THALASSAS

Thalassas, 2005, 21 (2): 31-38
An International Journal of Marine Sciences

ENVIRONMENTAL IMPACT ASSESSMENT IN A HARBOUR AREA, ARGENTINA

EDUARDO A. GÓMEZ [(1)], DIANA G. CUADRADO [(1) (2),(3) *] AND GISELA A. FEDERICI [,(3)]

Keywords: accumulation, dredging, coastal engineering, man-made modifications, Bahía Blanca estuary.

ABSTRACT

An environmental evaluation is carried out to define the impact that some man-made modifications done on tidal plains some years ago has produced into an adjacent harbour area. Understanding of marine processes and the behavior of the coastal ecosystem in Puerto Rosales is important to the successful implementation of any coastal projects. The environmental characteristics of the surroundings of the harbour were studied with the objective to analyze the involved process, as well as the alteration the human-modifications could generate. Once the impact was recognized a solution is proposed. The case discussed here highlights the necessity for carrying out an environmental impact assessment study before implementing a harbour project and any coastal modification. This approach that integrates the behaviour of coastal structures, impacts and alternatives, provides promising information for the planners of coastal projects, decision makers and impact assessment practitioners.

(1) Instituto Argentino de Oceanografía. CONICET. Camino La Carrindanga Km. 7. CC 804. 8000 Bahía Blanca. Argentina.
(2) Universidad Nacional del Sur. Departamento de Geología. San Juan 670. 8000 Bahía Blanca. Argentina
(3) Universidad Tecnológica Nacional, Facultad Regional Bahia Blanca. 11 de Abril 461. 8000. Bahia Blanca. Argentina
*Corresponding author: Fax: 54-291-4861519
E-mail addresses: cuadrado@criba.edu.ar, gmgomez@criba.edu.ar, federici@criba.edu.ar

INTRODUCTION

The coast and particularly the estuaries are environments that have a weak dynamical equilibrium due to the complex interaction of physical, chemical, biological and geological processes. So, any alteration caused by men on these environments can modify the equilibrium in a very important way, sometimes with unforeseen consequences.

Toorman E. A. (2001) pointed out that the cohesive sediment transport processes in coastal zones, especially in estuaries, have an important impact on the economy and the environment since cities and industries are located there and so recreational, fishing and port activities are developed. Owing to these activities, important environmental modifications are created due to industrial and sewer wastes discharges, sea defenses constructions, dredging works, location of disposal sites, etc. Several authors agree that an understanding of the transport mechanism of fine, cohesive sediment in estuaries is required as part of an effective management strategy for these systems (Mitchell, et al., 2003; Le Hir, et al., 2000; Fettweis and Van den Eynde, 2003; Winterwerp, 2002).

Usually, environmental studies are carried out before man-made modifications are done. Such knowledge allows anticipating the consequences that these modifications may have, thus allowing the correct decision in cases where they would impact negatively in the environment. Therefore, it is essential to carry out the study of physic-geological factors and their interaction (currents, winds, waves, sediments, geomorphology, etc.), prior to any coastal environment modification as its ignorance can lead to hard-to-solve mistakes with high economic and environmental costs (Stanley and Warne, 1993).

Nevertheless, man-made modifications in natural environments without prior studies are frequent in many countries. All the Latin American countries could still be classified as "underdeveloped nations" because of their economical uncertainties, delayed social development, unstable economy and political issues (Tafireño-Silva, 2002). Here, research projects are traditionally oriented through funding priorities from government institutions. Therefore, the limited budget to science results in shortages of work and investigation forces to cover the country's needs for research. This can be the explanation why many modifications are done without previous studies.

