-1}.

Due to the homogeneous physical vertical properties along the water column, no barrier to the vertical diffusion is expected, hence the vertical distribution of nitrate results also homogeneous. On the other hand, concentration in the upper layers in general do not decrease, because, at middle latitudes, in this season, the day length and irradiation is lower, and as a consequence phytoplanktonic activity limited. At the surface and 50 m depth, the horizontal patterns suggest that oceanic waters input of nitrate, probable transported by advection. It is similarly to the observed in autumn '82. The influence of this input seems to be limited to the area close to the mouth.

In spite of describing the horizontal distribution, at the surface, as only one area, there are some places, close to the coast, where nitrate is lower. Three of these four points, have in common that they are shallower places (no deeper than 40 m). Probable, the lower level of nitrate, in this places, may be due to consumption by phytoplankton cells receiving enough light for photosynthesis, in the whole water column, although another possibility may be the consumption by benthic plants that deplete nutrients in still waters [Mann et al., 1996].

5.1.2.2.3 - *Vertical and horizontal analysis of phosphate*

The phosphate analysis is based on Fig. 5.1.g and the horizontal distributions of phosphate at 0, 50 and 100 m depth of August '82 (Figs. 5.W.6a; 5.W.6b and 5.W.6c).

Mean phosphate concentrations are below 2 µg-at PO_4^{3-}-P.l^{-1}. It increases from surface to bottom, but mean value at the surface is not significantly different from 50 m and 100 m depth ($p<0.05$). At the surface, 50 m and 100 m depth, the horizontal distribution of phosphate does not show a pattern.

The vertical pattern matches with the homogeneous vertical description given for nitrate and the physical properties. In contrast to nitrate, in the horizontal patterns of surface and 50 m depth, it seems that oceanic waters are not an input of phosphate to the Gulf.

5.1.2.2. 4 - *Vertical and horizontal analysis of chlorophyll "a"*

The chlorophyll "a" analysis is carried out with Fig. 5.1.h and the horizontal distributions of chlorophyll "a" at the surface and 5 m depth, of August '82 (Figs. 5.W.7a; 5.W.7b and 5.W.7c).

Mean values at the surface and 5 m depth, are no significantly different ($p<0.05$). Concentrations are not higher than 1.6 $mg.m^{-3}$. From the horizontal distributions, it is observed that in most of the Gulf, chlorophyll "a" is less than 1 $mg.m^{-3}$; a slight higher concentration it is observed in a patch on the south, close to the mouth.

Because it is suspected low phytoplanktonic activity, chlorophyll "a" may be in low levels, in this season. The patch of higher chlorophyll "a", at the surface, is not associated to lower nutrients, probably, because it is close to the mouth, where, the horizontal patterns suggest a replenishment of nitrate by the oceanic waters. On the other side, there are no patches of higher chlorophyll "a" associated to the patches in the coastal areas, where the lower nitrate was observed, hence it is not possible to prove or reject this hypothesis given to explain the lower nitrate concentration, over this patches. It would have to be investigated if there is information about growth of bentic plants on these areas, to test the second hypothesis proposed.

5.1.2.3 - *Horizontal distribution by combination of the physical, chemical and biological variables*

In winter'82, it was performed a combination of maps, similarly to autumn'82. As a result, the following map (Fig. 5.W.8a) was obtained (see Codes in Table C3 - Annex C):

Fig. 5.W.8a - Horizontal distributions of temperature, salinity, nitrate, phosphate and chlorophyll "a" - Winter'82

From this procedure, eight zones can be identified, but in order to allow for easier identification of zones with the same chemical and biological properties, the following areas were defined, by selecting the chemical and biological properties:

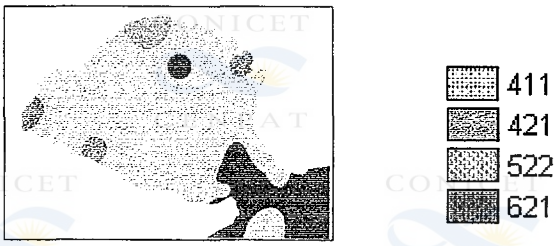
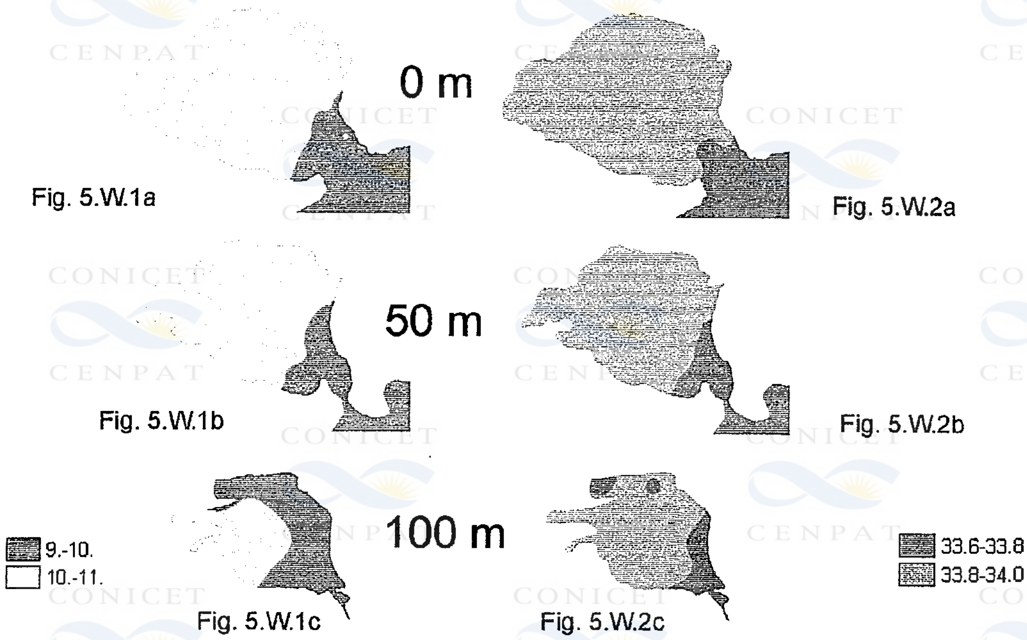


Fig. 5.W.8b - Horizontal distributions of nitrate, phosphate and chlorophyll "a" - Winter '82

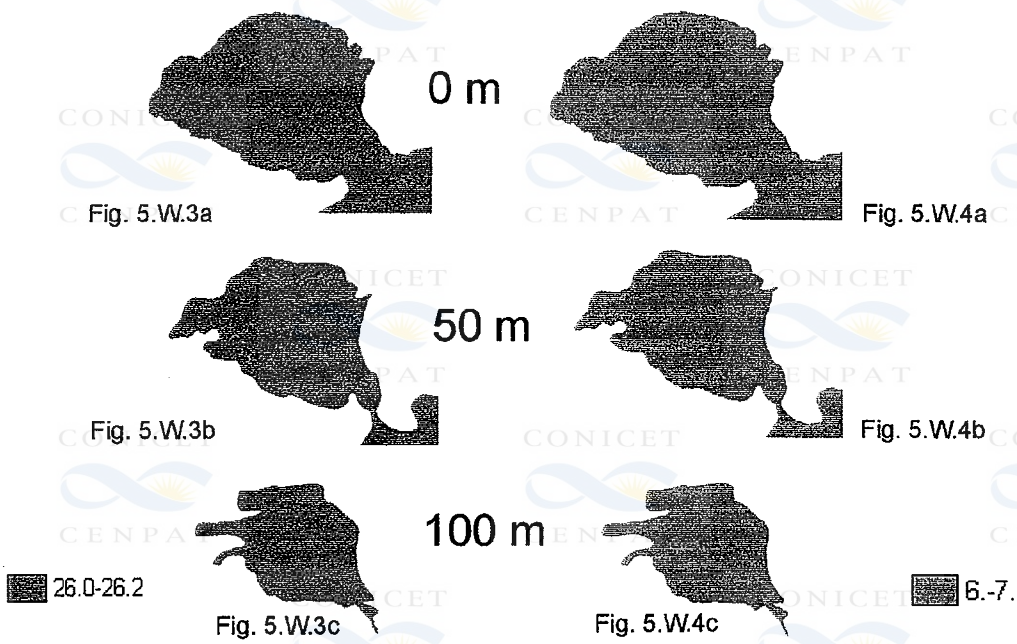
Tabla 5.2 - Codes of Fig. 5.W.8b

Code	NO_3^--N (µg-at.l^{-1})	PO_4^{3-}-P (µg-at.l^{-1})	Chloroph. (mg.m^{-3})	Temp. (°C)	Salinity (‰)	Observations
411	3-4	<=1	<=1	10-11	33.8-34.0	
421	3-4	1-2	<=1	10-11	33.8-34.0	
522	4-5	<=2	<=2	9-11	33.6-34.0	10-11 and 33.8-34.0 (1)
621	5-6	<=2	<=1	9-10	33.6-34.0	33.6-33.8 (2)

(1) predominant temperature and salinity.
(2) predominant salinity.



Temperature Salinity



Density (SigmaT) Dissolved oxygen

Horizontal distributions - August '82

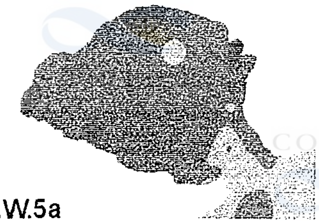
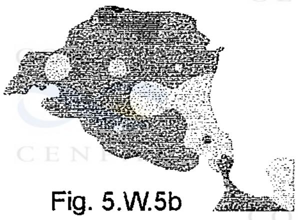


Fig. 5.W.5a

0 m

Fig. 5.W.6a



50 m

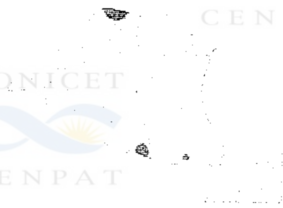
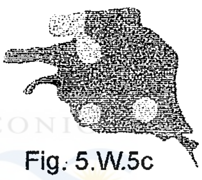


Fig. 5.W.6b

2.-3.
3.-4.
4.-5.
5.-6.
6.-7.
7.-8.

Fig. 5.W.5b



100 m

0.-1.
1.-2.
2.-3.
3.-6

Fig. 5.W.5c

Fig. 5.W.6c

NO3(-)-N

PO4(3-)-P

Fig. 5.W.7a

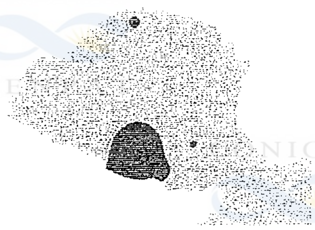


Fig. 5.W.7c

0.-1.
1.-2.

Fig. 5.W.7b

0.0-0.5
0.5-1.0
1.0-1.5

Chlorophyll "a"

Horizontal distributions - August '82

5.1.3 SPRING '82

5.1.3.1 - Physical variables

The analysis of the physical properties is based on Figs. 5.1.a, Fig.5.1.b, 5.1.c and the horizontal distributions of 0, 50 and 95 m depth of November'82 (Figs. 5.Sp.1a; 5.Sp.1b; 5.Sp.1c; 5.Sp.2a; 5.Sp.2b; 5.Sp.2c; 5.Sp.3a; 5.Sp.3b and 5.Sp.3c).

a) Vertical analysis

Mean values of temperature and density, at the surface, are significantly different from 50 m and 95 m depth ($p<0.05$). Opposite to these variables, mean salinity, at the surface, is no significantly different from 50 and 95 m depth ($p<0.05$). From this results and the figures with the horizontal distributions, it can be inferred that there is a change in the physical properties, due to temperature, between surface and 50 m depth; colder and more dense waters result towards the bottom. The change is expected to be slight, because from surface to bottom, temperature decreases less than 1.5 °C. As a result, the water column has a slight stratification.

b) Horizontal analysis

In the horizontal analysis is observed that:
-at the surface, salinity differs in less than 0.2 ‰ and no horizontal pattern is described; colder waters (10-11 °C) are in the oceanic area, in the southern side of the mouth. Temperature increases towards inside the Gulf, where in the north, reaches 12-13 °C. No pattern for density can be observed, it differs in less than 0.2 units;
- at the 50 m, the pattern is defined by colder waters on the eastern side of the basin; salinity does not show a pattern and density is lower (between 25.6-25.8) in the external waters;
- at 95 m, no pattern, in the horizontal distribution of the physical variables, is described.

According to the surface horizontal pattern of temperature, external waters seem to flow inside the Gulf by the southern side of the entrance, and the waters from the Gulf, to flow out by the northern side. This pattern has been also described by Barros et al. [1978] in summer and autumn.

From the vertical analysis it was inferred that the physical properties change between surface and 50 m depth, due to temperature. From the horizontal distribution, now it is observed, that on the east side, a stratification is expected above 50 m depth. The pattern at the 50 m, seems to be due to an input of colder oceanic waters.

5.1.3.2 - Chemical and biological properties

5.1.3.2.1 - *Vertical and horizontal analysis of dissolved oxygen*

The analysis of dissolved oxygen is based on Fig. 5.1.d and 5.1.e and horizontal distributions of dissolved oxygen at 0, 50 and 95 m depth of November '82 (Figs. 5.Sp.4a; 5.Sp.4b; 5.Sp.4c).

The minimum level of oxygen is 5.3 ml.l-1, in the whole water body, and the percentage of saturation is no lower than 85 %. Mean oxygen concentration, at the surface, is no significantly different from 50 m and significantly different from 100 m depth ($p<0.05$). In the horizontal distributions, no patterns are observed.

5.1.3.2.2 - *Vertical and horizontal analysis of nitrate*

The analysis of nitrate is carried out with Fig. 5.1.f and horizontal distributions of nitrate at 0, 50 and 95 m depth of November '82 (Figs. 5.Sp.5a; 5.Sp.5b; 5.Sp.5c; 5.Sp.5d; 5.Sp.5e).

At the surface and 50 m, mean concentration of nitrate is below 0.5 µg-at NO_3^--N.l^{-1} and the mean values are not significantly different ($p<0.05$). At 95 m depth, mean value is about 1.3 µg-at NO_3^--N.l^{-1}, being significantly different ($p<0.05$) from the mean value at the surface.

In the horizontal distribution is observed that:
-at the surface, outside of the Gulf, on the southern side of the mouth, nitrate concentrations are higher than 0.5 µg-at NO_3^--N.l^{-1} and up to 4 µg-at NO_3^--N.l^{-1}, inside the Gulf and in the northern side of the mouth, nitrate is almost depleted;
-at the 50 m, nitrate is higher on the eastern side of the basin. Concentrations in this area are similar to those found in the southern side of the entrance, at the surface (0.5-4 µg-at NO_3^--N.l^{-1});
-at 100 m depth, the higher concentrations (2-5 µg-at NO_3^--N.l^{-1}) are found in the central area, over the deepest zone of the Gulf.

The vertical pattern of nitrate, like in autumn'82, shows lower nitrate at the upper layers, but in this season, nitrate is almost depleted, mainly at the surface. In spring, at middle latitudes, the day length and irradiation start to increase and thus, phytoplanktonic activity. As a result, a higher consumption of nutrients is expected. On the other hand, the change in the physical properties, although slight, may reduce the nitrate vertical diffusion and limit the replenishment of nitrate from bottom.

The horizontal surface pattern, similarly to the previous seasons, suggests an input of nitrate by horizontal advection, due to the colder oceanic waters, coming, in this season, by the southern side of the mouth. Nevertheless, these waters, opposite to the other seasons, are also poor in nitrate. On the eastern side of the basin, a stratification above 50 m depth and influence of the oceanic waters was observed through the temperature horizontal pattern. Now, it is also observed that this pattern matches with the nitrate distribution. Due to the stratification, it is probable that phytoplankton cells mainly trapped above the 50 m, in the mixed layer (see Chapter 2), do not consume the nitrate of the oceanic waters that flow below the stratification.

5.1.3.2.3 - *Vertical and horizontal analysis of phosphate*

The analysis of phosphate is based on Fig. 5.1.g and the horizontal distributions of phosphate at 0, 50 and 95 m depth of November '82 (Figs. 5.Sp.6a; 5.Sp.6b; 5.Sp.6c; 5.Sp.6d; 5.Sp.6e and 5.Sp.6f).

Mean values of phosphate are below 1.6 µg-at PO_4^{3-}-P.l^{-1}. They decrease from the surface to the bottom, but mean value at the surface is not significantly different from mean values at 50 m and 100 m depth ($p<0.05$).

From the horizontal distribution figures, it can be observed that:
-at the surface and 50 m depth, no horizontal pattern is observed.
-at the 100 m depth, concentrations above 1 µg-at PO_4^{3-}-P.l^{-1} (up to 3 µg-at PO_4^{3-}-P.l^{-1}) are only found at the east of the basin.

Different from nitrate, the vertical distribution of phosphate is homogeneous and in spite of being at low levels, it is not so depleted as nitrate is. It may be a consequence of the easy remineralization in the water column, previously mentioned, and because, generally, phosphate is not a limiting nutrient in marine environments (see Chapter 2).

5.1.3.2.4 - *Vertical and horizontal analysis of chlorophyll "a"*

The analysis is carried out with Fig. 5.1.h and the horizontal distributions of chlorophyll "a" at 0 and 5 m depth (Figs. 5.Sp.7a; 5.Sp.7b and 5.Sp.7c).

Mean chlorophyll "a", at the surface, is no significantly different from 5 m depth ($p<0.05$). The highest concentration is 1.9 mg.m^{-3}. From the horizontal distributions it can be observed that most of the area is below 1 mg.m^{-3}. Concentrations above 1 mg.m^{-3}, although no higher than 2 mg.m^{-3}, are only found in patches.

Due to the low nitrate and phosphate concentrations in comparison with winter values (see paragraph 5.2.2.3) and the increase of day length and irradiation in spring time, at middle latitudes, a higher phytoplanktonic activity is expected. Nevertheless chlorophyll "a" concentration is close to the levels of the previous seasons.

Seawifs remote sensing images of chlorophyll "a", in spring '97, were downloaded from

Internet (see Chapter 4 and Annex F). In these images it was observed chlorophyll "a" in the range between 0.5 and 2 mg.m^{-3} (Fig. F.1; F.2; F.3; F.4; F.5), in September. At the beginning of October (Fig. F.6 - Annex F), the values reached up to 3 - 3.5 mg.m^{-3}, which may be due to the spring bloom.

