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CHUBUT RIVER ESTUARY (ARGENTINA): ESTUARINE VARIABILITY UNDER DIFFERENT CONDITIONS OF RIVER DISCHARGE

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E. Walter Helbling [1], Jose M. Santamarina [2], and Virginia Villafañe [1]: Chubut River Estuary (Argentina): Estuarine Variability Under Different Conditions of River Discharge.

Monthly samples were obtained during 1986 and 1987 at fixed stations along the estuary during low and high tide. Additional cruises were done during complete tidal cycles (around 12 h) to measure velocity and salinity at different sections of the estuary. During the time of study the river flux changed from low values in summer (<10 m^3 s^{-1}), to high values in winter-spring (>50 m^3 s^{-1}). A stratification-circulation diagram was used to classify the estuary that changed from well mixed to salt-wedge with increasing river flow. Velocity profiles showed low values near the bottom with a "null zone" that moved daily along the study area in relation with the height of the tide.

Nutrient concentrations were generally higher in river waters than in seawater. An increasing removal/utilization of nutrients within the estuary was particularly evident with an increment in the river flow. The two years considered showed similar amounts of silicon and phosphorus inputs into the Bahía Engaño area, however, nitrogen inputs during 1987 were three times higher than the values observed during 1986.

Keywords: Estuary, stratification, nutrients, new production

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RESUMEN

Durante 1986 y 1987 se realizaron muestreos mensuales en estaciones fijas a lo largo del estuario, durante marea baja y alta. En distintas secciones del estuario se midió la salinidad y se realizaron perfiles de velocidad durante campañas adicionales de aproximadamente 12 horas (ciclo de marea). El caudal de río varió desde menos de 10 m^3 s^{-1} en verano, hasta más de 50 m^3 s^{-1} en invierno-primavera. El estuario se clasificó usando un diagrama de estratificación-circulación; el estuario varió desde bien mezclado a tipo cuña salina con aumento del caudal. Los perfiles de velocidad mostraron que la "zona nula" se movió diariamente a lo largo del estuario y que su posición dependía de la altura de marea.

Las concentraciones de nutrientes fueron generalmente más altas en el río que en el agua de mar. Con un aumento del caudal del río una mayor cantidad de nutrientes fue removida/utilizada en el estuario. En los dos años considerados en este estudio, el río aportó cantidades similares de sílice y fósforo al área de Bahía Engaño; sin embargo la cantidad de nitrógeno aportada durante 1987 fue tres veces mayor que la de 1986.

Palabras Claves: Estuario, estratificación, nutrientes, nueva producción

INTRODUCTION

The estuaries are areas of transition from river to ocean. They are characterized by the possibility of tidal motions communicated from the sea and by gradients of salinity and density associated with progressive admixture of river and sea water (Hansen & Rattray, 1966). The main driving forces for circulation in estuaries are the freshwater runoff, the tide, and the wind stress (Cameron & Pritchard, 1963; Hansen & Rattray, 1965; Linden & Simpson, 1988; Kjerfve, 1989; Pritchard, 1989). Three regimes have been defined in an estuary according to the longitudinal salinity distribution: the outer, the central, and the inner regime (Hansen & Rattray, 1965; Hamilton & Rattray, 1978). Furthermore, Elliott (1976) defined six circulation modes that represented six different stages of the Potomac estuary, Virginia.

The distribution of nutrients and dissolved gases in estuarine waters are mainly controlled by the estuarine circulation and mixing, together with biological, sedimentological and chemical effects (Burton, 1976; Aston, 1980; Pritchard & Schubel, 1981). River waters usually have a concentration of nutrients that is well above the concentration in seawater (Liss, 1976; Biggs & Cronin, 1981). The nutrient content in river waters varies with freshwater discharge from land drainage, and the geological/geochemical character of the basin. The sources of nutrients also include ground water inflow, direct waste discharges, rainfall and atmosphere particles (Bigg & Cronin, 1981; Pritchard & Schubel, 1981).

The Chubut river is the most important river in the Chubut Province (Argentina) and crosses it from the Andes mountains to the Atlantic Ocean, discharging its waters into an area called Bahía Engaño. There are many cities along the river that utilize its water and discharge waste products into it. In the area of Gaiman and Trelew (>10 km upstream of the mouth of the river) it is especially utilized for agricultural purposes and during spring and summer the river is diverted into many watering channels.