Many examples on the Egyptian coast exposed by Frihy (2001) have clearly shown that projects implemented without environmental impact assessment (EIA) can create serious undesirable impacts. EIA is the systematic identification and evaluation of the potential effects of proposed project and actions relative to physical and socioeconomic components of the environment (Canter, 1966). The purpose of an EIA is to ensure that all development options under consideration are environmentally sound and sustainable and that any environmental consequences are recognized early and taken into account in a project design. After the identification and evaluation of impact, it is a fundamental objective of an EIA to highlight measures that mitigate the unavoidable adverse consequences of the project alternative under consideration.

Understanding of marine processes and the behavior of the coastal ecosystem are important to the successful implementation of coastal projects. If such knowledge is not included in the design, significant adverse impacts are likely to occur. In this study an environment evaluation on tidal plains is done in terms of their impacts in a harbour area.

This paper presents the environmental characteristics of the surroundings of Puerto Rosales, which were greatly modified in 1995 with the objective of preventing siltation in the harbour area without any previous study (Gómez et al., 1998). The objective in the present study is the analysis of the involved process, as well as the modifications made in the port to detect the impact they produce into the environment. Once the impact was recognized a solution is proposed.

STUDY AREA

Puerto Rosales is located on the northern coast of the Principal Channel of the Bahía Blanca Estuary, at the south of Buenos Aires Province (Fig. 1). The estuary is composed by a system of different channel extent, islands, and extensive tidal plains (Cuadrado and Perillo, 1997). The tidal condition at the location is semi-diurnal, with a tidal range varying between 2.3 to 1.4 m at the estuary mouth and between 3.8 and 2.7 m at the estuary head, during spring and neap tides respectively. The Principal Channel is dominated by ebb currents (Nedeco-Arconsult, 1983), which, due to diminishing velocity, form an ebb tidal delta at the estuary mouth (Gómez, 1989; Perillo and Cuadrado, 1991).

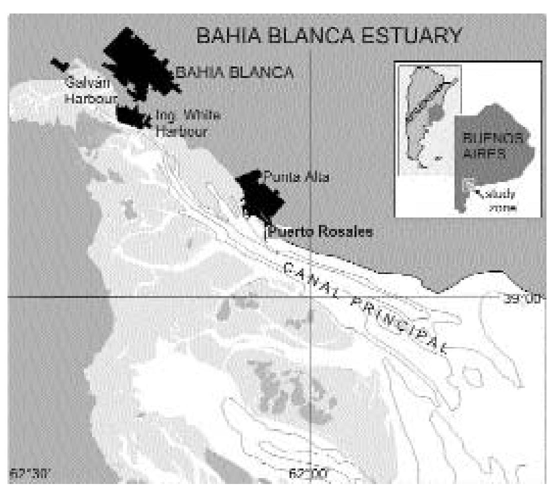

Figure 1.
Site map of the Puerto Rosales study area.

Puerto Rosales is the most external port of the most important deep harbor system of Argentina; a location which gives it some advantages over the others ports of the system. First, because the distance the vessels need to navigate to arrive to Puerto Rosales is much shorter than for the internal ports (Ingeniero White and Galván Ports are located 30 km inside the estuary). Secondly, the Principal Channel portion close to Puerto Rosales has natural depths greater than 20 m, unlike internal areas which have to be dredged periodically to allow navigation (Gómez et al., 1994).

However, despite the advantages this port has it could never be as fully developed as other ports of the system because of the high siltation rate of silt-clayey materials in its mooring sites and access channel, being these areas only suitable for the operation of small fishing boats. In order to keep the port working, large amounts of money were invested in dredging works although the attained depths did not persist over long time intervals.

The port has a 2 km length stone shore-connected breakwater in a north-south direction. As the largest harbour of the region was planned to be located here, this stone breakwater was originally built a century ago in order to protect the western area, where the mooring sites were to be originally constructed, from waves coming from the south and southeast (Melo et al., 1997). As soon as the construction began it was abandoned due to the First World War, the original scheme was discarded, and opposing to the original plan the eastside of the breakwater was adapted for ship anchorage.