5.1.3.3 - <u>Horizontal distribution by combination of the physical, chemical and biological variables</u>

Like in autumn'82 and winter'82, a combination of the physical, chemical and biological variables was carried out. The results are presented in Fig. 5.Sp.8a (see Codes in Table C.3 - Annex C).

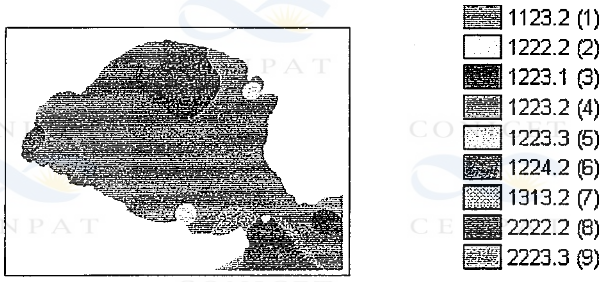


Fig. 5.Sp.8a - Horizontal distributions of temperature, salinity, nitrate, phosphate and chlorophyll "a" - Spring '82

From this procedure, nine zones were identified, but in order to allow for easier identification of zones with the same chemical and biological properties, the following areas were defined, by selecting the chemical and biological properties (Fig. 5.Sp.8b):

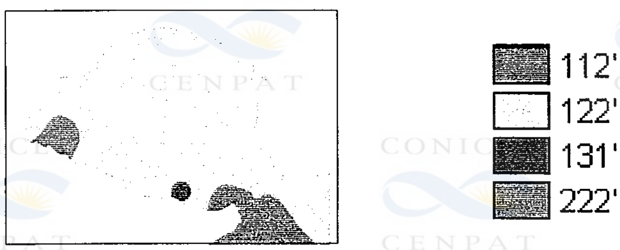


Fig. 5.Sp.8b - Horizontal distribution of nitrate, phosphate and chlorophyll "a" - Spring '82

Table 5.3 - Codes of Fig. 5.Sp.8b

Code	NO_3^--N (µg-at.l^{-1})	PO_4^{3-}-P (µg-at.l^{-1})	Chloroph. (mg.m^{-3})	Temp. (°C)	Salinity (‰)	Observations
112'	<=0.5	<=0.5	<=2	11-12	33.6-33.8	
122'	<=0.5	0.5-1	<=2	10-13	33.4-34.0	11-12 and 33.6-33.8 (1)
131'	<=0.5	1-2	<=1	11-12	33.6-33.8	
222'	0.5-1	0.5-1	<=2	10-12	33.6-34.0	10-11 and 33.6-33.8 (2)

(1) and (2): predominant temperatures and salinities.

Fig. 5.Sp.1a

0 m

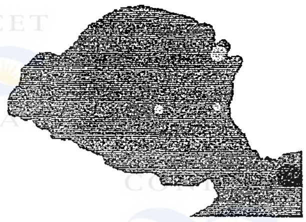


Fig. 5.Sp.2a

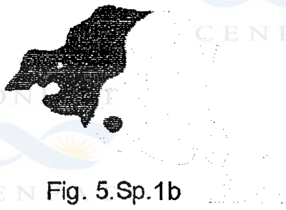


Fig. 5.Sp.1b

50 m

Fig. 5.Sp.2b

10.-11.
11.-12.
12.-13.
13.-14.

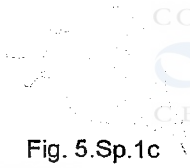


Fig. 5.Sp.1c

95 m

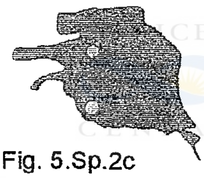


Fig. 5.Sp.2c

33.4-33.6
33.6-33.8
33.8-34.0

Temperature

Salinity

Fig. 5.Sp.3a

0 m

Fig. 5.Sp.4a

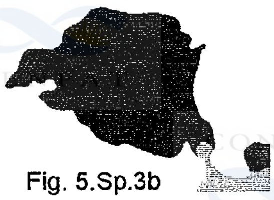


Fig. 5.Sp.3b

50 m

Fig. 5.Sp.4b

25.4-25.6
25.6-25.8
25.8-26.0

Fig. 5.Sp.3c

95 m

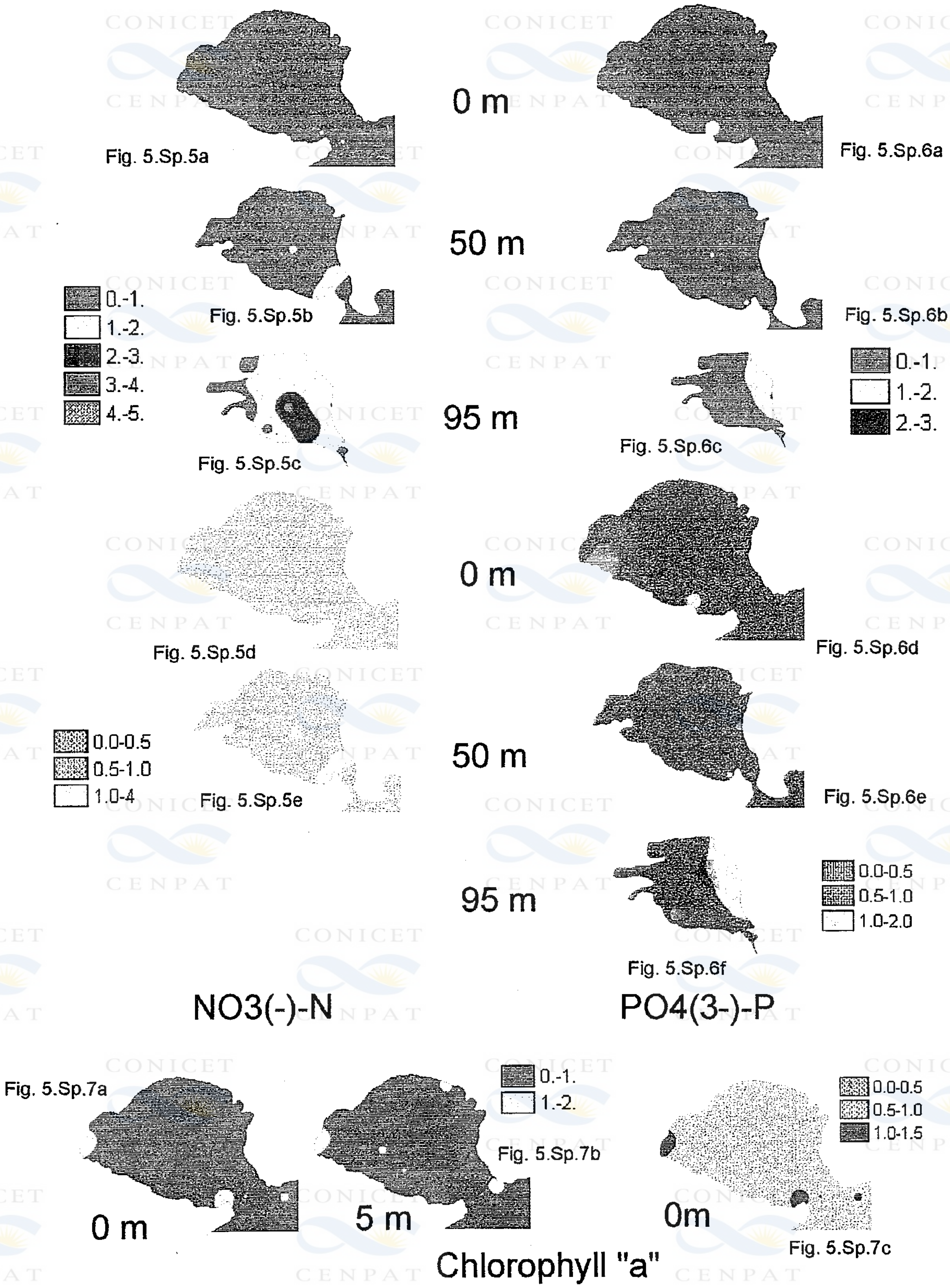
Fig. 5.Sp.4c

5.-6.
6.-7.

Density (Sigma T)

Dissolved oxygen

Horizontal distributions - November '82



Horizontal distributions - November '82

5.1.4 SUMMER '83

5.1.4.1 - Physical variables

The analysis of the physical properties is based on Figs. 5.1.a, 5.1.b and 5.1.c; the horizontal distributions at 0, 50 and 100 m depth of January '83 and the maps with temperature differences between horizontal distributions at the surface and 10, 20, 30 and 50 m depths, respectively (Figs. 5.Sm.1a; 5.Sm.1b; 5.Sm.1c; 5.Sm.1d; 5.Sm.1e; 5.Sm.1f; 5.Sm.1g; 5.Sm.2a; 5.Sm.2b; 5.Sm.2c; 5.Sm.3a; 5.Sm.3b and 5.Sm.3c).

a) Vertical analysis

Mean values of temperature and salinity are higher at the surface and coincident with the lowest density. Temperature and density mean values are significantly different from 50 and 100 m depth ($p<0.05$). Mean salinity at the surface, is significantly different from the 50 m and not significantly different from 100 m depth ($p<0.05$). From these results and the figures with the horizontal distributions, it is observed that physical properties strongly change along the water column. The change starts between the surface and the 50 m depth. When compared with the other seasons, it is more markedly, e.g. mean temperature differs in 5 °C, from the surface to the bottom, thus, water column has a stratified pattern.

In this season, the maps with the horizontal temperature distributions at 10, 20 and 50 m depth were subtracted one by one, from the map with the distribution of temperature at the surface. From the new maps, obtained after the procedure of substraction, it was observed that:
-the thermal stratification occurs below 10 m depth;
-the stratification, and thus the depth of the mixed layer, is shallower on the northern side than on the southern sector of the Gulf.

b) Horizontal analysis

From the horizontal analysis of the physical variables it can be observed that:
-at the surface, temperature is between 15 and 14 °C, at the southern side of the mouth, and increases towards inside the Gulf, reaching 19.5 °C, at the northern half; salinity is higher on the warmer area (33.8-34.0 ‰) and density shows a gradient that follows the temperature pattern. The oceanic waters are more dense (24.8-25.2); the less dense waters are at the warmer and more saline area, at the northern half of the Gulf;
-at 50 m, the main temperature range is between 14 and 15 °C, and there is a colder nucleus over the deepest area of the basin; salinity between 33.4-33.6 ‰ is observed outside of the Gulf; density follows the temperature pattern, with higher density on the colder central nucleus;
-at 100 m depth, the horizontal pattern of temperature is similar to that described at 50 m, but the main range is now between 12 and 13 °C; the higher salinity (33.8-34.0 ‰) is observed on the east zone; density between 25.6 and 25.8 is observed in the central area of the basin.

For summer'86, the results of one temperature (pre-processed) Landsat TM remote sensing image (19/02/86) (see Chapter 4 and Annex E) showed a pattern similar to that observed in summer'83. Blue colour, that means colder waters, is observed in the southern coast and oceanic waters, meanwhile the red colour, or warmer waters are in the centre and northern sector.

Similar to the observed in Spring'82, the horizontal pattern, at the surface, suggests that colder, more dense and less saline oceanic waters seem to flow inside to the Gulf by the southern side of the mouth, and waters from the Gulf, to flow out by the northern side.

Mann et al. [1996] described, that due to the net gain of energy from the sun, in this season, and in presence of low wind, a thinner mixed layer is produced and temperature of water, increases. In the horizontal distribution of temperature, a warmer area was described on the northern half of the Gulf. It is expected that sea surface receives the same irradiance in the whole Gulf, hence, the warming may be produced in this sector, probably because waters are more calm and the mixed layer is not deepened by the effect of by wind or currents.

The warmer area at the surface also matches with the more saline waters. If the warmer area may be explained by the low movement of the waters, an explanation to the higher salinity may be based on higher evaporation rates on this area.

The oceanic waters are more dense than the inside waters. The lighter waters are found on the more saline and warmer area, thus, temperature over salinity changes, regulates the density (see Chapter 2). Density results agree with those given by Barros et al. [1978]. This author states that, in summer, the Gulf is a dilution basin with lower density inside than outside of the Gulf (see Chapter 3).

5.1.4.2 - Chemical and biological variables

5.1.4.2.1 - *Vertical and horizontal analysis of dissolved oxygen*

The analysis of dissolved oxygen is based on Fig. 5.1.d and 5.1.e, and the horizontal distributions of dissolved oxygen at 0, 50 and 100 m depth, of January '83 (Figs. 5.Sm.4a; 5.Sm.4b; 5.Sm.4c).

The minimum level of oxygen is 5 ml.l-1, in the whole water body. The percentage of saturation is higher than 70 %. Mean dissolved oxygen at the surface is no significantly different from 50 m but significantly different from 100 m depth ($p<0.05$). In the horizontal distributions, no patterns are observed. In the three layers, a patch of lower oxygen concentration, coincides over the deepest area of the Gulf.

5.1.4.2.2 - *Vertical and horizontal analysis of nitrate*

The analysis of nitrate is carried out with Fig. 5.1.f and horizontal distributions of nitrate at 0, 50 and 100 m depth, of January '83 (Figs. 5.Sm.5a; 5.Sm.5b; 5.Sm.5c; 5.Sm.5d and 5.Sm.5e).

Like temperature and density, mean values of nitrate at the surface are significantly different from 50 m and 100 m depth ($p<0.05$). At the surface and 50 m depth, the mean values are below 1 µg-at NO_3^--N.l^{-1}, and at the 100 m, it is around 2.5 µg-at NO_3^--N.l^{-1}.

From the horizontal distributions, it can be observed that:
-at the surface, the nitrate pattern is similar to that observed in spring'82. The oceanic waters, on the southern side of the entrance, are above 0.5 µg-at NO_3^--N.l^{-1} (up to 4 µg-at NO_3^--N.l^{-1}); in the rest of the Gulf, nitrate is almost depleted;
-at 50 m, some patches above 1 µg-at NO_3^--N.l^{-1} (between 1-2 µg-at NO_3^--N.l^{-1}) have appeared inside the Gulf, but the dominant range is between 0.5 and 1.0 µg-at NO_3^--N.l^{-1};
-at 100 m depth, the range is between 1-5 µg-at NO_3^--N.l^{-1}. There is a gradient that increases from NW to SE.

The vertical nitrate pattern, like in autumn'82 and spring'82 is given by lower concentrations, at the surface and 50 m depth. In this season, irradiation is high, and directly related to the photosynthetic activity. Nevertheless it may be probably limited due to the scarcity of nutrients, mainly of nitrate (and other factors like grazing, see Chapter 2). In spring'82, nitrate was almost depleted and the replenishment by vertical diffusion, from the bottom was expected low, but now, it is supposed, more limited, because of the stratification. Like in spring'82, the colder and higher nitrate waters seem to flow inside the Gulf, by the southern side of the mouth, and to recharge with nitrate the layers below the stratification, at the 50 m.

5.1.4.2.3 - *Vertical and horizontal analysis of phosphate*

The phosphate analysis is based on Fig. 5.1.g and the horizontal distributions at 0, 50 and 100 m depth of January '83 (Figs. 5.Sm.6a; 5.Sm.6b; 5.Sm.6c; 5.Sm.6d; 5.Sm.6e and 5.Sm.6f).

Phosphate mean values, from the surface to bottom, remain almost constant and lower than 1 µg-at PO_4^{3-}-P.l^{-1}. Mean value at the surface, is not significantly different from 50 m and 100 m depth ($p<0.05$).

From the horizontal distributions, it can be observed that:
-at the surface, phosphate is between 0.5 and 1 µg-at PO_4^{3-}-P.l^{-1}, in most of the Gulf, but on the west and northwestern area, it is below 0 0.5 µg-at PO_4^{3-}-P.l^{-1};
-at the 50 m, no pattern is observed, and the main range of concentrations is between 0.5 and 1.0 µg-at PO_4^{3-}-P.l^{-1};

-at 100 m depth, the higher concentrations, between 1 and 2 µg-at PO_4^{3-}-P.l^{-1}, are on the east side of the basin.

Similarly to the previous seasons, the vertical distribution of phosphate is more homogeneous than that of nitrate. From the horizontal distribution, at the surface, it can be observed that in west and northwestern area, not only nitrate, but also phosphate is almost depleted.

5.1.4.2.4 - *Vertical and horizontal analysis of chlorophyll "a"*

The analysis is carried out with Fig. 5.1.h and the horizontal distributions of chlorophyll "a" at 0 and 5 m depth (Figs. 5.Sm.7a; 5.Sp.7m and 5.Sm.7c).

Mean values at the surface are not significantly different from 5 m depth ($p<0.05$). In most of the Gulf, concentrations are lower than 0.5 $mg.m^{-3}$; values between 1 and 2 $mg.m^{-3}$ are only found in patches.