In the case of the Chubut river estuary the estuarine circulation and classification under low river discharge have been presented in other studies (Perillo *et al*. 1987, Perillo *et al*. 1989). Villafañe *et al*. (1991) also presented how changes in stratification influenced the development of phytoplanktonic blooms in the estuary. However, seasonal changes in the estuarine circulation and nutrient availability with different river discharges have not been described before.

The present study seeks to answer questions regarding the dynamic and circulation of the estuary and its temporal variations due to fluctuating river discharge. Also the behavior of the nutrients with different conditions of river flux are considered. Finally, the contribution of the Chubut river to the biological production (new production) of the coastal area of Bahía Engaño during 1986-1987 is addressed.

STUDY AREA

The Chubut river estuary is located in the province of Chubut, at latitude 43°20'S and a longitude 65°04'W. The area of study was from the Rawson Bridge to the mouth of the river (Fig.1). The distances between the Tide Gauge (St. 1), Harbor (St. 2), Elsa (St. 3), Matadero and Rawson Bridge were 0.8 km, 2.5 km, 5 km and 8 km, respectively.

In this area the river has a width that varied from 40 to 100 m during low tide and from 70 to near 200 m during high tide. The mean depth of the principal channel was approximately 1.5 meters at low tide. The tides are semidiurnal and have a mean amplitude of 3.33 m for spring tides and 2.28 m for neap tides (Servicio Hidrografía Naval, 1986, 1987).

The river discharge is primarily regulated by the Florentino Ameghino Dam (located about 120 km upstream from the mouth) and has a historical mean discharge of 56 $m^3 s^{-1}$ (Eddy Jones, Agua y Energia, pers. comm.).

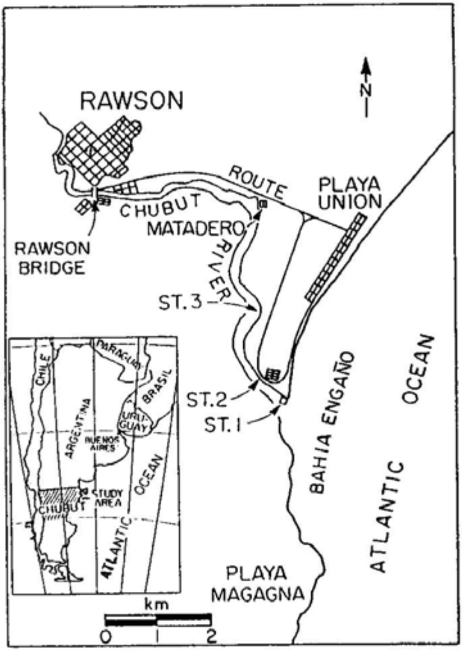

Figure 1. Study area and location of fixed sampling stations. ST1: Tide Gauge; ST2: Harbor; ST3: Elsa.

MATERIAL AND METHODS

Water samples were obtained from two different types of cruises during 1986 and 1987. Also parameters such as temperature, conductivity and water velocity were measured. The first type were monthly cruises in which water samples were taken at three fixed stations; St 1: Tide gauge, St 2: Harbor, and St 3: Elsa (Fig. 1), at both surface and bottom, and during high and low tide. Measurements of *in situ* temperature and conductivity of the water were obtained at each station with a protected SIAP thermometer and a WTW conductivity sensor, respectively. A 3-liter Van Dorn bottle was used to obtain water samples for measurements of salinity (Plesey salinometer) and nutrient concentrations.

Water from the Van Dorn bottle was transferred to a) 100 ml Pyrex cylinders for ammonium determinations, b) 500 ml acid washed plastic bottles for nitrate, nitrite, phosphate and silicic acid analyses, and c) 250 ml glass bottles for salinity determinations. Ammonium was done by the blue indophenol method inmediately after each cruise. The samples for other nutrients were frozen (-20°C) until analyses. Nitrate and nitrite analyses were carried out using a Technicon autoanalyzer while phosphate and silicic acid were measured in a Hitachi 110 spectrophotometer. All nutrient analyses were done following the techniques described by Strickland & Parsons (1972).

The second type of cruises were designed to measure velocity and conductivity of the water column at two stations. These cruises were performed with conditions of river discharge that fluctuated from 10 to 70 $m^3 s^{-1}$ and with data taken at a depth interval of 20 cm and every 15 minute over the whole tidal period. Conductivity was measured with a WTW conductivity sensor and the data converted to salinity (Dietrich *et al*, 1980) while velocity was measured with a SIAP speedometer. Five of these cruises were done at fixed stations (Tide Gauge and Harbor), and other four were done, during high tide, from the Tide Gauge to the Rawson Bridge (Fig. 1). In these latter surveys only conductivity was measured in the water column.