In 1922, the Department of Public Works forced the port concessionaire to maintain 9 m depth (30 feet). This required depth was reduced to 5.5 m (18 feet), because maintaining a greater depth was not profited. Finally, in 1971, the Ports General Administration dredged the access channel up to 8 m (26.4 feet), without any further maintenance works during the following years. Nowadays, sedimentation has restricted the use of the access channel for commercial traffic and also limited access to local dock for fishermen. As a result of channel filling and narrowing, some vessels must await high tides and only one-way traffic at a time is permitted.

Cuadrado et al. (1996) analyzed the evolution of the siltation rate occurred during 18 years (1972-1990) since the 1971 dredging. During the first year after dredging 1.6 m of sediment was accumulated and then, after 10 years, this rate diminished to 0.06 m/yr during the last 8 years of the analyzed period.

Later, during a dredging carried out in 1995 a discontinuous barrier was built over the eastward intertidal plains with the objective of diminishing the amount of sediment coming into the port area. These coastal modifications, which have been done without conducting any environmental impact analysis, consisted in wrecking two 40 m length vessels in the mid-lower intertidal zone, and dumping the dredged materials on the mid-upper intertidal plain located eastward the harbour (Cuadrado et al., 2000). In order to protect these sediments from the current and wave action that would erode and re-transport them into the harbour, hoses filled with sandy materials were placed as containment. However, shortly afterwards the hoses failed as they underwent deterioration until its total failure (Fig. 2).

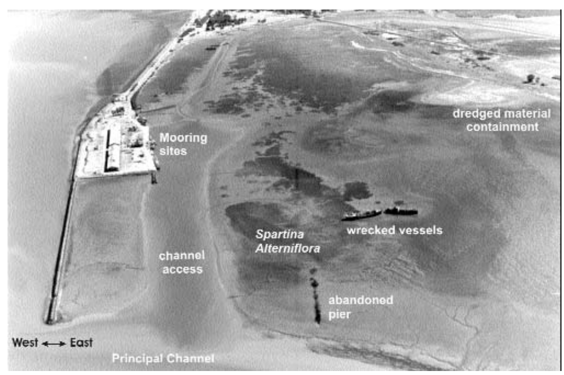

Figure 2.
Aerial view of Puerto Rosales at low tide in January, 1999.

ENVIRONMENTAL EVALUATION

By means of the comparison between successive bathymetric charts obtained in the periods 1972-1990, 1995-2000 and 2000-2001, the evolution of the siltation rate within the harbour sector is determined. The first period began after 8 m depth dredging; the second period began after 6 m depth dredging, while in the last period the dredging reached 4 m depth.

In each period the successive bathymetric charts were subtracted throughout a 10 m grid, getting the respective residual charts (Cuadrado et al., 2000). The common area for each chart was considered to calculate the accumulation over the residual charts in m3/m2. Negative values were not considered because they are located outside the access channel and mooring sites. The residual chart comparisons showed significant variations in the evolution of the sediment accumulation among the three periods.

The siltation rate in an enclosed dock (mooring sites and access channel) is mainly due to the water suspended sediment concentration (SSC) coming into the port during each tidal cycle. The higher the water sediment contents, the higher the siltation rate of the port. Since the suspended sediment concentration in estuaries is strongly influenced by the presence of locally generated waves (Silva and Le Hir, 2001), it is important to determine the direction and velocity of the predominant winds blowing through the area, as they generate a swell that can rise the locally SSC.

The most external portion of the Principal Channel, where Puerto Rosales is located, is affected by local wave activity in a greater extent than the internal estuary ports (Cuadrado et al., 2005). The studies carried out in Puerto Rosales by Federici et al. (2001, 2001) during a whole tidal cycle, showed that maximum SSC values due to the tidal current action alone reached 100 mg/l, but increased up to 240 mg/l when the wind blows from the SE quadrant. Such an increase is explained by the erosive activity of locally generated waves that re-suspends the silty and clayey materials from the intertidal plains located eastward of the port, increasing thus the amount of material that may be deposited and that comes into the tidal cycle. By this way, the abnormally high siltation rate of port during the Rosales when is compared with the remaining harbors of the system would be explained.