5.1.4.3 - Horizontal distribution by combination of the physical, chemical and biological variables

Similarly to the previous seasons, a combination of maps was carried out in summer '83. As a result, the following map (Fig. 5.Sm.8a) was obtained:

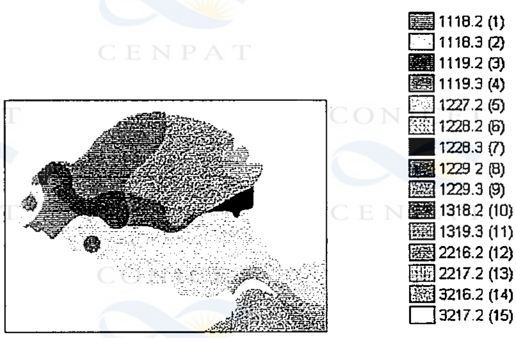


Fig. 5.Sm.8a - Horizontal distributions of temperature, salinity, nitrate, phosphate and chlorophyll "a" - Summer '83

From this procedure, fifteen zones were identified, but grouping the zones with the same chemical and biological properties, the following areas were defined:

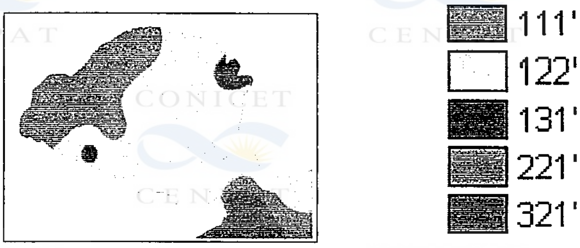
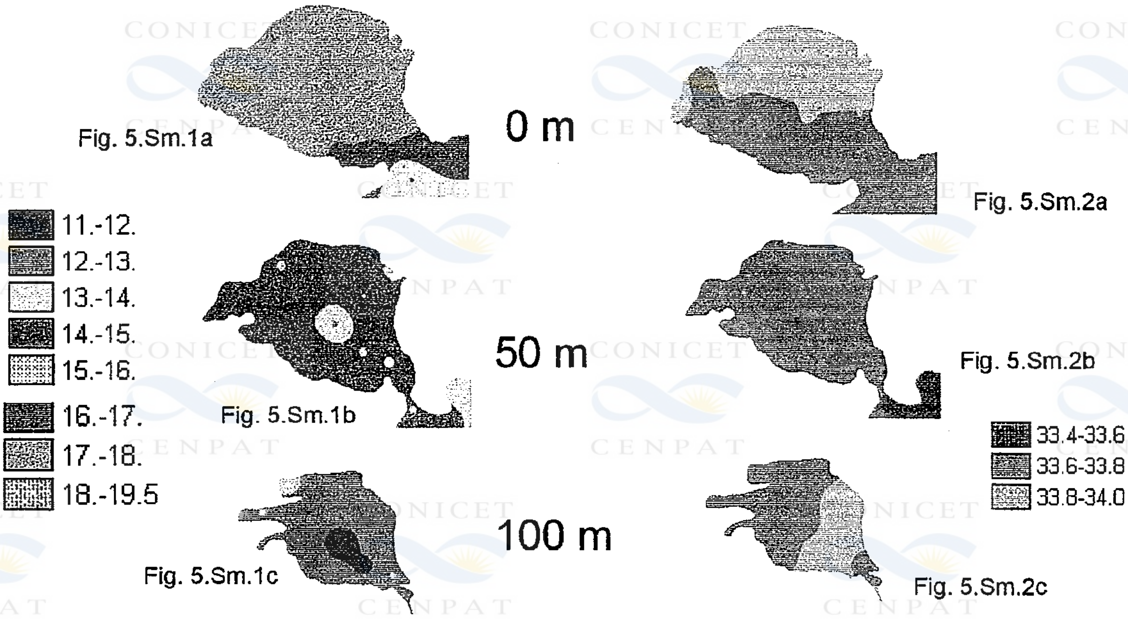


Fig. 5.Sm.8b - Horizontal distributions of nitrate, phosphate and chlorophyll "a" - Summer '83

Table 5.4 - Codes of Fig. 5.Sm.8b

Code	NO_3^--N (µg-at.l^{-1})	PO_4^{3-}-P (µg-at.l^{-1})	Chloroph. (mg.m^{-3})	Temp. (°C)	Salinity (‰)	Observations
111'	<=0.5	<=0.5	<=1	17-19.5	33.6-34.0	18-19.5 and 33.8-34.0 (1)
122'	<=0.5	0.5-1	<=2	16-19.5	33.6-34.0	17-18 and 33.6-33.8 (1)
131'	<=0.5	1-2	<=1	17-19.5	33.6-34.0	17-18 and 33.8-34.0 (1)
221'	0.5-1	0.5-1	<=1	15-17	33.6-33.8	16-17 (2)
321'	1-4	0.5-1	<=1	15-17	33.6-33.8	15-16 (2)

(1) Predominant temperature and salinity.
(2) Predominant temperature.



Temperature

Salinity

Fig. 5.Sm.1d

Temperature differences
(surface - 10 m)

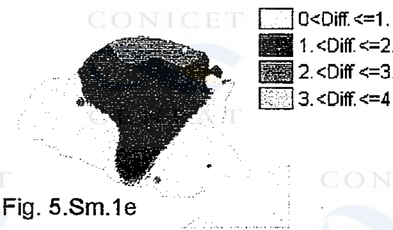


Fig. 5.Sm.1e

Temperature differences
(surface - 20 m)

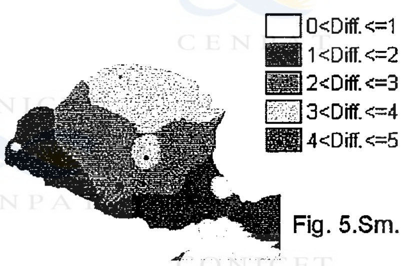


Fig. 5.Sm.1f

Temperature differences
(surface - 30 m)

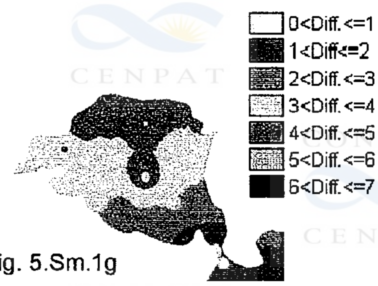
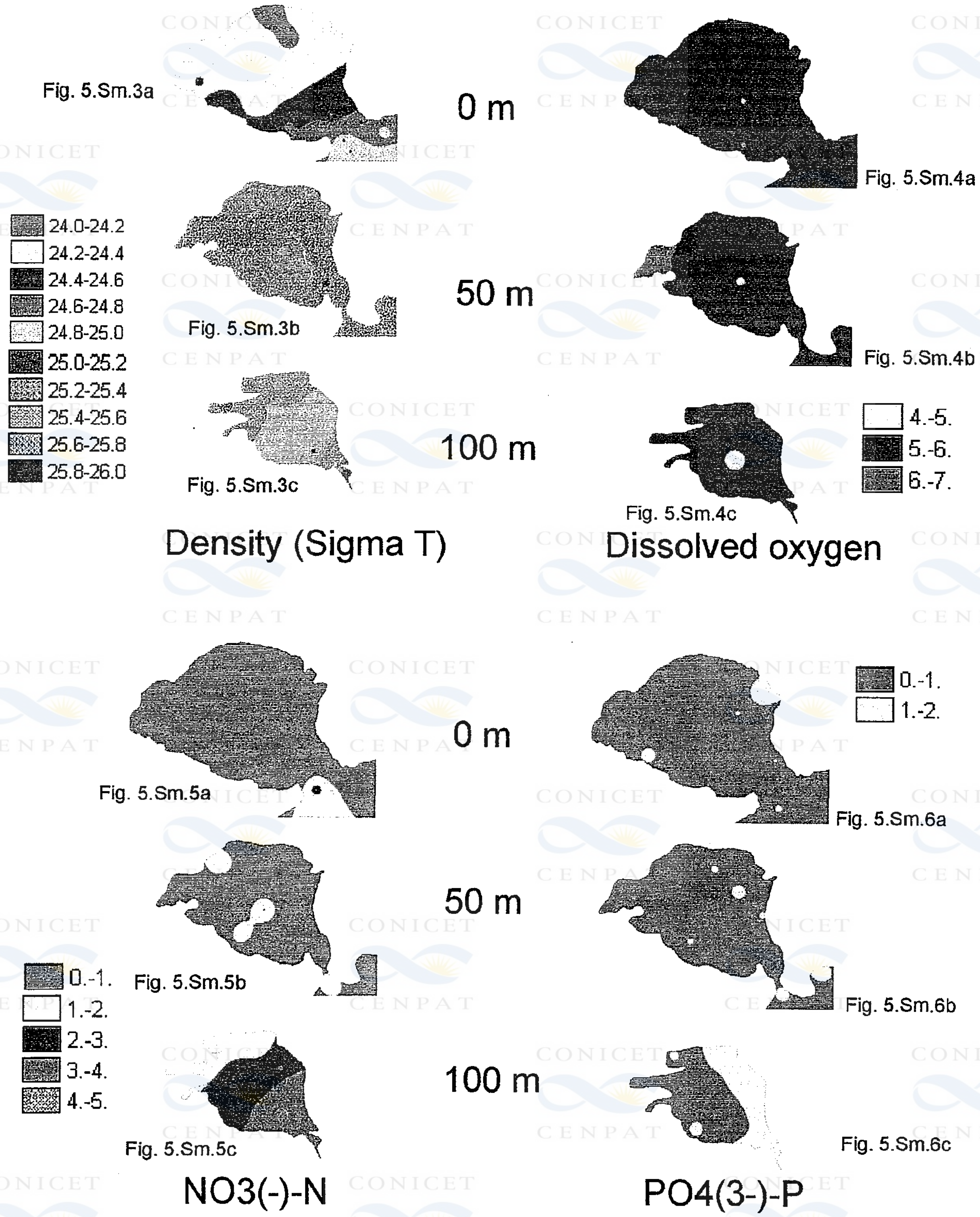


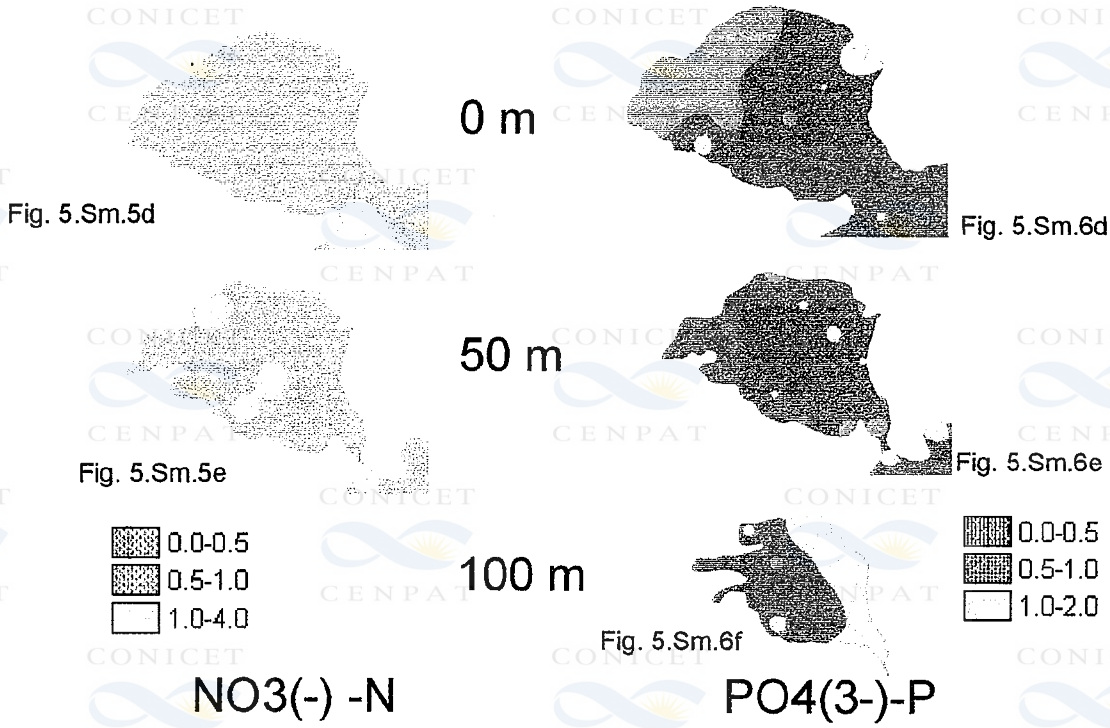
Fig. 5.Sm.1g

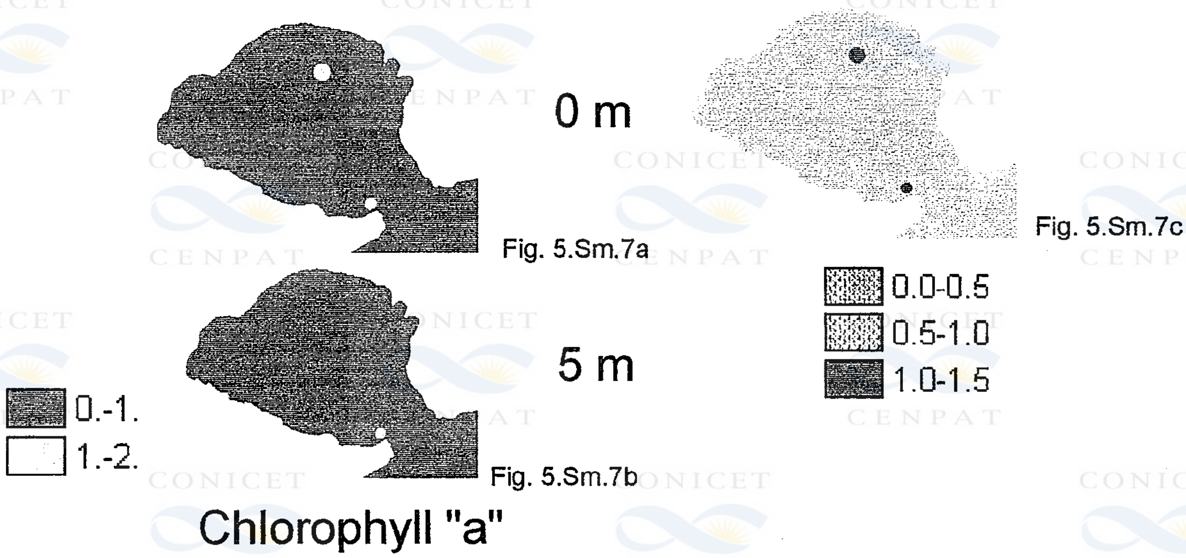
Temperature differences
(surface - 50 m)

Horizontal distributions - January '83



Horizontal distributions - January '83





Horizontal distributions - January '83

5.1.5 - AUTUMN '83

5.1.5.1 - Physical variables

The analysis of the physical variables is based on Figs. 5.1.a; 5.1.b; 5.1.c and the horizontal distributions at 0, 50 and 100 m of April'83 (Figs. 5.A2.1a; 5.A2.1b; 5.A2.1c; 5.A2.2a; 5.A2.2b; 5.A2.2c; 5.A2.3a; 5.A2.3b and 5.A2.3c).

a) Vertical analysis

Mean values of temperature and density, at the surface, are significantly different from mean values at 50 m and 100 m depth ($p<0.05$), but mean salinity at the surface is no significantly different from means at 50 m and 100 m depth ($p<0.05$). From the above results and the figures of horizontal distributions, it can be inferred that there are changes in the physical properties of the water column, between surface and 50 m depth. The change is ruled by temperature, nevertheless, it is slight, e.g.mean temperature from surface to bottom differs about 1.2 °C, hence the water column results slight or close to a non stratified pattern.

b) Horizontal analysis

In horizontal distribution of these variables is observed that:
-at the surface, the colder temperatures (15-16 °C) are on the southern side of the mouth and the oceanic waters; for salinity and density no horizontal patterns are observed. Salinity differs in less than 0.2 ‰, and density, in less than 0.2 units;
-at 50 m depth, temperature and salinity do not describe patterns and density is lower (24.6-24.8) outside of the Gulf;
-at 100 m depth, the temperature range between 14 and 15 °C, is extended in most of the basin; salinity does no describe a pattern; density follows the temperature pattern, colder waters coincide with heavier waters.

5.1.5.2 - Chemical and biological variables

5.1.5.2.1 - *Vertical and horizontal analysis of dissolved oxygen*

The analysis of dissolved oxygen is based on Fig. 5.1.d and 5.1.e, and the horizontal distributions of oxygen at 0, 50 and 100 m depth, of April '83 (Figs. 5.A2.4a; 5.A2.4b; 5.A2.4c).

The minimum oxygen concentration is about 4 $ml.l^{-1}$, in the whole water body. Mean dissolved oxygen levels are above 4.8 $ml.l^{-1}$ and the mean percentage of saturation above 80 %. For both variables, mean value at the surface is significantly different from mean values at 50 m and 100 m depth ($p<0.05$). As it is expected because of the diffusion from atmosphere and also probably by photosynthetic production, the higher concentrations are found in the upper layers. From the horizontal distributions, it can be observed that no pattern may be described in the three layers.

5.1.5.2.2 - *Vertical and horizontal analysis of nitrate*

The analysis of nitrate is carried out by Fig. 5.1.f and the horizontal distributions of nitrate at 0, 50 and 100 m depth of April '83 (Figs. 5.A2.5a; 5.A2.5b; 5.A2.5c and 5.A2.5d).

Nitrate mean value, at the surface, is significantly different from mean values at 50 m and 100 m depth ($p<0.05$). Concentrations are lower in the upper layers. Mean value decrease 3 µg-at NO_3^--N.l^{-1} from surface to bottom.

In the horizontal analysis is observed that:
-at the surface, concentrations below 0.5 µg-at NO_3^--N.l^{-1} are found in most of the Gulf, but are higher than this level (up to 2 µg-at NO_3^--N.l^{-1}) on the southern coast, the mouth and the oceanic waters;
-at 50 m depth, no pattern can be described, the main range is between 1 and 2 µg-at NO_3^--N.l^{-1};
-at 100 m depth, the main range is between 3 and 4 µg-at NO_3^--N.l^{-1}. As it was observed in other seasons, there is a patch with higher nitrate over the deepest area of the basin.

The vertical pattern, similarly to other seasons, shows lower nitrate in the upper layers. Consumption by phytoplankton and low replenishment by vertical diffusion may explain this vertical pattern. The low vertical diffusion may be due to the slight change in the vertical properties of the water column. Like in the other seasons, the horizontal distributions seem to indicate that oceanic waters input nitrate to the Gulf, by horizontal advection.

5.1.5.2.3 - *Vertical and horizontal analysis of phosphate*

The phosphate analysis is carried out by Fig. 5.1.g and the horizontal distributions of phosphate at 0, 50 and 100 m depth of April '83 (Figs. 5.A2.6a; 5.A2.6b; 5.A2.6c and 5.A2.6d).

Phosphate mean concentrations, in the water column, are lower than 1.6 µg-at PO_4^{3-}-P.l^{-1}. The mean value at the surface is not significantly different from mean values at 50 m and 100 m depth ($p<0.05$).

In the horizontal distributions is observed that:
-at the surface, the higher concentrations, between 1 and 3 µg-at PO_4^{3-}-P.l^{-1}, are on the eastern half of the Gulf and the oceanic waters;
-at 50 m; an area below 1 µg-at PO_4^{3-}-P.l^{-1} is on the north eastern corner, but the main range is between 1 and 2 µg-at PO_4^{3-}-P.l^{-1};
-at 100 m depth, the range is mainly between 1 and 2 µg-at PO_4^{3-}-P.l^{-1}, and no pattern is described.

Similarly to nitrate, phosphate is lower at the surface, nevertheless, the concentration in the vertical distribution is more homogeneous than the pattern for nitrate.

5.1.5.2.4 - *Vertical and horizontal analysis of chlorophyll "a"*

The analysis is carried out with Fig. 5.1.h and the horizontal distributions of chlorophyll "a" at 0 and 5 m depth (Figs. 5.A2.7a; 5.A2.7b and 5.A2.7c).

Mean values at the surface are not significantly different from mean values at 5 m depth ($p<0.05$). Most of the Gulf is below 1 mg.m^{-3} and above these concentrations only patches are found.