In this study the nomenclature of Hansen & Rattray (1965) is used for the different regimes encountered in the estuary as follow: a) **outer regime** was considered as the mass of water with salinity equal to or greater than 30, b) **central regime** corresponded to the mass of water with salinity between 30 and 1.5, and c) **inner regime** was the mass of water with salinity equal to or less than 1.5.

RESULTS

The Chubut river showed seasonal fluctuations in discharge due to rainfall and snowfall during winter, and melting of snow during spring, however, as mentioned above is important to emphasize that the flux in the lower portion of the river is mainly regulated by the Florentino Ameghino Dam. The flux showed high values (54 and 75 $m^3 s^{-1}$ for 1986 and 1987, respectively) during late winter-spring and low values (<10 $m^3 s^{-1}$) at the end of the summer (Fig. 2).

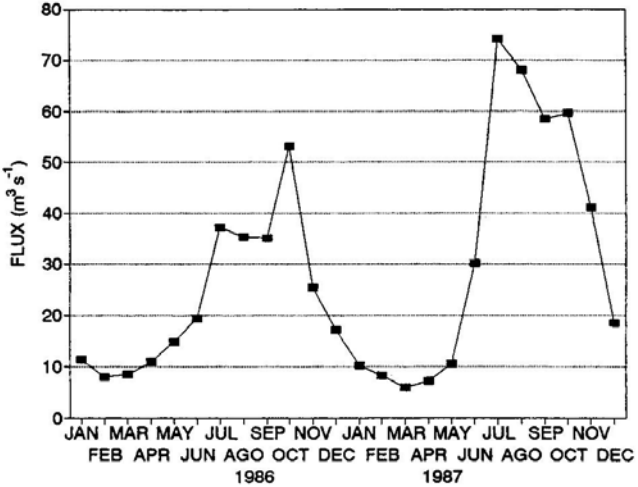

Figure 2. Flux of the Chubut river. Data are monthly mean in m^3 s^{-1} for the years 1986 and 1987. Data provided by Agua y Energía.

SALT DISTRIBUTIONS:

At the sampling stations (Fig. 1) the inner regime was found only during low tide only (Fig. 3a), however, the three regimes mentioned above were found during high tide (Fig. 3b, c). The position of these regimes, especially the central regime, shifted with changing height of the tide. The 30 isohaline at mid depth moved nearly 2 km between a high tide of 3.3 m and other of 4.3 m, with the same river discharge (40 m^3 s^{-1}).

At the station Tide Gauge small vertical stratification was observed during the ebb tide with low river discharge (10 m^3 s^{-1}). However, during the flood there were big differences in salinity between surface and waters at depth (Fig. 4a). With an increase in discharge (40 m^3 s^{-1}) this station showed vertical salinity stratification only during two hours at both, the rising and the ebb tide (Fig. 4b). With the same conditions of discharge (40 m^3 s^{-1}) the Harbor station showed a great vertical stratification during the whole high tide (Fig. 4c).