Depth variation within a given harbor is maximum immediately after its deepening, and if no other factor is involved (i.e. side slope land slide, storm surges, etc.) it will exponentially diminish as tidal current speeds become increased due to the decrease of the harbor section as it fills with time.

The averaged depth evolution with time (y) within Puerto Rosales (mooring sites and access channel) after the dredging done in 1971 (corresponding with 1972-1990 period), may be represented by the following equation:

$$y(t) = -7.4195 * e^{\frac{-t}{54.7915}} - 0.5596 \qquad (1)$$

where it is the time in months elapsed after dredging, and the change in y represents the siltation rate for a given period of time (t). In Fig. 3 the adjusted curve obtained from a point which corresponds to the averaged depth of each compared chart is shown. Immediately after dredging the siltation rate was 13.54 10^{-2} m/months, diminishing to 26.8 10^{-4} m/month at the end of the 18 years. This curve becomes asymptotic to 0.56 m/month, a value that represents the equilibrium averaged depth, where sedimentation equals erosion and the harbor is totally silted.

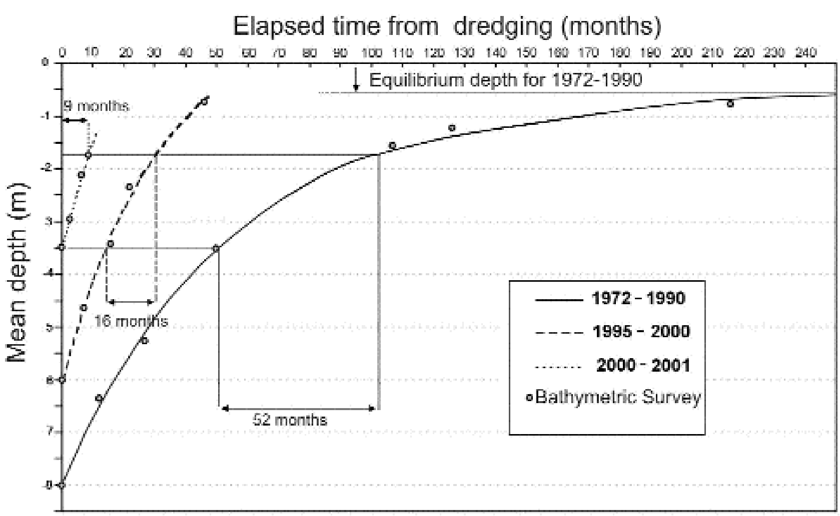

Figure 3.
Evolution of the mean depth after the dredging works over three different periods. (Modified Federici et al. in submitted to Geocta)

In order to evaluate the impact generated by the modifications introduced into the environment in 1995, the variation in the averaged harbor depths after dredging during 1995-2000 was analyzed and compared with the evolution happened prior to 1995. For the period 1995-2000, the maximum siltation rate was 22.07 10^{-2} m/month immediately after a 6 m dredging, diminishing to values of 5.2 10^{-2} m/month after 45 months. A maximum siltation rate of 22.9 10^{-2} m/month was computed for the last period (2000-2001) after the 4 m dredging.

If the environment was not altered and independently of the dredged depths, the average-depth evolution should coincide at least in an approximate way with the behavior shown in the 1972-1990 period. However, the curves corresponding to the 1995-2000 and 2000-2001 are much steeper, so the siltation rate have significantly increased after the modifications in the environment were done.