5.1.5.3 - Horizontal distribution by combination of the physical, chemical and biological variables

Similarly to the previous seasons, a combination of maps was carried out in autumn '83. As a result, the following map (Fig. 5.A2.8a) was obtained (see Codes in Table C.3 - Annex C):

Fig. 5.A2.8a - Horizontal distribution of temperature, salinity, nitrate, phosphate and chlorophyll "a" - Autumn '83

From this procedure, five zones were identified. By grouping the zones with the same chemical and biological properties, the following areas were defined:

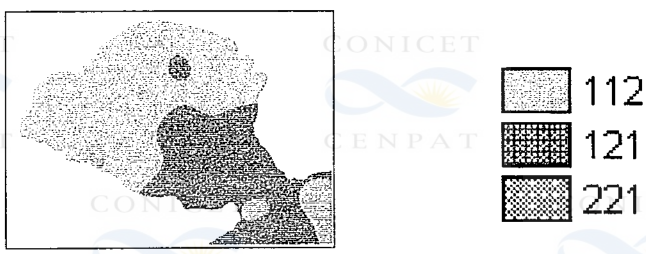
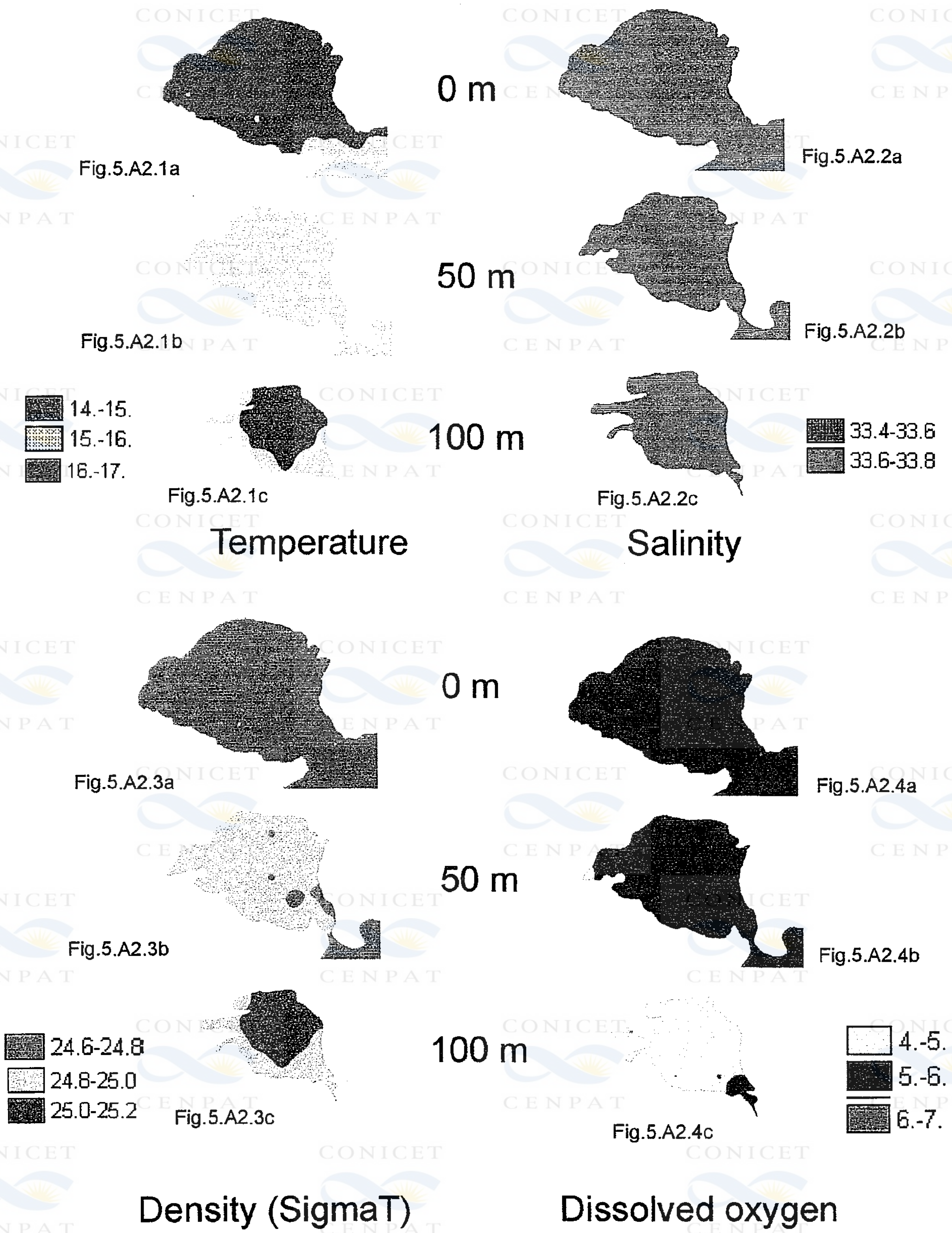


Fig. 5.A2.8b - Horizontal distribution of nitrate, phosphate and chlorophyll "a" - Autumn '83

Table 5.5 - Codes of Fig. 5.A2-8b

Code	NO_3^--N (μg-at.l^{-1})	PO_4^{3-}-P (μg-at.l^{-1})	Chloroph. (mg.m^{-3})	Temp. (°C)	Salinity (‰)	Observations
112	<=1	<=1	<=2	16-17	33.6-33.8	
121	<=1	1-2	<=1	15-17	33.6-33.8	16-17 (1)
221	1-2	<=2	<=1	15-17	33.6-33.8	15-16 (1)

(1) predominant temperature.



Horizontal distributions - April '83

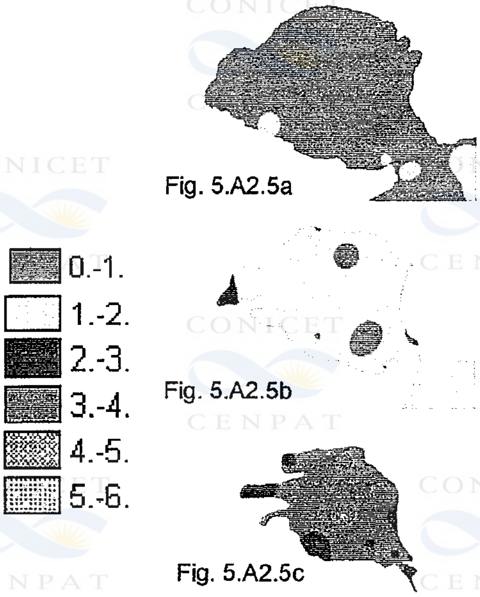


Fig. 5.A2.5a

Fig. 5.A2.5b

Fig. 5.A2.5c

0 m

50 m

100 m

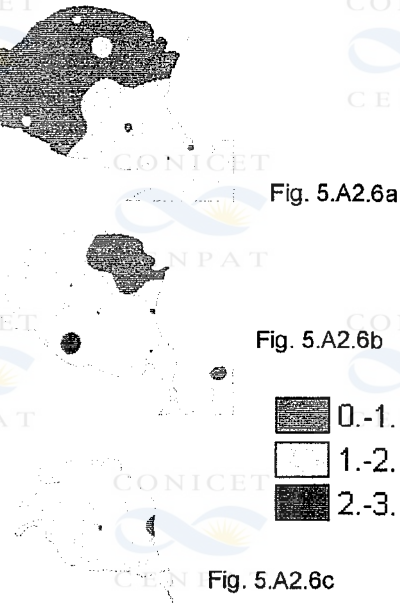


Fig. 5.A2.6a

Fig. 5.A2.6b

Fig. 5.A2.6c

N03(-)-N

PO4(3-)-P

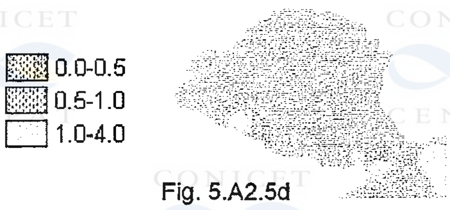


Fig. 5.A2.5d

0 m

Fig. 5.A2.6d

N03(-)-N

PO4(3-)-P

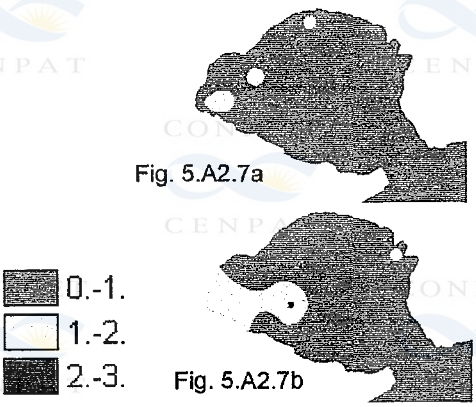


Fig. 5.A2.7a

0 m

Fig. 5.A2.7b

5 m

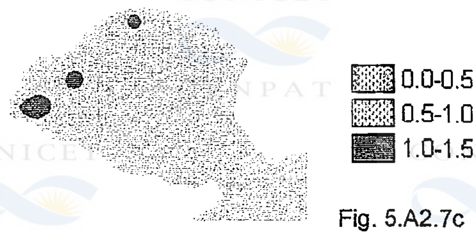


Fig. 5.A2.7c

Chlorophyll "a"

Horizontal distributions - April '83

Fig. 5.1 - Mean values of variables from the five campaigns, at the surface, 50 m and 100 m depth.

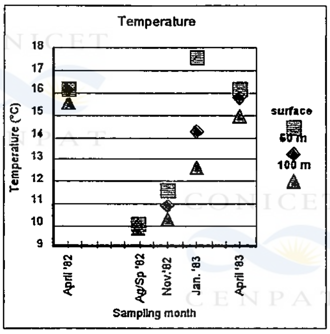


Fig. 5.1.a

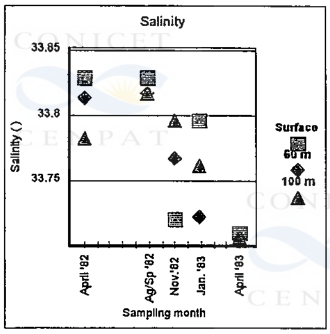


Fig. 5.1.b

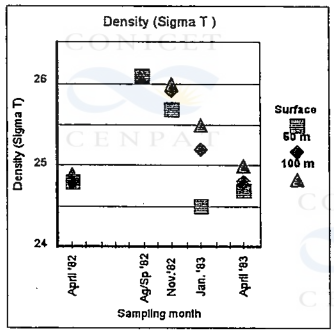


Fig. 5.1.c

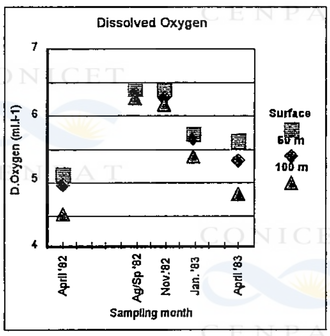


Fig.5.1.d

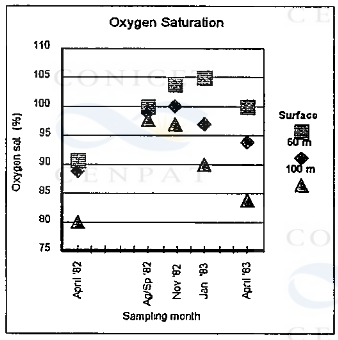


Fig.5.1.e

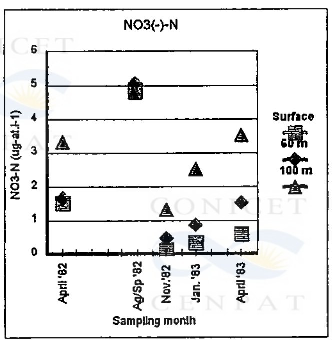


Fig.5.1.f

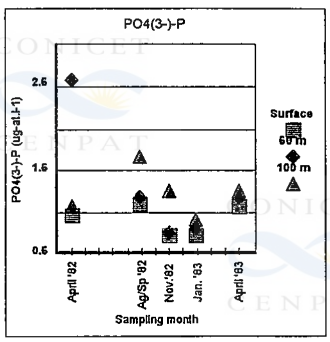


Fig.5.1.g

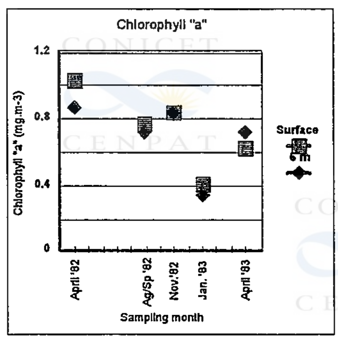


Fig. 5.1.h

A complete representation of mean values and standard deviations at different depths, for all the data collected on the field, is included in Annex A.

5.2 - Characterization of the water body

The characterization of the Gulf, will be carried out with the results presented and discussed in the previous Seasonal and spatial analysis. It will be based on the water temperature range and on the evolution of the structure of the water column along the year.

5.2.1 - Characterization based on the water temperature range

According to the literature, a system with annual water temperature between 5 and 30 °C, is defined as temperate(see Chapter 2). From the results of Nuevo Gulf, previously analysed, the annual range for the water temperature is between 10 and 19.5 °C, hence the system is temperate.

5.2.2 - Characterization based on the evolution of the structure of the water column along the year

A temperate system may also be characterized by the structure of the water column along the year, which evolves from not stratified water column, in winter, to stratified conditions, in summer. Transitions between both stages are found in autumn and spring seasons.

5.2.2.1 Autumn '82

In temperate seas, the literature reviewed describes autumn seasons as a transitional period. The stratification of summer, starts to be disrupted and evolves towards a homogeneous vertical structure. The results of autumn '82, showed a slight change in the vertical physical properties of the water column, between 50 and 100 m depths and hence, a slight, or almost no stratified column pattern.

As it was observed in the Seasonal and Spatial analysis, the slight change in the physical properties is followed by the nitrate vertical pattern but not by the phosphate vertical distribution. The highest chlorophyll "a" (2.6 mg.m-3), from all the data analysed in this work, was observed in this season. In temperate systems, an autumn phytoplankton bloom is cited (see Chapter 2). Data collected in Nueva Bay, during weekly sampling, in 1975 and 1976, reported chlorophyll "a" peaks of 1.5 and 2.5 mg.m^{-3}, in september'75 and april'76, respectively [De Vido et al., 1978]. Concentrations of 8 mg.m^{-3} have been reported in relationship to an upwelling process, in the same place, in January '88 [Esteves et al., 1992]. From the comparison of the chlorophyll "a" levels of autumn'82 and those from 1975 and 1976, it can be supposed that this campaign has been, probably, carried out during or close to the autumn bloom.

5.2.2.2 Winter '82

Since autumn '82 to winter '82, temperature of the water column has decreased. When the mean values at each depth are compared, they are significantly different ($p<0.05$). At the surface, mean temperature has decreased 6 °C. Salinity in the water column remains almost constantly and only at the 100 m, the mean values are significantly different from its equivalent in autumn '82 ($p<0.05$). Density has increased in the whole water column, which indicates that this variable is mainly ruled by temperature changes. From the vertical analysis of the physical properties carried out in the Seasonal and Spatial analysis, it was observed that the water column, in winter '82, is not stratified.

A not stratified water column, is a property of temperate seas, in winter, described by the literature reviewed. It is due to downwards mixing process that starts to the end of summer, as a consequence of the decrease of surface water temperature, the increase of density, that sinks water masses, and the influence of wind, that helps in the mixing, breaking the summer thermocline.

The oxygen levels are higher in this season than in autumn'82. The mean values at the surface, 50 m and 100 m depth, of autumn '82, are significantly different from the respective mean values of winter '82 ($p<0.05$). The homogeneous vertical and horizontal distributions of oxygen, similarly to the vertical pattern of the physical variables, described in the Seasonal and Spatial analysis, may be due to the mixing conditions of the water column, above explained. At the bottom, consumption, by mineralization rate, is probably low in this season, because of the lower temperatures.

In winter '82, nitrate in the water column is higher than in autumn'82. Mean values at the surface, 50 m and 100 m depth, are significantly different ($p<0.05$). From the Seasonal and Spatial analysis it was observed that the vertical concentration is homogeneous from the surface to the bottom. This pattern for nitrate in the water column also agrees with the winter description, in temperate seas, from the literature reviewed. Because of the downwards mixing process, remineralized nitrate from bottom is brought to the surface, but by the same process, phytoplankton cells are transported to deep zones where there is no enough light for photosynthesis. At the surface, phytoplanktonic activity is reduced because of the shorter day length and the lower irradiation of winter seasons. According to the literature reviewed, in winter, critical depth became shallower, the mixing conditions results in a deep mixed layer and not net growth of phytoplankton is observed.

Since autumn '82, phosphate values have also increased, except at 50 m depth. Nevertheless, the mean values of winter '82, at the surface, 50 m and 100 m depth, are not significantly different from its respective levels in autumn'82 ($p<0.05$). The seasonal phosphate increase is not so high as it was observed for nitrate (e.g. at the surface mean value of nitrate increased 32 % and surface mean value of phosphate, 14 %), probably due to the lower temperatures of this season. The lower temperatures may decrease the phosphate rate of remineralization in the water column. According to Valiela [1995], the zooplankton, which has an important role in this process, has growth and reproduction temperature dependant.

Since the low phytoplanktonic activity of winter, chlorophyll "a" concentrations are expected to be low. In fact, they are, but mean values at surface and 5 m depth, when compared with the previous season are not significantly different ($p<0.05$).

5.2.2.3 - Spring '82

From winter'82 to spring '82, the whole water column has increased the temperature. The mean values in winter '82, at the surface, 50 m and 100 m depth, are significantly different from its respective levels in spring '82 ($p<0.05$). At the surface, the mean value has increased in 1.5 °C.

As it was observed in the Seasonal and Spatial analysis, the warming of the surface waters has reached the 50 m, on the west, but on the east, if it is the case, is still above 50 m. As a consequence, a stratification is appearing on the east side of the Gulf. Salinity still maintains the isohaline structure, like in winter. Density has decreased along the water column, and mean values are significantly different ($p<0.05$), at the surface, 50 m and 100 m depth. From the vertical analysis of the physical properties, in the Seasonal and spatial analysis, it was observed that the water column has a slight stratification, between surface and 50 m depth.