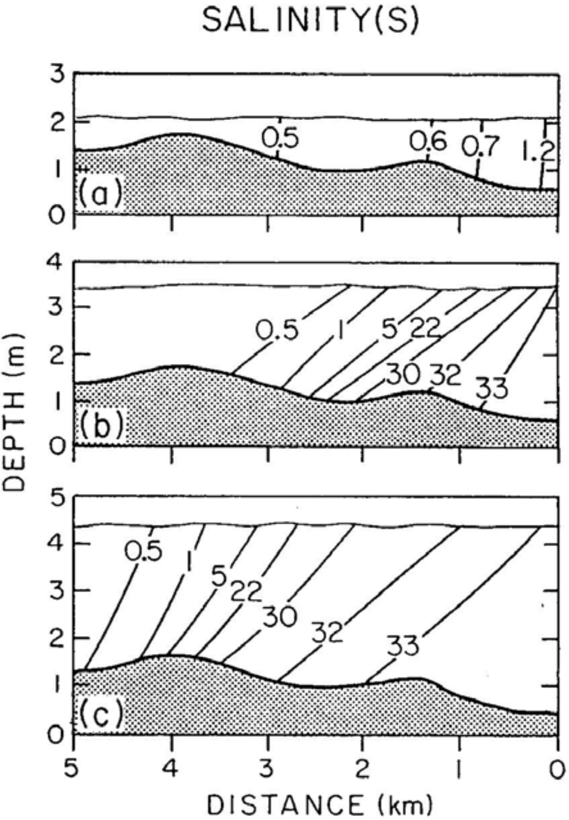

Figure 3. Longitudinal salinity distribution with a river discharge of 40 $m^3 s^{-1}$. Distance in km from the mouth of the river (Tide gauge). **a**, low tide. 1.1 m. **b**, high tide, 3.3 m. **c**, high tide, 4.3 m.

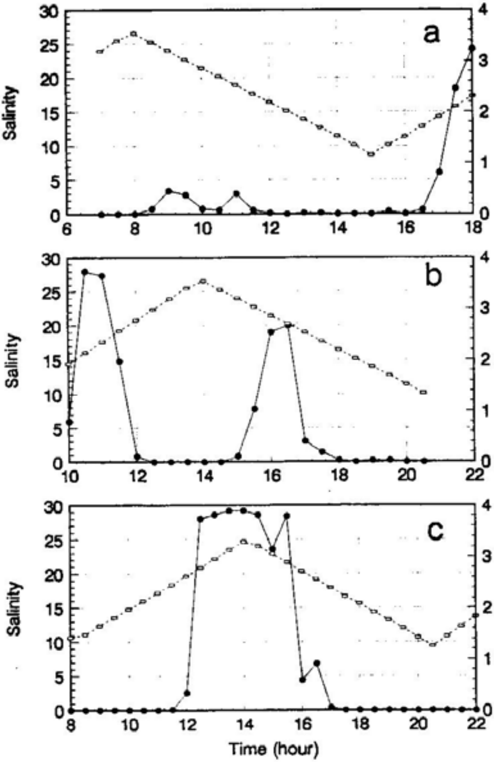

Figure 4. Measurements of bottom to surface salinity difference (filled circle) and height of the tide (empty square) over time. **a**, station Tide gauge with a river discharge of 10 $m^3 s^{-1}$. **b**, same as A but for a river discharge of 40 $m^3 s^{-1}$. **c**, station Harbor with a river discharge of 40 $m^3 s^{-1}$.

VELOCITY PROFILES AND CIRCULATION:

Velocity profiles measured with a river flux of 40 $m^3 s^{-1}$ are shown in Fig. 5. These profiles indicate that during low tide the flow at all depth was seaward, however, the effect of the rising tide was noted, in a reduction of the velocity at all depths, up to about 1.5 h after the low tide (Fig. 5b). With an increase of the height of the tide an inversion of velocity (i.e., landward) was noticeable at depth (Fig. 5c). This landward velocity increased in magnitude and in extension to depth with the continuing rising of the tide. A seaward flow in the upper surface layer was noted to about 2.5 hours after the low tide. After this time the flow reversed completely at all depths and a net landward flow continued until the high tide (Fig. 5).

Three modes of circulation were observed in the study area during the time of this study, they were: discharge, classical and storage circulation. At the mouth of the river (Tide Gauge station) the discharge circulation prevailed during low tide with outflow of freshwater at all depths (Fig. 5a). Seaward from this station a plume was formed, with freshwater overriding seawater. During the rising tide the classical circulation was observed (Fig. 5c, d), with outflow of freshwater at surface and inflow of seawater at depth (Fig. 4b). During high tide, the storage circulation occurred, with an inflow of seawater at all depths (Fig. 4b, 5). The percentages of time that each one of these three circulation modes appeared in a single day are presented in Table 1. They were function of the river flux, height of the tide, and the distance from the mouth of the river.

Table 1. Percentage of time that each circulation mode (discharge, classical, and storage) appeared in a single day with different condition of river discharge for stations Tide Gauge and Harbor.

	TIDE GAUGE			HARBOR
Caudal ($m^3 s^{-1}$)	10	40	70	40
Discharge circulation	40%	50%	60%	60%
Classical circulation	15%	15%	25%	30%
Storage circulation	45%	35%	15%	10%

CLASSIFICATION OF THE ESTUARY

The classification of Hansen & Rattray (1966) was applied at two stations, Tide Gauge (for a river discharge of 10, 40, and 70$m^3 s^{-1}$) and Harbor (for a river discharge of 40$m^3 s^{-1}$). The classification was done for tide amplitudes of 2.1 m, value that was close to the mean amplitude of the neap tides, 2.28 m. The characteristic parameters for the stratification-circulation diagram (Fig. 6) for these two stations and conditions are shown in Table 2.

Figure 5. Velocity profiles (velocity in cm s^{-1} and depth in m) measured at station Tide gauge with a river discharge of 40 m^3 s^{-1}. Positive values indicate that the flow is in a seaward direction, negative values indicate landward flow. Time after the low tide: **a**, 45 min; **b**, 1h 25 min; **c**, 1h 50 min; **d**, 2h 55 min; **f**, 5h 15 min; and **g**, 6h 24 min (high tide).

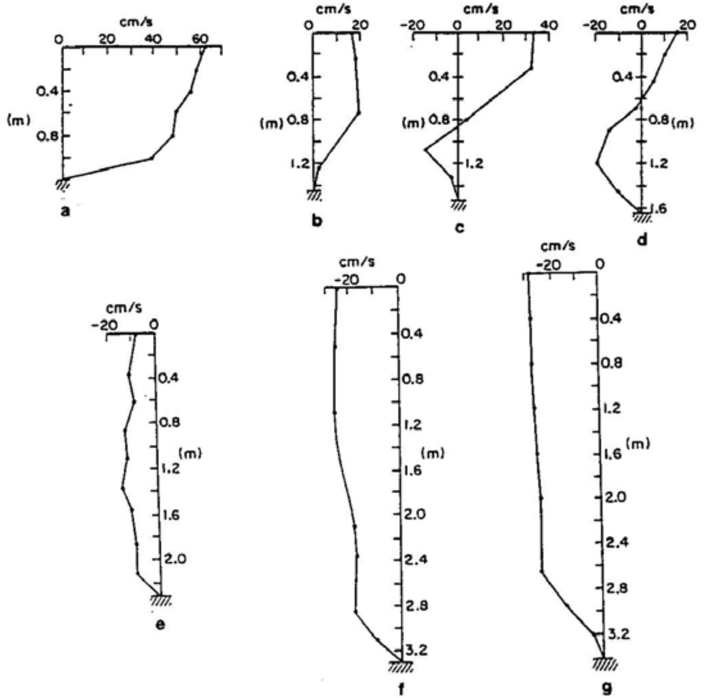

Table 2. Characteristic parameters of the Chubut river estuary for the stratification circulation diagram.

	TIDE GAUGE			HARBOR
Caudal(m^3 s^{-1})	10	40	70	40
A(m^2)	150	200	280	160
dS/So	0.06	0.2	1.4	1.0
Us/Uf	1.28	1.25	13.5	2.7

The classification on the Tide Gauge station changed according to the river discharge. For a river flux of 10 m^3 s^{-1} the classification obtained was a type 1a estuary (point A in Fig. 6), which corresponds to an estuary with a net seaward flow at all depths and the upstream salt transfer is carried out by diffusion. This type 1a corresponds to a typical well-mixed estuary in which salinity stratification is low. With an increase in river discharge (40 m^3 s^{-1}) the classification changed to a **type 1b** estuary, (point B in Fig. 6), which also corresponds to a net seaward flow at all depths and an upstream salt transfer effected by diffusion, but with an appreciable stratification. For a river discharge of 70 m^3 s^{-1} the classification was a **type 4** estuary (point C in Fig. 6). In a type 4 estuary, the stratification is great and is normally referred to as a salt-wedge estuary.

For the Harbor station the classification with a river discharge of 40 m^3 s^{-1} was a **type 2 b** estuary (point D in Fig. 6). In this type the net flow reverses at depth and both advection and diffusion contributes importantly to the upstream salt flux. In this type 2b estuary there is also appreciable stratification.