Changes in the physical properties, that start to appear in the homogeneous vertical pattern of winter, and evolve towards stratified conditions in summer, is described in the literature reviewed for spring period. At the middle latitudes, the increase in the day length and the irradiation reaching the sea surface, starts to warm the upper layers, to develop a thermocline, to reduce the depth of the mixed layer and to deep the critical depth, given as a result a net growth of phytoplankton (see Chapter 2). In the region of Nuevo Gulf, the action of wind, during spring, may introduce a factor that influences the changes of the water column. Winds are more frequent in this period [Riveroet al., 1977], the velocities range between 20 and 30 km.h-1 [data from Centro Nacional Patagonico] and they may interfere in the development of the thermocline.

Since winter'82, nitrate and phosphate concentration in the water column, has decreased; mean values of nitrate at the surface, 50 m and 100 m depth, are significantly different ($p<0.05$); mean values of phosphate are only significantly different at the level of the surface and 50 m depth ($p<0.05$). Due to the decrease of nutrients, it is expected that a phytoplankton bloom has started or occurred between these campaigns. In the literature reviewed, a spring bloom is mentioned in temperate seas.

Chlorophyll "a" mean values, from winter '82 have increased but, mean values at the surface and 5 m depth, in winter and spring '82 are not significantly different ($p<0.05$). In spring the mean values are about 0.8 mg.m-3, and concentrations in the range of 1-2 mg.m-3 are only found on few patches. Chlorophyll "a" concentration does not look like during a phytoplankton bloom process, but in the Gulf, the only reference to levels of chlorophyll "a" under peak conditions, are the data from Nueva Bay (see above Autumn '82); according to them the highest values seem to be around 2.5 mg.m-3.

Are the phytoplankton blooms detected in the Gulf, by chlorophyll "a" levels around 2.5-3 mg.m-3, or are the peaks higher, but located at deeper places? In the literature reviewed, subsurface chlorophyll "a" maxima are mentioned [Mann et al., 1996]. This author also states that, specially in early theories, it was explained on the base of biological factors like the sinking of diatoms, but recently another group of theories argue that it is due to the faster growth and decay of phytoplankton in the upper mixed layer than in and below the thermocline. Unfortunately, for this campaign there is no chlorophyll "a" data, below 5 m depth, to test if subsurface levels show a maximum and the bloom conditions.

On the other hand, the grazing by zooplankton is also given as an explanation to the low surface chlorophyll "a" values. Nevertheless it seems not to be a good explanation, here. Phytoplankton growth is highly dependent of light and thus a bloom may occur at early spring. In contrast, zooplankton growth is more temperature dependant, hence the effects of grazing by zooplankton over phytoplankton suffer a lag until temperature increases [Valiela, 1995]. In this way, grazing seems not to be the factor to explain the low level of chlorophyll "a" detected, unless that the increase of about 1°C in temperature, since winter '82, is enough to make zooplankton population more active.

5.2.2.4 - Summer '83

In the Seasonal and spatial analysis, it was observed that, in summer '83, the water column is stratified. It agrees with the summer description of temperate seas, given in the literature reviewed. The stratified condition of the water column is a consequence of the increasing water warming since spring, and the low influence of winds (see Seasonal and spatial analysis). In effect, in this system, since spring'82 to summer'82, the temperature of the water column has increased and the mean values at the surface, 50 m and 100 m depth are significantly different ($p<0.05$). At the surface, the increase of the mean value is 6 °C. Opposite to temperature, density has decreased along the water column and the mean values of spring '82 at the surface, 50 m and 100 m depth are significantly different ($p<0.05$).

From spring '82, mean values of dissolved oxygen in the water column have decreased and, at the surface, 50 m and 100 m depth, they are significantly different ($p<0.05$) from its respective level in summer'82. The decrease of the mean values, mainly at the bottom, may reflect the consumption by mineralization process.

The mean values of nitrate of summer '83, at the surface and 50 m depth, are no significantly different from the respective mean values of spring '82 ($p<0.05$). From the Seasonal and spatial analysis it was observed that it is almost depleted, mainly at the surface. Mann et al. [1996] state that the inputs of nitrogen to the mixed layer are due to vertical diffusion and to the excretion by zooplankton and other heterotrophos, meanwhile the outputs are based on the uptake of phytoplankton, sinking of phytoplankton out of the mixed layer and consumption of phytoplankton by zooplankton. In this system, according to the observed on the horizontal distributions, principally close to the mouth, perhaps it may also be included an input by horizontal advection from the oceanic waters. In summer' 83, the oceanic input, if it is the case, is low, because oceanic waters have a low nitrate level. On the other side, due to the summer thermocline, chiefly on the northern half sector, there must be a barrier to the vertical diffusion of nitrate from bottom. As a consequence, in this season, the input of nitrogen to the mixed layer must be supported by the excretion process, that is to say, to the input of recycled nitrogen as ammonium (see Chapter 2). Unfortunately no data of ammonia are available in these campaigns to know the ammonium levels.

At 100 m depth, mean nitrate concentration is higher than in spring '82 (mean values are significantly different ($p<0.05$)). It is probably due to the higher temperatures of the season that favours the mineralization process (see Chapter 2). Mean phosphate values, at the surface, 50 m and 100 m depth, are no significantly different from its equivalents in spring'82 ($p<0.05$).

The level of nutrients, in summer '83, similar to that in spring '82, suggest that the phytoplankton consumption still remains high. Nevertheless, if chlorophyll "a" concentrations were low in spring '82, they are now still lower. Mean values at the surface and 5 m depth in summer '83 are significantly different from its respective means in spring'82 ($p<0.05$). Opposite to spring '82, in this season, the grazing by zooplankton may also explain the low chlorophyll "a" levels in this season.

5.2.2.5 - Autumn '83

From the Seasonal and Spatial analysis of autumn '83, it was observed that the water column is slightly, or close to no stratified pattern, due to the slight change of physical properties between surface and 50 m depth. This pattern suggests that the summer thermocline has been broken and that the cycle is starting again, with the transitional period towards winter, like it was explained in autumn '82.

From January '83, mean temperature at the surface has decreased around 1.5 °C and is significantly different from the mean value at the surface of April '83. Nevertheless, at the 50 m and 100 m, the mean values are, now, higher, and significantly different ($p<0.05$) from the mean values at these depths in summer '83. A possible explanation to this fact, may be based on the hypothesis that the warming of the waters was not still reached the maximum in January '83. In consequence, the higher temperatures occurred in February or March, and now the 50 and 100 m show this effect. As expected, the surface waters started to become colder but they have not deepened too much, yet, probably due to a calm autumn '83.

Salinity has an isohaline structure. It has decreased along the water column but is only significantly different ($p<0.05$) at the surface. Density at the surface increase (mean values from summer'83 and autumn '83, are significantly different ($p<0.05$)), due to the lower temperature, but at 50 m and 100 decreased, influenced by the increase of temperatures.

Nitrate level has increased, but only mean values, at the surface, are significantly different from summer '83. On other hand, phosphate mean values are no significantly different at the surface, 50 m and 100 m depth. Chlorophyll "a" mean values have increased but they are significantly different ($p<0.05$) at 5 m depth.

The data from autumn were collected from 15 to 18 of April '82 and then from 8 to 12 of April '83, hence an annual cycle was completed. Due to that, the structure of the water column will be compared.

Table 5.6 - Comparison of some result from autumn'82 and autumn'83

	April '82 / April '83
Physical properties change between	50-100 m / 0-50 m
From surface to bottom, temperature decrease	< 1 °C / < 1.5 °C
Temperature of the water column	$T_{April '82} > T_{April '83}$ mean values at the surface = NSD mean values at 50 m = SD mean values at 100 m = SD ($p<0.05$)
Salinity of the water column	$S_{April '82} > S_{April '83}$ mean values at the surface = SD mean values at the 50 m = SD mean values at the 100 m = SD ($p<0.05$)
Nitrate	mean values at the surface= SD; April'82>April '83 mean values at the 50 m = NSD; April '82>April'83 mean values at the 100 m = NSD; April '82≈April'83 ($p<0.05$) Horizontal distribution at the surface, closer to summer features, in autumn '83.
Chlorophyll "a"	$Chl_{April '82} > Chl_{April '83}$ mean values at the surface = SD mean values at the 5 m = NSD ($p<0.05$)

NSD= no significantly different; SD= significantly different

In autumn '82, the slight change of the physical properties is observed between 50 and 100 m depth, meanwhile in autumn '83, it is shallower, between the surface and 50 m depth. On the other side, the decrease of temperature from surface to the bottom is 1 °C in autumn '82 and 1.5 °C in autum'83. As a consequence, according to this results, the physical properties of the water column in autumn '82 would be closer to the winter features: deeper mixed layer and slighter change in the vertical properties of the water column.

On the other side, if the values of the mean temperature and mean salinity are compared between autumn'82 and autumn'83, the mean values from autumn'82 seem to be closer to the summer features: higher temperature and salinity.

This opposite conditions may be explained perhaps through the action of wind. In this way, it may be supposed that the action of wind may be higher in autumn'82 than in autumn '83, given as a consequence a deeper mixed layer mainly due to the action of wind than to the deepening of the surface waters by the effect of cooling.

CHAPTER 6

CONCLUSIONS

A seasonal and spatial analysis of a set of oceanographic data (temperature, salinity, dissolved oxygen, nitrate, phosphate and chlorophyll "a") has been carried out. The data were collected in Nuevo Gulf (Argentina) during 1982-1983. The objective of this analysis was to:
- characterize the system;
- define spatial patterns that can be applied to the selection of sampling sites; and
- define seasonal patterns that can be applied to set the frequency of sampling.

From this analysis has been got information to design a network for a background monitoring, or evaluation of present or future eutrophication, as well as to identify areas sensitive to present or future pollution problems and background concentrations of natural compounds to be taken as reference for water quality guidelines for the area.

6.1 - Characterization of the system

Due to the annual water temperature range, between 10 and 19.5 °C, and the evolution of the vertical structure of the water column during the year, the system is characterized as temperate. The water column is characterized by homogeneous vertical distribution of the physical and chemical properties in winter, stratified conditions in summer, and transitional stages between these patterns in spring and autumn. Temperature and nitrate are the parameters that mainly describe the spatial and seasonal variations of this system.

6.2 - Definition of spatial and seasonal patterns

From the spatial analysis in the "z" dimension, it can be concluded that seasonal vertical patterns, may be defined for this ecosystem and used to select sampling sites. A different vertical distribution of the analysed properties is observed for each season. In winter, the water column has a homogeneous structure due to the negligible variation in the properties from the surface to the bottom. In summer, a thermocline occurs below 10 m depth. The water column is therefore stratified, but the stratification is not at the same depth in the whole gulf, it is shallower in the northern sector. In autumn and spring, the vertical patterns go through transitional stages towards a homogeneous water column, or towards the development of a thermocline, respectively. Due to these stages, the vertical distribution of the analysed variables may be influenced by how far or close from "winter" or "summer" conditions the sea is at the date of sampling. It is also probable that the frequency and intensity of winds may influence the development of this vertical structure. In this area, periods of calm, through the year, are lower than 16 %, and winds are more frequent in spring.

From the spatial analysis, in the "x, y" dimensions (horizontal distributions) it can be concluded that seasonal horizontal patterns, can be defined on the basis of this set of physical, chemical and biological variables and used to select sampling sites. These patterns are represented in the maps (see Chapter 5 - Figs 5.A1.8a; 5.W.8a; 5.Sp.8a; 5.Sm.8a and

5.A2.8a). Based on the chemical (nitrate and phosphate) and the biological (chlorophyll "a") variables, the horizontal seasonal patterns may be simplified in order to allow for easier identification of areas by the level of nutrients (see Chapter 5 - Figs. 5.A1.8b; 5.W.8b; 5.Sp.8b; 5.Sm.8b and 5.A2.8b).

6.3 - Identification of sensitive areas to eutrophication

On the basis of the analysed data, it has been observed that the lower nutrient concentrations (mainly of nitrate) have been found, in most seasons, in the western and northwestern coast of the gulf. As a consequence, the natural conditions of this sector are the most oligotrophic in the area, hence the probability of eutrophication problems in this sector, is high.

The oceanic waters, colder than the inside waters of the gulf, seem input nitrate to this ecosystem. Nevertheless, if this is the case, the influence of this input seems to be limited, at the surface, to the mouth and the adjacent area, and in the eastern half of the basin, to the 50 m depth.

6.4 - Levels of natural compounds to the 1982-1983 years

In the years 1982-1983, this ecosystem showed dissolved oxygen concentrations at minimum levels in autumn but always above saturated conditions, even at the bottom (Ranges at 100 m depth: dissolved oxygen concentration: 4-5 $ml.l^{-1}$, percentage of saturation: 69-90 %). Nitrogen and phosphorus reached almost depleted levels, at the surface, in summer, and the maximum, in winter. Surface winter maximum did not exceed 7.5 µg-at NO_3^--N and 1.5 µg-at PO_4^{3-}-$P.l^{-1}$, respectively. Maximum of chlorophyll "a", was observed in autumn. The values were not higher than 3 $mg.m^{-3}$. Chlorophyll "a" values in '82-'83 are inside the ranges detected by the Seawifs images from 1997, hence high credibility and accuracy are expected from the application of this type of images to studies of this compound in the area.

CHAPTER 7

RECOMMENDATIONS

The seasonal and spatial patterns have been obtained from the analysis of only one annual set of annual data, collected during five campaigns, hence, the patterns have to be considered as preliminary information for the whole area. Nevertheless, if these patterns are going to be tested with new data collected in the field, it should be taken into account that in some areas, e.g. the west coast of the gulf, human activities have increased considerably in the last the sixteen years, and differences may be found due to anthropogenic influences.

7.1 - Recommended frequency of sampling and sampling sites for monitoring

For background monitoring of natural compounds, or the evaluation of present and future eutrophication problems, a minimum of one collection of samples of nitrate, phosphate, ammonium, chlorophyll “a”, temperature and transparency per season is recommended, although other biological variables, such as phytoplankton could well be included. At the end of winter, the vertical selection of the sampling sites may be reduced to the surface and the bottom. In summer, samples at the surface, above and below the limits of the thermocline and at the bottom would have to be collected. If no CTD (conductivity, temperature, depth sensors) is available for the detection of the thermocline limits, the samples would have to be collected at the surface, 10, 20, 30, 50 m depth and the bottom. For autumn and spring, due to the transitional stages of the water column, sampling at the same depths are recommended, until such time that the system is well characterized.

For the horizontal distribution of sampling sites, transects are suggested (Fig. 7.1). Since coastal areas are generally more affected by pollution, in each transect, a higher frequency of sites would have to be selected inside the shallower zones (below 50 m depth).

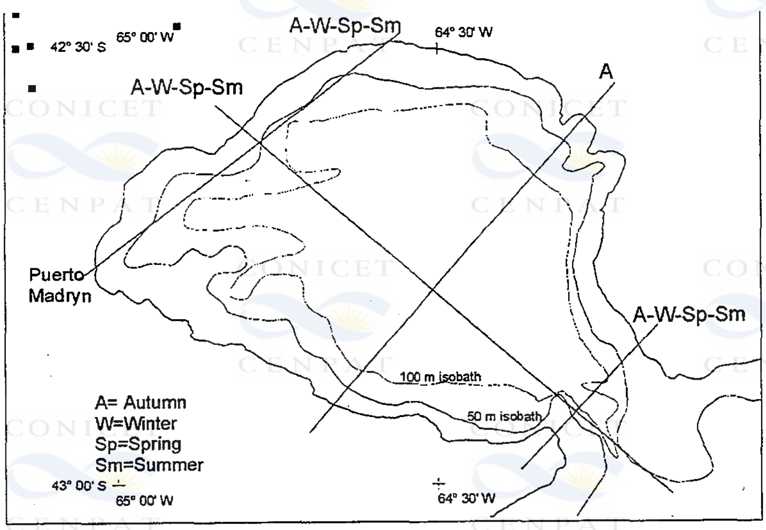


Fig. 7.1 - Transects for sampling sites

It is known that monitoring networks such as these proposed, may be limited by economic constraints and the availability of a vessel for sampling. Without denying the value of the previous recommendation, an alternative may be, a coastal network capable of being sampled by boat, following the frequency and the sampling patterns above recommended.

Due to the influence that wind may exert on the area, some brief information and analysis about meterological conditions would have to be including in the sampling. It will be necessary not only to register the weather conditions on the date of sampling, but also to know the frequencies and predominant directions of the wind during the previous day. This will help in the data interpretation. A survey to test the tidal influences on the sampling sites, would also have to be carried out prior to the monitoring.

7.2 - About the sensitive areas to eutrophication

Due to the low nutrient levels found in the west and northwestern area, and the information collected from reports on Nueva Bay, strict control of the discharge of effluents should be carried out on this area. According to the seasonal and spatial analysis, Puerto Madryn City is located in one of the most oligotrophic areas of the gulf. For this area and the gulf in general, it is a priority to develop water quality standards, and to improve the actual legislation. The level of natural compounds observed here and previous works on Nueva Bay [Esteves et al.,1981, 1992,1997] should be taken as a point of reference.

7.3 - Further research needed for this ecosystem

By means of field works alone, or combined with other tools like GIS, remote sensing (see the paragraph below) and models, knowledge of the following topics could be improved:
- velocities and directions of currents, as well as factors that exerts influence on them (the shape of the coast, tidal effects, winds, etc.);
- the action of the wind and its influence in the physical, chemical and biological conditions of the water body;
- frequencies, magnitude and ecological effects of upwelling processes;
- levels of chlorophyll "a" reached during autumn, spring or upwelling bloom conditions, and where the more concentrated patches are detected.

7.4 -The application of remote sensing images

The use of remote sensing images is highly recommended to find out more about the system, but also to optimize monitoring efforts. The study of currents, distribution of temperatures, suspended solids, transparency and phytoplankton, may be achieved by mean of satellite images. From Archive, images from the CZCS satellite and NOOA could give relevant information to be analysed, and by the contribution of Seawifs from 1997, another important tool has been obtained. In the future, new possibilities will be reached by the introduction of more oceanographic sensors: MODIS'98 (USA-Nasa) and MERIS'99 (France-ESA).

In the future, the development of algorithms in order to relate water quality parameters and the information obtained through satellite images in the area, such as those developed by Dekker [1993] for water quality parameters in inland waters, would reduce the monitoring efforts. Due to the properties of the system, these type of equations may reduce the monitoring, in winter, to the observation of remote sensing images and to the combination of remote sensing images and vertical field sampling in the other seasons.

7.5 - General recommendation

The recommended strategy for monitoring the area would have to be considered not in isolation, but integrated into a water quality assessment programme as a part for a larger management plan for the whole gulf. Obviously, the monitoring, should not focus merely on collecting dat, but on being a dynamic and practical means to test and adjust management decisions.