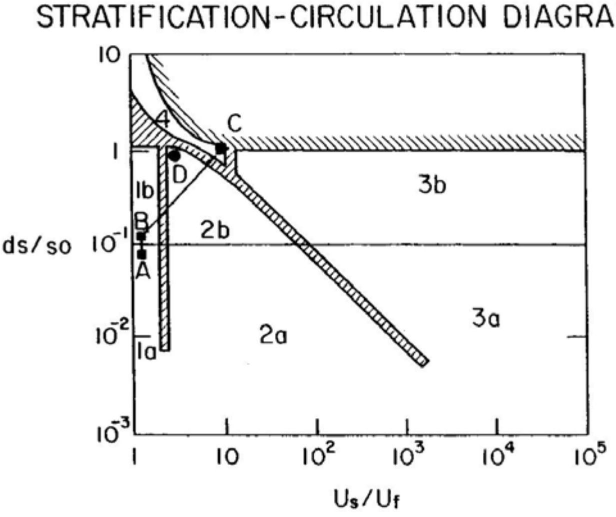

Figure 6. Stratification-circulation diagram. Points A, B, and C correspond to the Tide Gauge station for a river discharge of 10, 40 and 70 m^3 s^{-1}, respectively. Point D correspond to Harbor station for a river discharge of 40 m^3 s^{-1}.

MIXING DIAGRAMS AND NUTRIENT DISCHARGE

The flux of the river was one of the most important parameters that determined the mode of circulation and type of classification of the estuary. Therefore, it was important to study the behavior of nutrients such as DIN (DIN = $NH_4^+ + NO_3^- + NO_2^-$), phosphate and silicic acid, with changing conditions of river flux. The behavior of nutrients was studied using mixing diagrams (concentration vs. salinity). In these diagrams salinity was assumed to behave conservatively during the mixing of the two end members of the estuary.

Representative diagrams are presented for extreme conditions of discharge. With a river flux of approximately 10 $m^3\ s^{-1}$ phosphate concentration was almost the same in the low and high salinity waters, with small variation in between (Fig. 7a). However, DIN behaved as a non-conservative property and apparently the estuary served as a source of DIN during this condition (Fig. 7a). Silicic acid was an almost conservative property, with only a very small deviation from a straight line at around salinity 7 (Fig. 7b). With an increase in discharge (around 40 $m^3\ s^{-1}$) phosphate and DIN were close to a straight line with small deviations at salinities near 25. Since the data is scarce for this condition it is difficult to assess the behavior of phosphate and DIN but it seems that they showed a conservative way (Fig. 7c), however, silicic acid responded as a non-conservative property (Fig. 7d). With a river discharge of around 70 $m^3\ s^{-1}$ all dissolved nutrients showed a non-conservative behavior with an important removal of nutrients in the central regime (Fig. 7e, f).

The concentrations of dissolved nutrients were generally much higher in the inner than in the outer regime (Fig. 7). The amount of nutrients that were removed in the estuary during mixing was obtained using mixing diagrams (Liss, 1976; Hydes & Liss, 1977; Officer, 1979). The fractional loss of nutrients, G, within the estuary was calculated as:

$$G = [Co - Co^*]/Co$$

where Co is the concentration of the river end member, and Co* the concentration value when the concentration at high salinity values is extrapolated back to salinity equal to the river member.

When river waters discharge into the ocean great amounts of nutrients are transferred into it. The annual budget of nutrient input the Bahia Engaño area by the Chubut river was calculated as follow: each year was divided in three intervals according to the river flux; a) the first interval was composed by all months with river flux <30 $m^3\ s^{-1}$; b) the second one was the months with river flux between 30 and 60 $m^3\ s^{-1}$; and c) the third was the months with river flux >60 $m^3\ s^{-1}$. The percentage of time that each mode of circulation was present at the Tide Gauge station for 10, 40, and 70 $m^3\ s^{-1}$ of river flux was assumed to be representative of each one of these three intervals. For each one of these intervals the mean concentration of nutrients (DIN, phosphate and silicic acid) was multiplied by the mean river flux, then by a factor that depended on the circulation mode and finally by the