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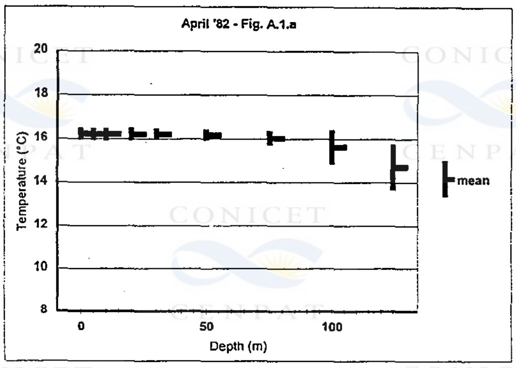
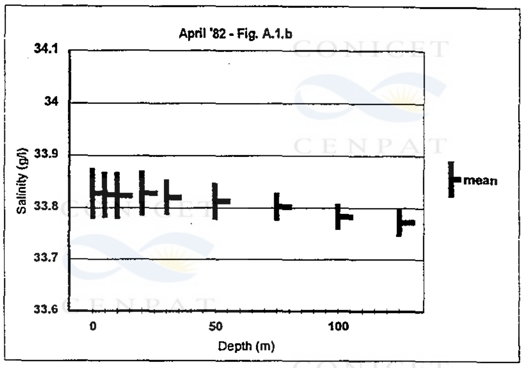
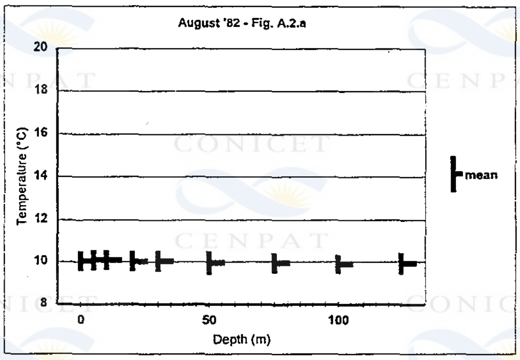
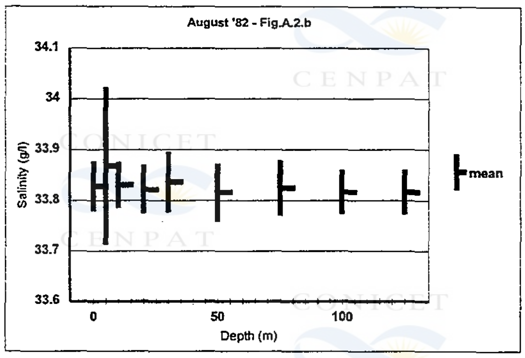
ANNEX A

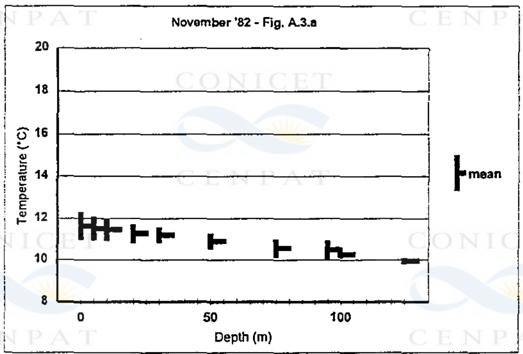
Vertical profiles - Representations of mean values and standard deviations in function of depth

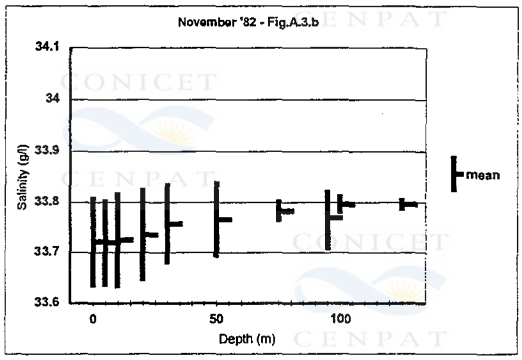


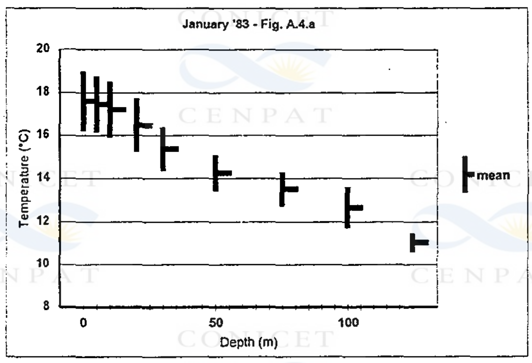


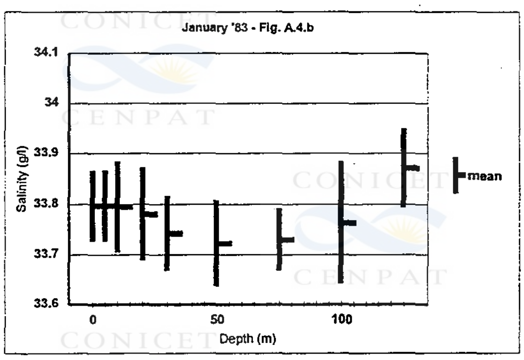


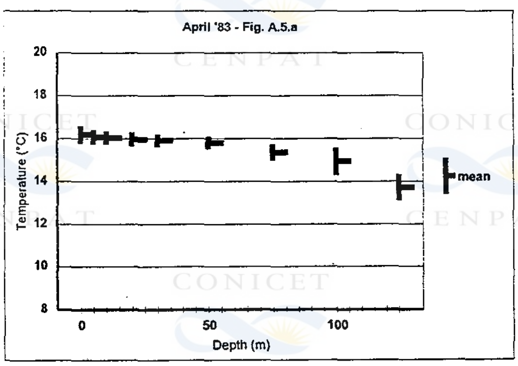


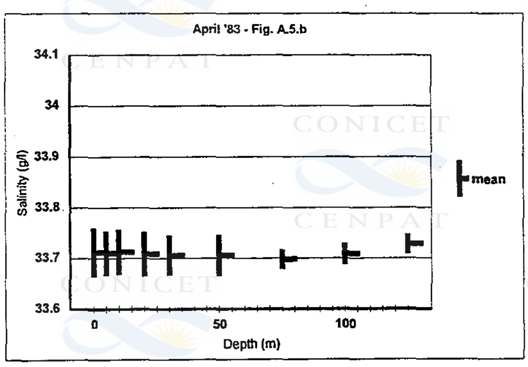




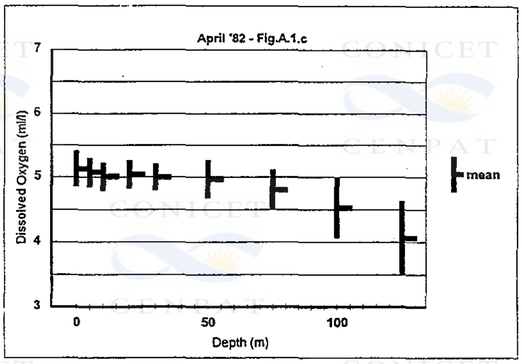


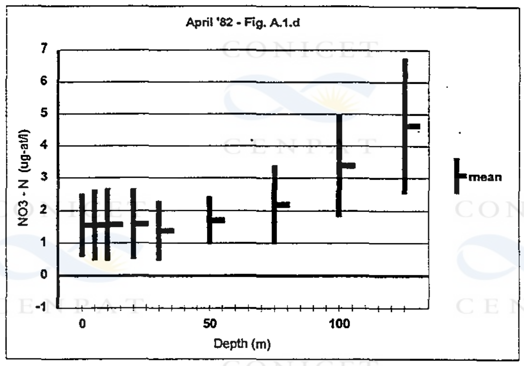


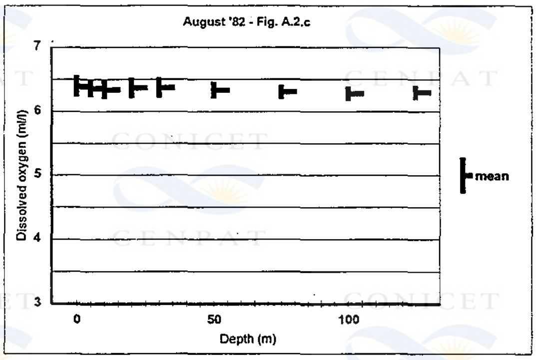


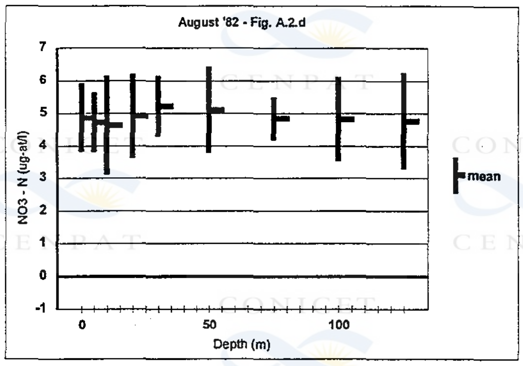


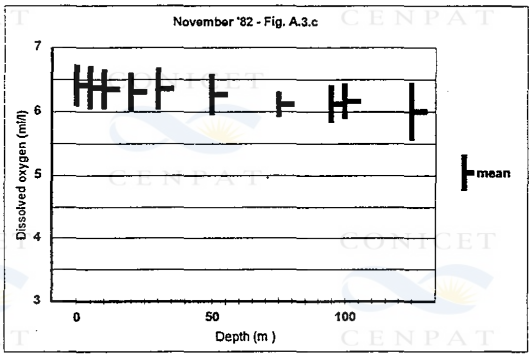
ANNEX A - Vertical profiles
Representations of mean values and standard deviations in function of depth.

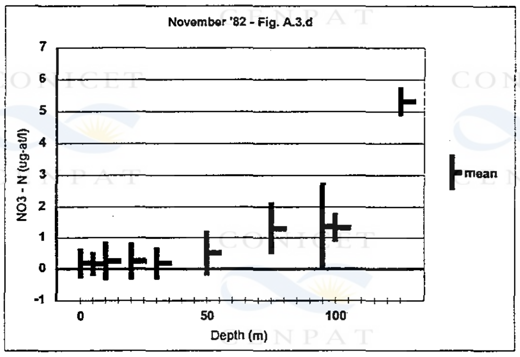


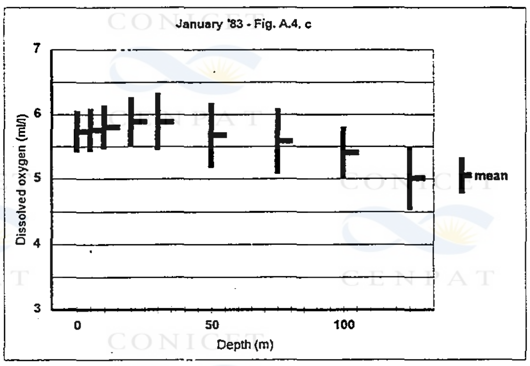


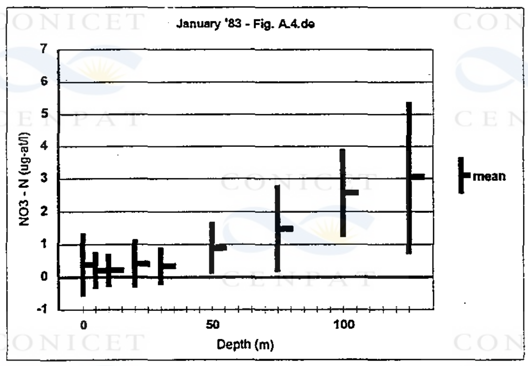


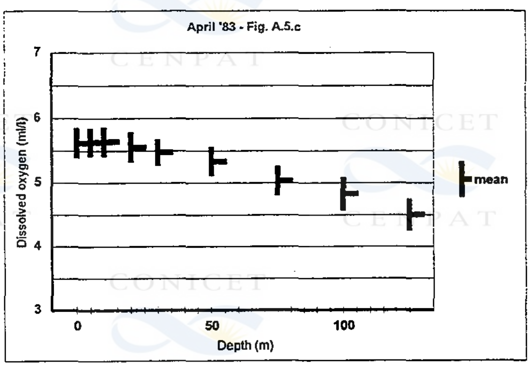


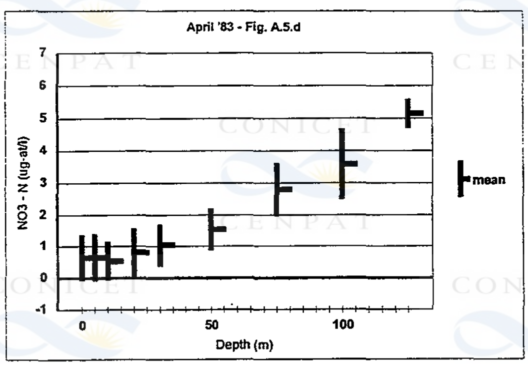




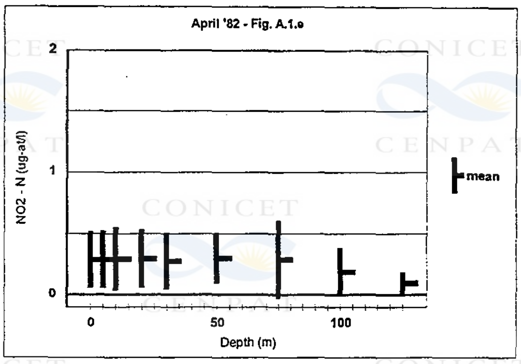


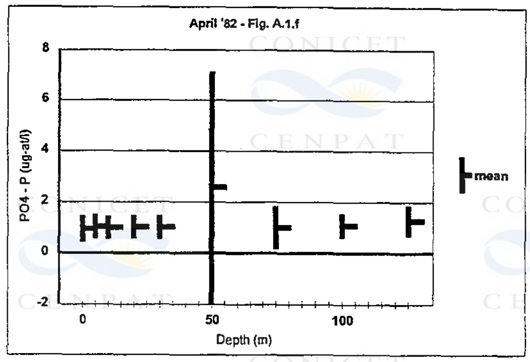


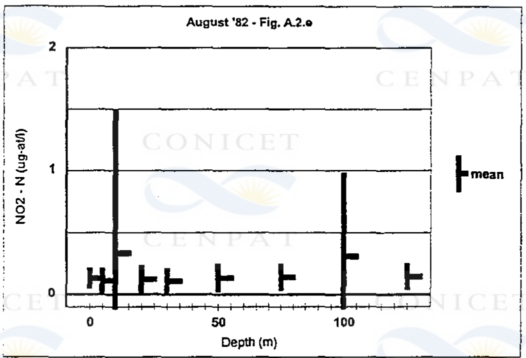


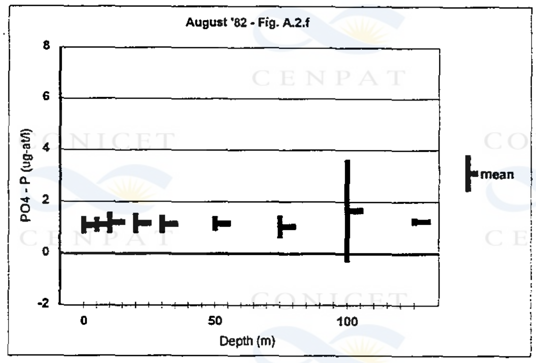


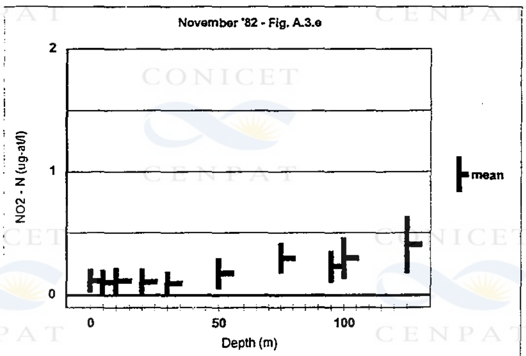
ANNEX A - Vertical profiles
Representations of mean values and standard deviations in function of depth.