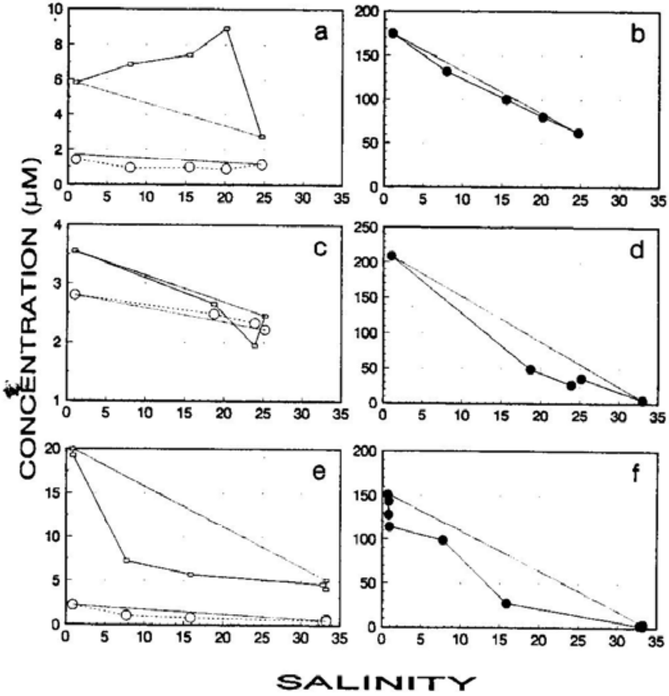

Figure 7. Mixing diagrams, concentration of nutrients (µM) vs. salinity, of DIN (open squares), phosphate (open circles) and silicic acid (solid circles). **a** and **b**, river flux 8.1 m^3 s^{-1}; **c** and **d**, river flux 35 m^3 s^{-1}; river flux 60 m^3 s^{-1}.

percentage that the circulation mode was present for that particular flux. For the discharge circulation the factor used was one, and for the normal and storage circulation the factor used was also affected by removing the percentage of nutrients that were lost during mixing (Table 3A). The total nutrient inputs for 1986 and 1987 are shown in Table 3B. For 1986 only 11 months were considered due to lack of data for January.

The concentration of nutrients did not show any correlation with the flux during 1986; but apparently nitrate concentration decreased with increase river discharge ($r^2 = 0.74$, $n = 11$). However, during 1987 nitrate and phosphate concentrations presented a positive correlation with increased river discharge ($r^2 = 0.84$ and 0.85, $n = 12$ for nitrate and phosphate, respectively).

Table 3: Chubut river estuary, nutrient behavior and inputs in the Bahía Engaño area.

A) Lost fraction, G, for each nutrient in each interval

Interval	silicate	phosphate	D.I.N.
a) $X<30\ m^3\ s^{-1}$	7%	—	—
b) $30<X<60\ m^3\ s^{-1}$	47%	—	7%
c) $X>60\ m^3\ s^{-1}$	65%	50%	62%

B) Nutrient inputs, values are in metric tons per year.

year	silicate	phosphate	D.I.N.
1986*	36,700	675	448
1987	27,000	647	1,529

* For 1986 only eleven months were considered due to lack of data for January.

DISCUSSION

An estuary would tend to shift from highly stratified through partially mixed to well mixed with: a) decreasing flow, b) increasing tidal velocities, c) increasing width and d) decreasing depth (Pritchard, 1989). Hansen & Rattray (1965) observed that the vertical salinity stratification in the central regime was nearly independent of the longitudinal position. However, in this study it was observed that the stratification of the water column increased at the mouth of the river (Tide Gauge station) with increasing flux of the river, and also from the Tide Gauge station (mean width and depth 150 m and 2.5 m, respectively) to the Harbor station (mean width and depth 100 m and 1.5 m, respectively) with the same conditions of river discharge (Fig. 6). This increase in stratification with decreasing depth and position seems to be different from studies in other estuaries (Pritchard, 1989), but in agreement with the work of Festa & Hansen (1976).

Although the classification of the Chubut river estuary corresponded to a well mixed estuary at the mouth with low river discharge (Fig. 6), during the rising tide there was an appreciable stratification with an intrusion of salt water at depth (Fig. 4). A rather similar behavior was observed in early studies (Perillo *et al.*, 1989) at one station 4.5 km upstream from the mouth of the river. Perillo *et al.* (1989) also noted that the salt intrusion reached up to 4.5 km from the mouth with a river flux of 20 m^3 s^{-1} , however, strong winds (in the order of 100 km h^{-1}) distorted the tidal wave and the amplitudes of the tides were around one meter below the predicted ones. These strong winds are frequently present during spring, and it is expected that without wind the salt wedge would reach farther upstream during seasons of low river discharge.

River waters were present at all depths during the discharge circulation, but only at surface during the classical circulation. The availability of freshwater at the mouth of the river (Tide Gauge station) was at least 40% to 60% of the day for low and high river discharge, respectively. For landward stations the percentage of time freshwater availability was greater.

One of the most distinctive features of sediment transport in estuaries is the presence of a turbidity maximum (Dyer, 1986). The location of the "null zone" varies according to the type of estuary, river flow and it can also move between neap and spring tides (Dyer, 1978, 1979, 1986; McCave, 1979). For the Chubut river estuary the null zone varied with time along the study area and was noticed at least up to the Rawson Bridge (Fig. 1). It is expected that with this variation of the null zone great sedimentation takes place along the whole area, from the Rawson Bridge to the ocean. Also with the weak velocities measured close to the bottom (Fig. 5) during the rising and high tide, it is expected an enhancement of sedimentation during this conditions. According to Dyer (1979) for salt-wedge estuaries the bedload sediment will be deposited at the tip of the salt wedge and the fine suspended sediments are generally carried out into the sea as a plume.

The knowledge of the estuarine circulation, with different river discharges, allowed to have a better understanding of the circulation of nutrients and waste materials and their discharge into the Bahía Engaño area. Many authors considered that the majority of biotically important compounds entering an estuary are from riverine sources (Burton & Liss, 1973; Boyle *et al*, 1974; Officer & Ryther, 1980; Kemp, 1989). Silicon comes from the weathering of land coastal zones, while nitrogen and phosphorus come from sewage, industrial and agricultural sources. In the Chubut river estuary the concentrations of nutrients were higher in river waters than in the seawater, having silicates the most noticeable differences, with a concentration an order of magnitude higher (Fig. 7).

The two years considered in this study (1986 and 1987) showed big differences in nutrient concentrations, with interannual variations greater than seasonal ones (Helbling, 1989). These differences were not only observed in the behavior of the constituents over time, but also in the total amount of nutrients that the river discharged into the Bahía Engaño area. During 1987 the amounts of silicon and phosphorus discharged were lower than in 1986 but in the same order of magnitude (Table 3B). On the other hand the amounts of nitrogen discharged during 1987 were more than three times the values of 1986 (1,529 and 448 metric tons, respectively). Comparing the total amount of nutrients discharged into Bahía Engaño with the worldwide river nutrient transport giben by Meybeck (1982) and Levingstone (this latter cited in Burton & Liss, 1973) the quantity of phosphorus exported each year by the river was three orders of magnitude less than the worldwide average. In the case of nitrogen the inputs were three and four orders of magnitude less than the worldwide value for 1987 and 1986, respectively. In the case of silicon the input was close to four orders of magnitude less than the worlwide value.

Although the lack data of the amounts of inputs of sewage, industrial waste, or agricultural products into the Chubut river, it is thought that these inputs could explain great part of the variability between years. It is expected that at least the agricultural products increased during spring due to the addition of fertilizers to the land (National Institute of Agriculture Technology, INTA, pers. comm.). During this season the river is diverted in watering channels and this increases the possibility that nutrients from land sources were carried by the river.

Silicate is considered as a nutrient that behaves almost conservatively and that is often insensitive to changes in discharge compared with other major nutrients (Edwards & Liss, 1973; Boyle *et al*., 1974; D'Elia *et al*., 1983). Considerations have been made regarding the removal of silicates by biological processes (uptake by diatoms and silicoflagellates) or by chemical precipitation (Liss & Spencer, 1970; Wollast & DeBroeu, 1971; Burton & Liss, 1973; Edwards & Liss, 1973; D'Elia *et al*., 1983). For the Chubut river estuary silicates behaved as an almost conservative nutrient with low river discharge, which expect a well-mixed condition. However, when the river discharge was greater than 30 m^3 s^{-1} silicate behaved as a non-conservative nutrient and much of it were removed within the estuary (Table 3A and Fig. 7). Phosphates and DIN also behaved as non-conservative constituents, but they were removed within the estuary primarily at high river flux (Table 3A).

According to the results presented in this paper it seems that with low river discharge (well-mixed conditions) nutrients were mainly discharged directly into the area of Bahía Engaño. However, as soon as the river flux increased (high stratification), more nutrients were removed/utilized within the estuary (Table 3A). It is thought that high percentage of the variability in the removal and utilization of nutrients in the area was due to phytoplankton (Villafañe *et al*., 1991). This complex situation of changing in stratification conditions together with a greater input of nitrogen during 1987 allowed high blooms of phytoplankton to develop as described by Villafañe *et al*. (1991).

In conclusion the types of circulation and estuarine classification were mainly driven by the river discharge. With low discharge (low stratification) nutrients were not used or removed within the estuary. However, high river fluxes (high stratification) nutrients behaved as non-conservative property (when compared with salinity) and were removed within the estuary.

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