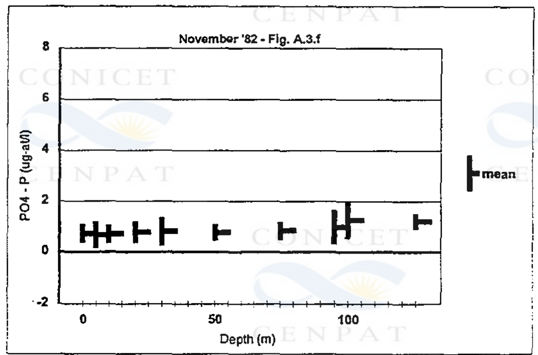


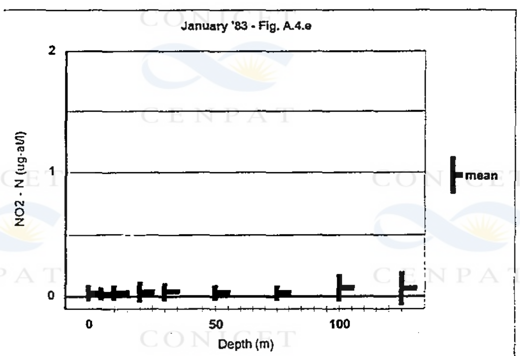


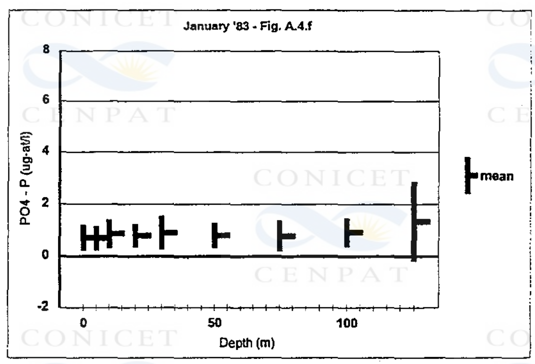


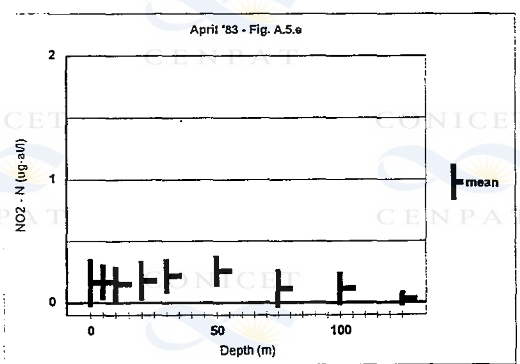


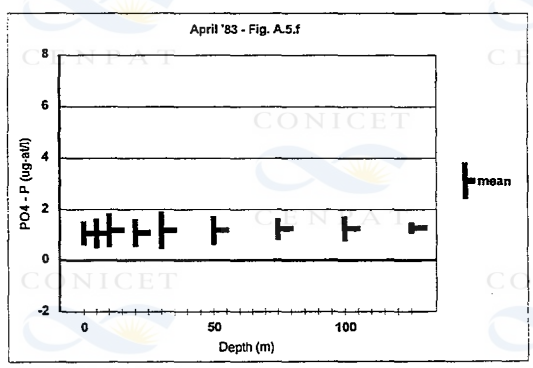




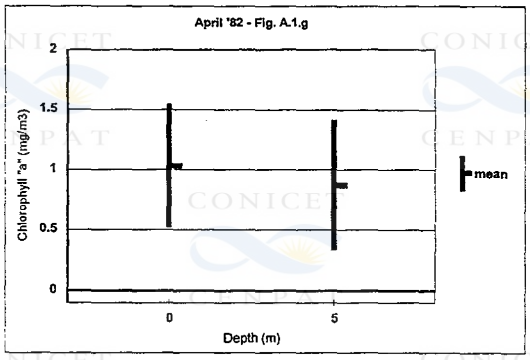


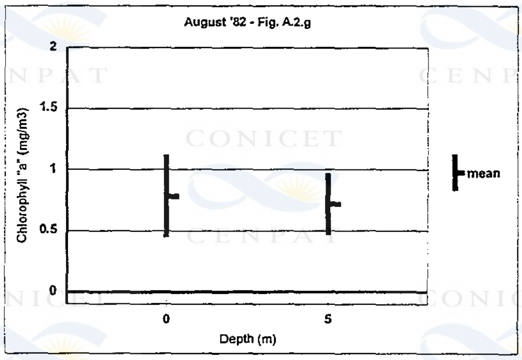


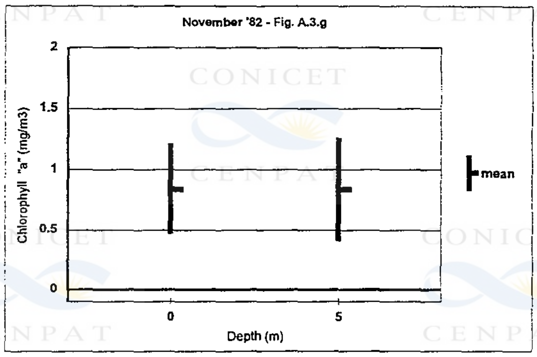


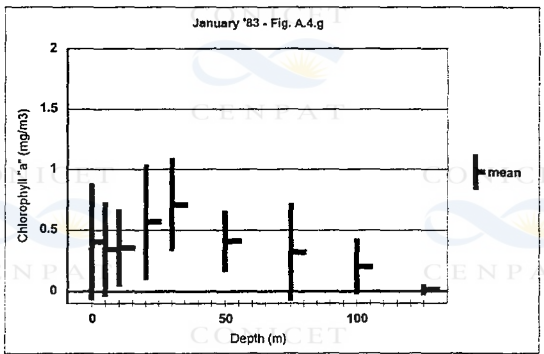


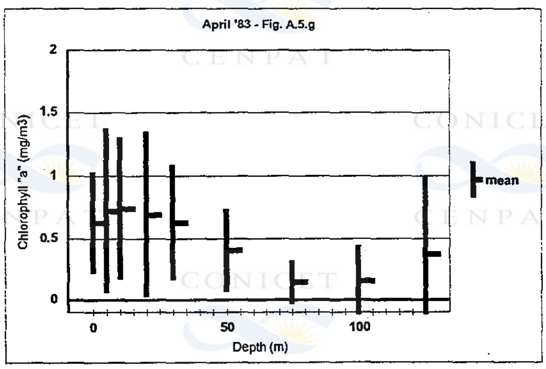
ANNEX A- Vertical profiles
Representations of mean values and standard deviations in function of depth.











ANNEX A- Vertical profiles
Representations of mean values and standard deviations in function of depth.

ANNEX B
Number of data for mean value and standard deviation calculations

ANNEX B

Table 1 - Number of data for mean value and standard deviation calculations of Figs. A.1.a to A.5.g.

	April '82	August '82	November '82	January '83	April '83
Depth (m)	sampling points	sampling points	sampling points	sampling points	sampling points
0	25	23	26	26	24
5	25	26	25	26	25
10	25	26	25	26	24
20	25	25	26	26	24
30	22	23	23	24	22
50	18	19	18	20	19
75	12	14	5	15	13
95	---	----	13	---	----
100	9	12	5	10	11
125	6	5	4	2	6

ANNEX C
Codes applied to the classified raster maps

ANNEX C

Table C.1 - Codes applied to the classified raster maps of temperature, salinity, NO_3^--N, PO_4^{3-}-P and chlorophyll "a" to produce combined maps.

Temperature				Salinity		Chlorophyll "a"	
April '82, August '82, November '82 and April '83		January '83		April '82, August '82, November '82, January '83 and April '83			
° C	CODE	° C	CODE	‰	CODE	$mg.m^{-3}$	CODE
9-10	1	15-16	6	33.4-33.6	0.1	0-1	10
10-11	2	16-17	7	33.6-33.8	0.2	1-2	20
11-12	3	17-18	8	33.8-34.0	0.3	2-3	30
12-13	4	18-19.5	9				
13-14	5						
14-15	6						
15-16	7						
16-17	8						

NO_3^--N				PO_4^{3-}-P			
April '82 - August '82 - April '83		January '83		April '82 - August '82 - April '83		January '83	
$\mu g\text{-}at.l^{-1}$	CODE	$\mu g\text{-}at.l^{-1}$	CODE	$\mu g\text{-}at.l^{-1}$	CODE	$\mu g\text{-}at.l^{-1}$	CODE
0-1	1000	0-0.5	1000	0-1	100	0-0.5	100
1-2	2000	0.5-1	2000	1-2	200	0.5-1	200
2-3	3000	> 1	3000	2-3	300	1-2	300
3-4	4000			3-15	400		
4-5	5000						
5-6	6000						

Table C.2 - Codes obtained after the addition of NO_3^--N, PO_4^{3-}-P and chlorophyll "a" maps and new assignation of codes.

Campaign (1)	Codes obtained after NO_3^--N, PO_4^{3-}-P and chlorophyll "a" maps addition (2)	New code for final maps (3)	NO_3^--N (μg-at.l^{-1}) (4)	PO_4^{3-}-P (μg-at.l^{-1}) (5)	Chlorophyll "a" (mg.m^{-3}) (6)
April '82	1110-1120-1130	1130	0-1	0-1	0-3
	1210-1220	1220	0-1	1-2	0-2
	2110-2120-2210-2220	2220	1-2	0-2	0-2
	3110-3210	3210	2-3	0-2	0-1
August '82	4110	4110	3-4	0-1	0-1
	4210	4210	3-4	1-2	0-1
	5110-5210-5220	5220	4-5	0-2	0-2
	6110-6210	6210	5-6	0-2	0-1
November '82	1110-1120	1120	0-0.5	0-0.5	0-2
	1210-1220	1220	0-0.5	0.5-1	0-2
	1310	1310	0-0.5	1-2	0-1
	2210-2220	2220	0.5-1	0.5-1	0-2
January '83	1110	1110	0-0.5	0-0.5	0-1
	1210-1220	1220	0-0.5	0.5-1	0-2
	1310	1310	0-0.5	1-2	0-1
	2210	2210	0.5-1	0.5-1	0-1
	3210	3210	1-4	0.5-1	0-1
April '83	1110-1120	1120	0-1	0-1	0-2
	1210	1210	0-1	1-2	0-1
	2110-2210	2210	1-2	0-2	0-1

Table C.3 - Codes obtained after the addition of temperature, salinity, NO_3^--N, PO_4^{3-}-P and chlorophyll "a" raster maps.

April '82							
AREA	CODE	NO_3^--N	PO_4^{3-}-P	Chloroph.	Temp.	Salinity	Area size(%)[1]
1	1138.3	0-1	0-1	0-3	16-17	33.8-34.0	21.70
2	1228.3	0-1	1-2	0-2	16-17	33.8-34.0	14.00
3	2228.2	1-2	0-2	0-2	16-17	33.6-33.8	2.72
4	2228.3	1-2	0-2	0-2	16-17	33.8-34.0	40.41
5	3217.2	2-3	0-2	0-1	15-16	33.6-33.8	1.93
6	3218.2	2-3	0-2	0-1	16-17	33.6-33.8	19.23
August '82							
AREA	CODE	NO_3^--N	PO_4^{3-}-P	Chloroph.	Temp.	Salinity	Area size(%)[1]
1	4112.3	3-4	0-1	0-1	10-11	33.8-34.0	2.98
2	4212.3	3-4	1-2	0-1	10-11	33.8-34.0	4.06
3	5221.2	4-5	0-2	0-2	9-10	33.6-33.8	4.27
4	5221.3	4-5	0-2	0-2	9-10	33.8-34.0	4.30
5	5222.3	4-5	0-2	0-2	10-11	33.8-34.0	66.51
6	6211.2	5-6	0-2	0-1	9-10	33.6-33.8	14.92
7	6211.3	5-6	0-2	0-1	9-10	33.8-34.0	1.72
8	6212.3	5-6	0-2	0-1	9-10	33.8-34.0	1.25
November '82							
AREA	CODE	NO_3^--N	PO_4^{3-}-P	Chloroph.	Temp.	Salinity	Area size(%)[1]
1	1123.2	0-0.5	0-0.5	0-2	11-12	33.6-33.8	3.35
2	1222.2	0-0.5	0.5-1	0-2	10-11	33.6-33.8	0.11
3	1223.1	0-0.5	0.5-1	0-2	11-12	33.4-33.6	1.52
4	1223.2	0-0.5	0.5-1	0-2	11-12	33.6-33.8	71.29
5	1223.3	0-0.5	0.5-1	0-2	11-12	33.8-34.0	0.56
6	1224.2	0-0.5	0.5-1	0-2	12-13	33.6-33.8	12.14
7	1313.2	0-0.5	1-2	0-1	11-12	33.6-33.8	0.84
8	2222.2	0.5-1	0.5-1	0-2	10-11	33.6-33.8	6.05
9	2223.3	0.5-1	0.5-1	0-2	11-12	33.8-34.0	4.14

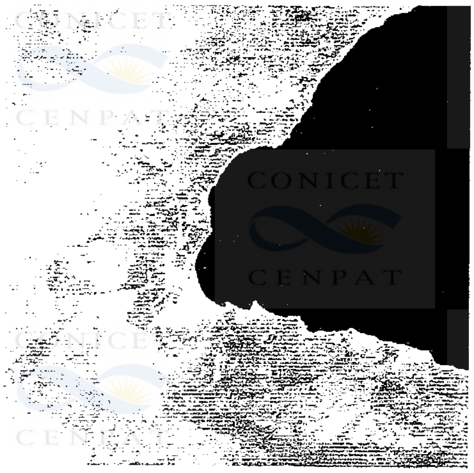
Table C.3 - Codes obtained after the addition of temperature, salinity, NO_3^--N, PO_4^{3-}-P and chlorophyll "a" raster maps (cont.).

January '83							
AREA	CODE	NO_3^--N	PO_4^{3-}-P	Chloroph.	Temp.	Salinity	Area size(%)[1]
1	1118.2	0-0.5	0-0.5	0-1	17-18	33.6-33.8	4.19
2	1118.3	0-0.5	0-0.5	0-1	17-18	33.8-34.0	1.27
3	1119.2	0-0.5	0-0.5	0-1	18-19.5	33.6-33.8	5.81
4	1119.3	0-0.5	0-0.5	0-1	18-19.5	33.8-34.0	13.90
5	1227.2	0-0.5	0.5-1	0-2	16-17	33.6-33.8	9.76
6	1228.2	0-0.5	0.5-1	0-2	17-18	33.6-33.8	23.78
7	1228.3	0-0.5	0.5-1	0-2	17-18	33.8-34.0	1.58
8	1229.2	0-0.5	0.5-1	0-2	18-19.5	33.6-33.8	3.64
9	1229.3	0-0.5	0.5-1	0-2	18-19.5	33.8-34.0	20.72
10	1318.2	0-0.5	1-2	0-1	17-18	33.6-33.8	0.65
11	1319.3	0-0.5	1-2	0-1	18-19.5	33.8-34.0	2.30
12	2216.2	0.5-1	0.5-1	0-1	15-16	33.6-33.8	2.07
13	2217.2	0.5-1	0.5-1	0-1	16-17	33.6-33.8	3.13
14	3216.2	1-4	0.5-1	0-1	15-16	33.6-33.8	6.43
15	3217.2	1-4	0.5-1	0-1	16-17	33.6-33.8	0.76
April'83							
AREA	CODE	NO_3^--N	PO_4^{3-}-P	Chloroph.	Temp.	Salinity	Area size(%)[1]
1	1128.2	0-1	0-1	0-2	16-17	33.6-33.8	55.89
2	1217.2	0-1	1-2	0-1	15-16	33.6-33.8	10.08
3	1218.2	0-1	1-2	0-1	16-17	33.6-33.8	27.94
4	2217.2	1-2	0-2	0-1	15-16	33.6-33.8	4.62
5	2218.2	1-2	0-2	0-1	16-17	33.6-33.8	1.47

1 - Size of the area in the histogram of the raster maps.

ANNEX D

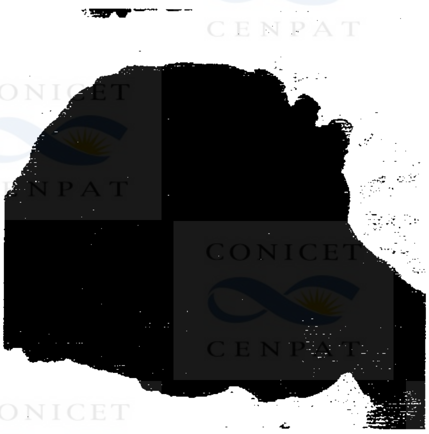
Remote sensing images of Nuevo Gulf - SPOT satellite

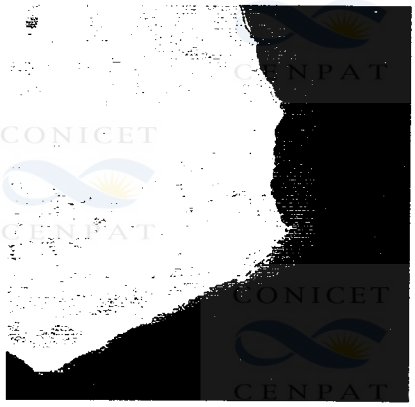


95/09/09 - PATH/ROW: 690/437

SPOT

PATH/ROW
691/436





PATH/ROW
693/436

PATH/ROW
691/437

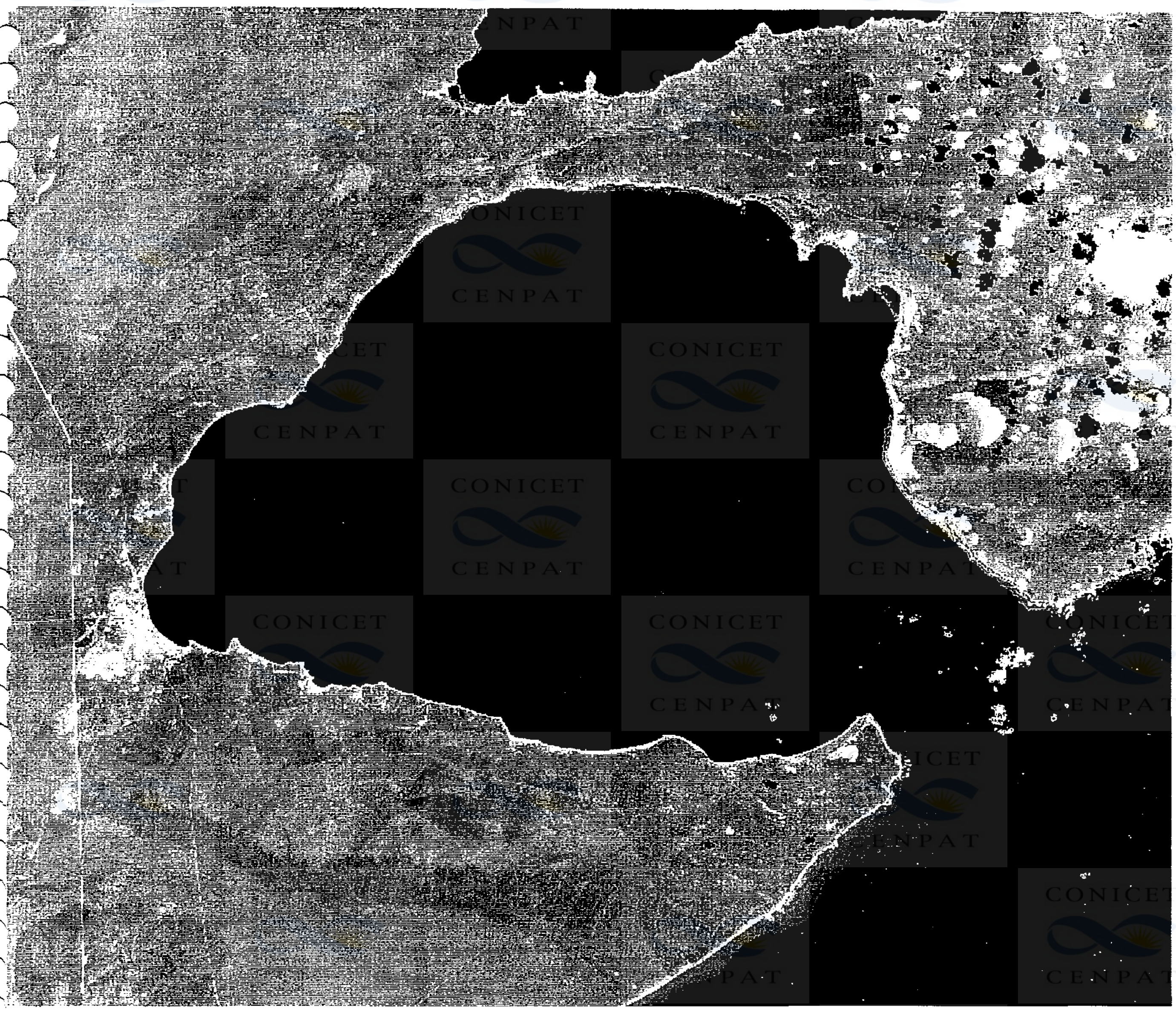
95/10/26

PATH/ROW: 693/437

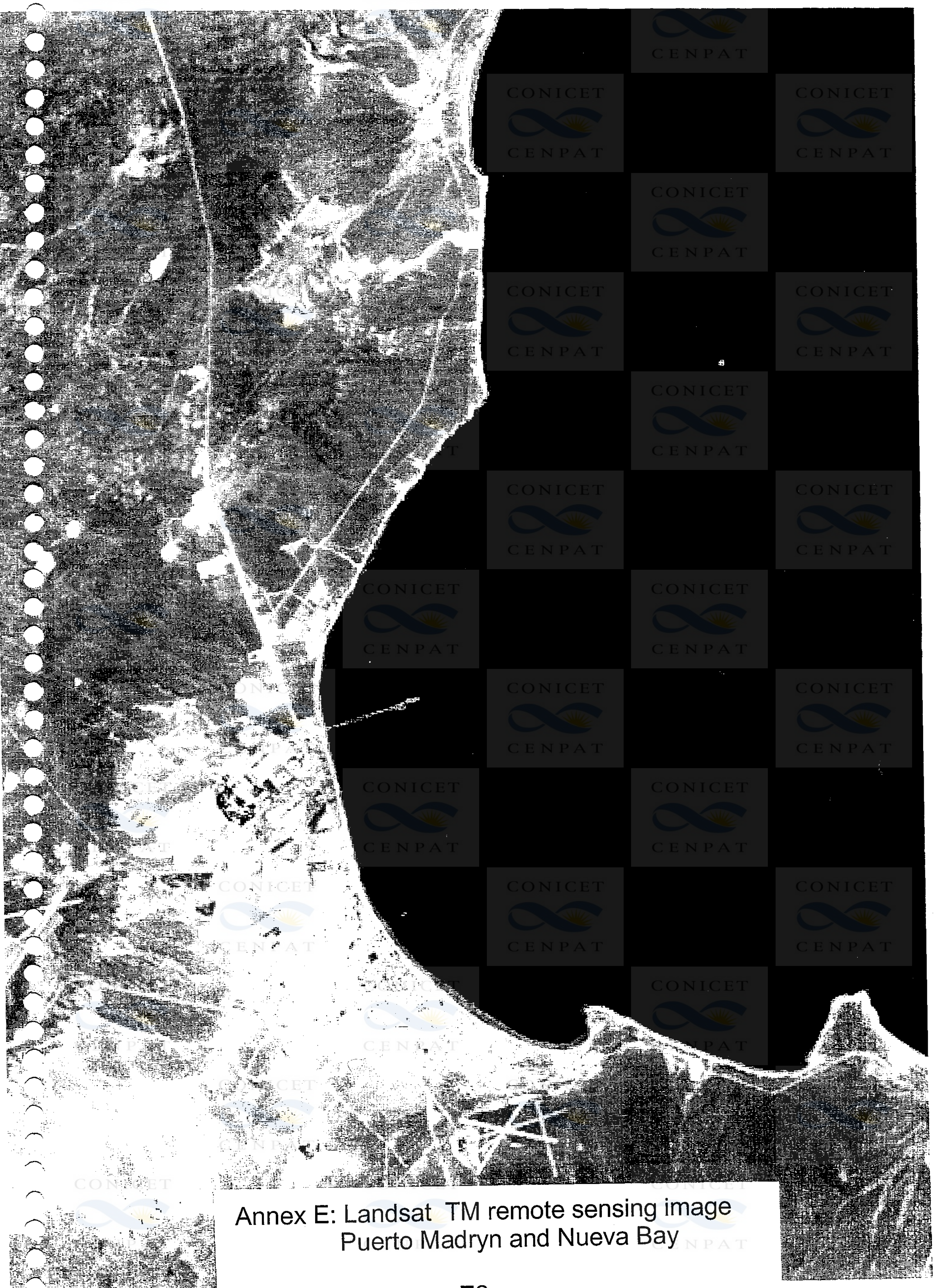
Annex D: Spot remote sensing images (Nuevo Gulf)

ANNEX E

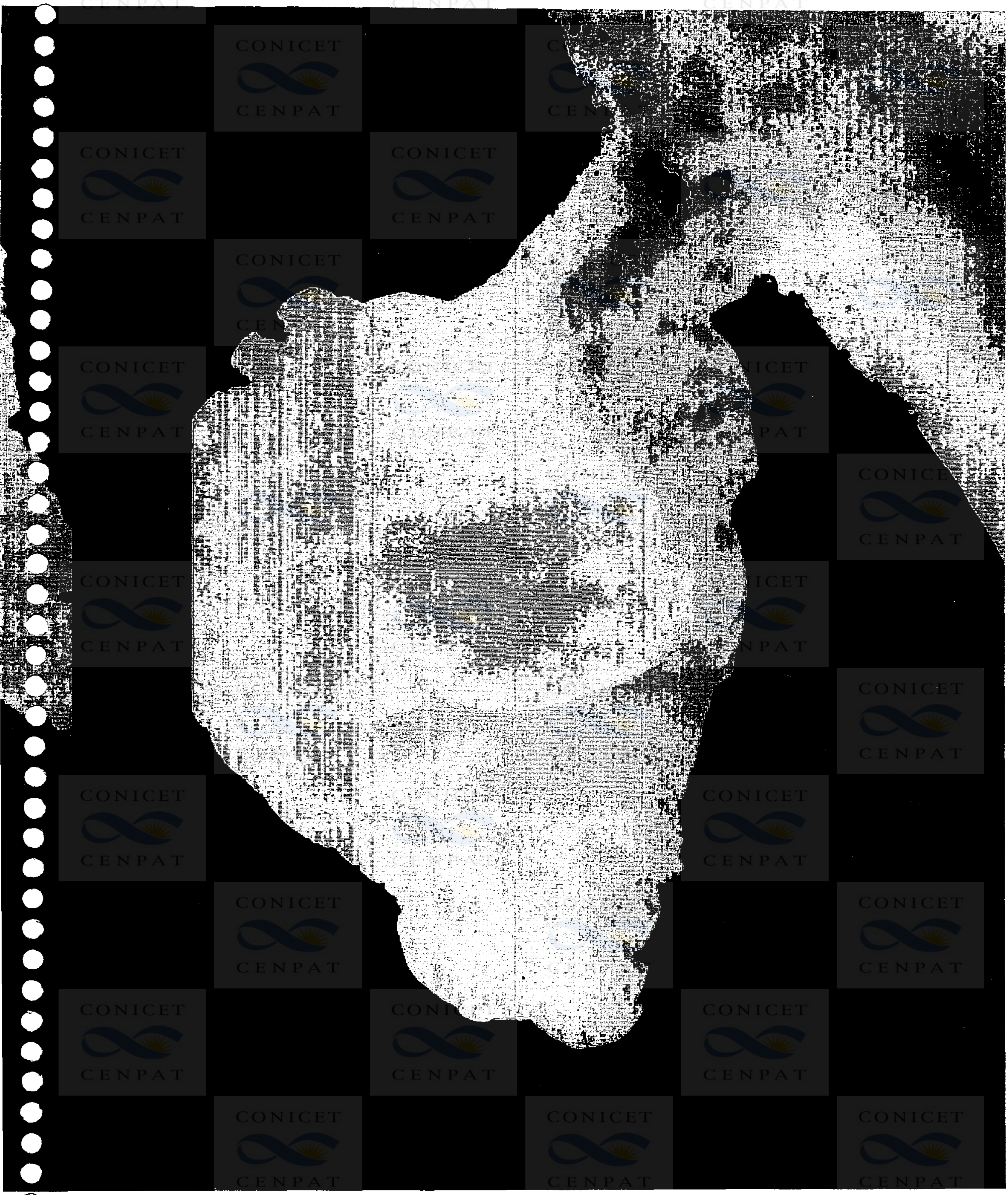
Remote sensing images of Nuevo Gulf - LANSAT TM



Annex E: Landsat TM remote sensing image
Nuevo Gulf



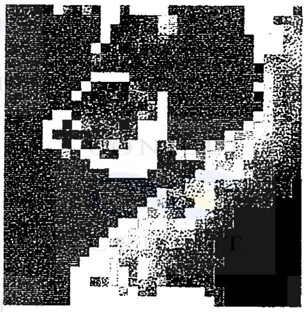
Annex E: Landsat TM remote sensing image
Puerto Madryn and Nueva Bay



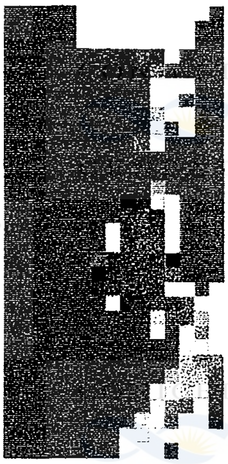
Annex E: Landsat TM remote sensing image
Golfo Nuevo - Temperature - February 19/2/86

ANNEX F

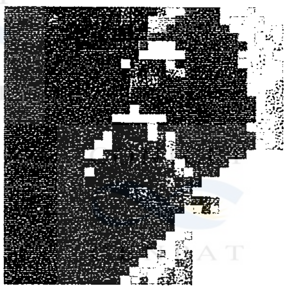
Remote sensing images: Chlorophyll “a” - SEAWIFS



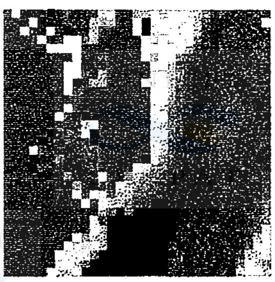
97/09/16



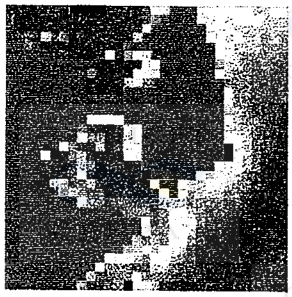
97/09/19



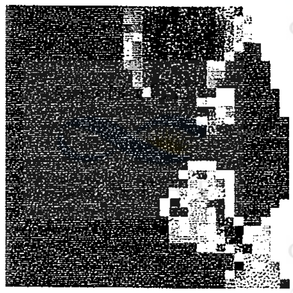
97/09/20



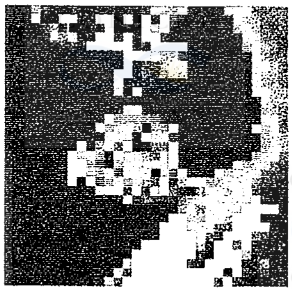
97/09/21



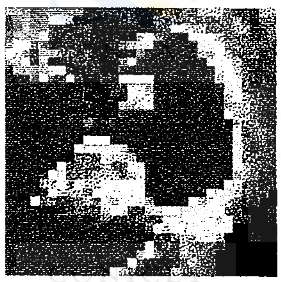
97/09/25



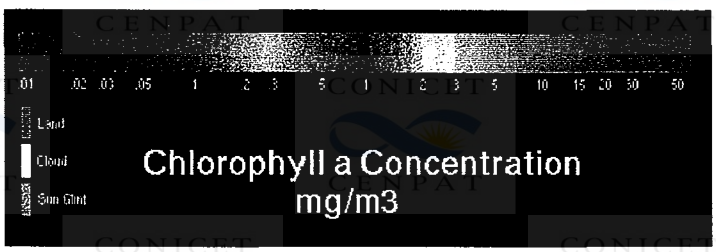
97/10/03



97/10/06

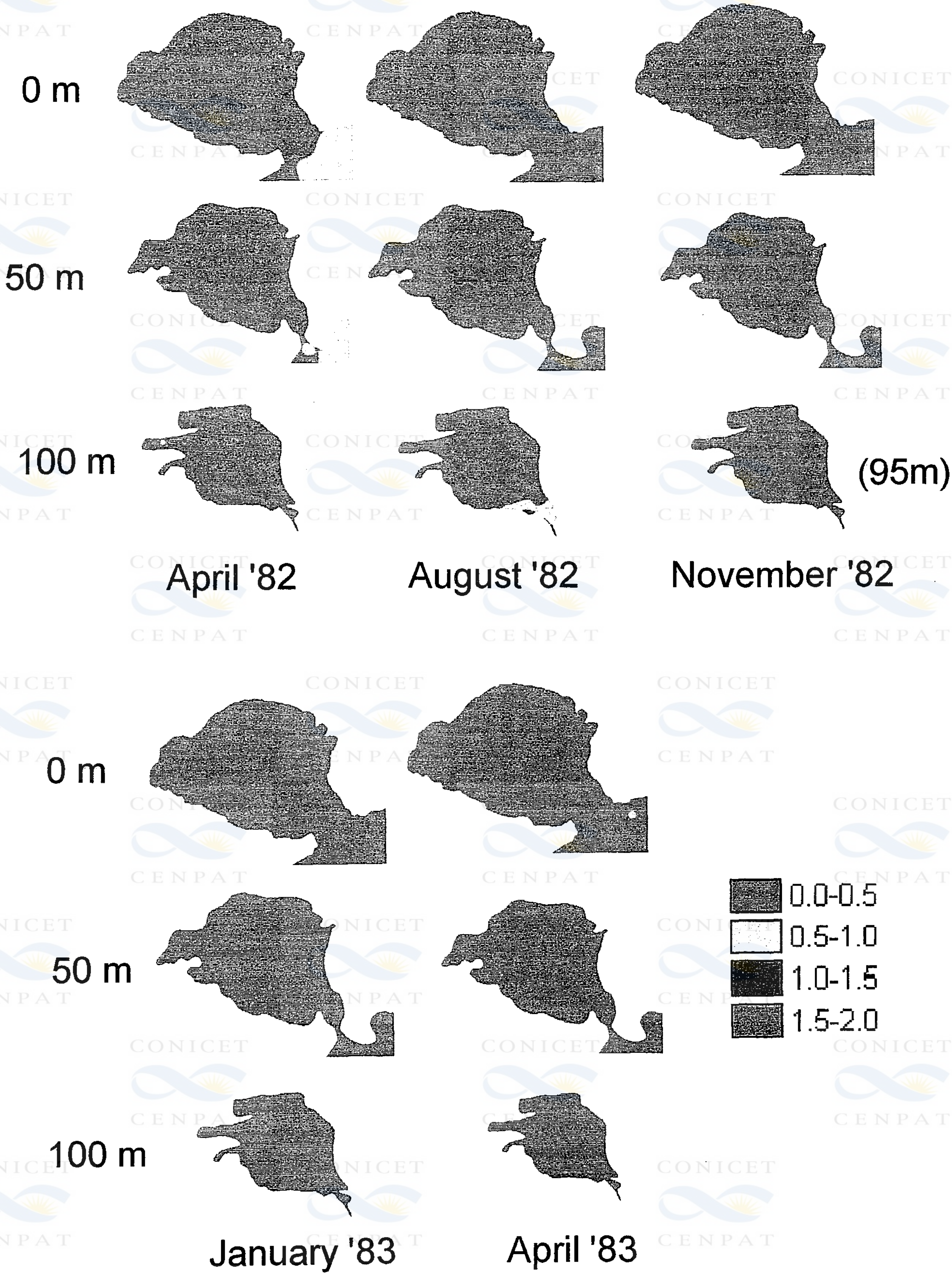


97/10/08



Annex F: Seawifs remote sensing images - Chlorophyll "a"

ANNEX G
Horizontal distributions of nitrite



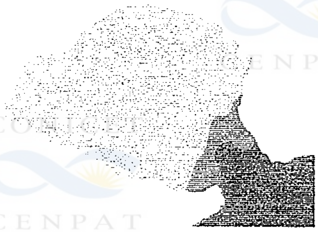
Annex G: Horizontal distributions of nitrite

ANNEX H
Combined horizontal distributions

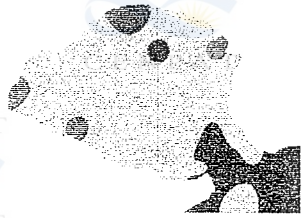
Temperature and salinity

NO3(-)-N, PO4(3-)-P and Chlorophyll

April '82

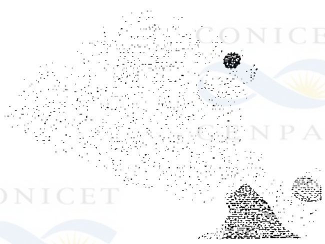


Temperature and salinity

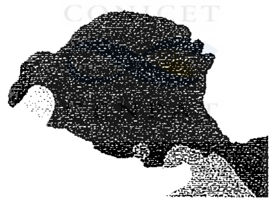


NO3(-)-N, PO4(3-)-P and Chlorophyll

August '82



Temperature and salinity



NO3(-)-N, PO4(3-)-P and Chlorophyll

November '82

Annex H:Combined horizontal distributions

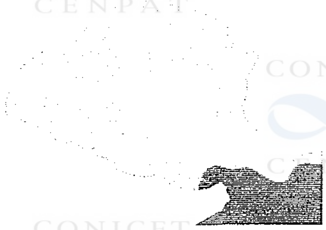
T=15-16/S=33.6-33.8
T=16-17/S=33.6-33.8
T=17-18/S=33.6-33.8
T=17-18/S=33.8=34.0
T=18-19.5/S=33.6-33.8
T=18-19.5/S=33.8-34.0

Temperature and salinity

NO3=0-0.5/PO4=0-0.5/Ch=0-1 (low nutrients, Ch 0-1)
NO3=0-0.5/PO4=0.5-1/Ch=0-2
NO3=0-0.5/PO4=1-2/Ch=0-1
NO3=0.5-1/0.5-1/Ch=0-1
NO3=1-4/PO4=0.5-1/Ch=0.1 (high nutrients, Ch 0-1)

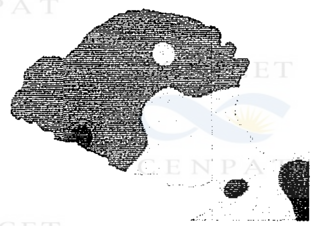
NO3(-)-N, PO4(3-)-P and Chlorophyll

January '82



T=15-16/S=33.6=33.8
T=16-17/S=33.6=33.8

Temperature and salinity



NO3=0-1/PO4=0-1/Ch=0-2 (low nutrients, Ch 0-2)
NO3=0-1/PO4=1-2/Ch=0-1
NO3=1-2/PO4=0-1/Ch=0-2 (high nutrients, Ch 0-2)

NO3(-)-N, PO4(3-)-P and Chlorophyll

April '83

Annex H:Combined horizontal distributions