In order to compare in a direct way the evolution of depths among the three analyzed periods, a common depth range should be used, a circumstance that occurs between depths of 3.5 m and 1.75 m. The filling of this depth range took more than four years (52 months) for the 1972-1990 period, but only 16 months for the 1995-2000 period and 9 month for the 2000-2001 period (see Fig. 3). Undoubtedly, this notable increment of the siltation rate within the harbor is related to the modifications introduced into the environment in 1995. Such modifications far from reduce the problem, have notably increased it.

DISCUSSION

The increase on the SSC of the incoming water and the decrease in the energy within the harbor are the two factors that independently or in conjunction may induce an increase on the siltation rate. The disposal site on the mid-upper portion of the tidal plain, as well as the wrecked vessels on the mid-lower portion, directly or indirectly induces an increase of the natural SSC of the area. The rupture of the containment of the disposal site produced a fast dispersion of the dumped materials by wave and current action. Whereas, the wrecked vessels act as a reflective seawall forming in situ standing waves that may double the local wave height seaward of the vessels. The double height, generate double energy that provokes a bottom deepening close to the vessels, with the consequent change in morphology and increase in SSC in the area.

Both processes would acted as extra SSC sources, explaining the siltation rate raise during the 1995-2000 period when it is compared with the previous one. However, the SSC extra provision caused by both process would be maximum at the beginning, diminishing progressively with time whereas a new equilibrium is reached as the sediment sources are drained off. This means that in successive comparisons after 1995, siltation rate within the harbor should progressively diminish. Nevertheless, the contrary seems to happen when the period 2000-2001 is compared with the 1995-2000 one.

On the lower sector of the tidal plain located eastward Puerto Rosales, there are the remains of a pier whose construction was abandoned before its completion and since then sediment was accumulated around it. In this zone, there is an embankment almost totally covered by spartina *(Spartina Alterniflora)*, which were present here prior 1995. This bank has expanded since the introduction of the environmental modifications. Such expansion is probably due to two simultaneous causes. By one hand, the presence of the wrecked vessels generates a relative small low energy area at the stoss sector by diffraction of the incident waves, promoting the expansion of intertidal vegetation (Landin, 1991; Frey and Basan, 1985). On the other hand, the presence of such intertidal vegetation acts as a trap for sediments transported through it by diminishing the energy of the water, as well as the *Spartina* stabilize and prevent erosion of settled soft mud as a consequence of its dense rooting system. This consists of a series of stout roots descending vertically and another series of more horizontally disposed roots which ramify in the surface layers of the mud. The rate of accumulation of new sediment is greater in an area of *Spartina* than in any other part of an estuary (Green, 1968). The *Spartina Alterniflora* is the plant that colonizes the intertidal zone and initiates the marsh development process. Once established, it spreads vegetatively by sending rhizomes into surrounding sediments, diminishing water flow and accelerating sedimentation (Bertness, (1999)).

Since the SSC of the water running though the vegetation becomes greater (due to the spreading of dumped materials and the rise in the local energy as a consequence of the presence of the wrecked vessels) the amount of trapped sediment will be greater. This fact would enhance a growing in the embankment, whose presence at the time promotes a westward decrease in the wave energy. This may result in a progressive increase of siltation rate within the harbor, which may counterbalance at least temporally the progressive decrease of SSC incoming to the harbor.

The mechanism described above may explain why the siltation rate has not diminished between the 1995-2000 and 2000-2001 periods, although the conditions of sedimentation within Puerto Rosales is expected to tend to return at those registered during the 1972-1990 period once the sources for the extra SSC were totally drained off. However, the primary cause that has promoted the historical high siltation rate of Puerto Rosales is the influx of water with a relative excess in SSC, caused by the erosive action of waves on the adjacent tidal plains. For this reason, the only way to attain smaller siltation rates here, similar to those registered on the neighboring harbors, would be to avoid the influx of water with such SSC excess.

One way to reach a lasting solution for the problem presented in Puerto Rosales would be to impede the harbour influx of water with high SSC from the neighbouring intertidal zones by constructing a continuous barrier crossing the entire tidal plain. The project might be promising not to allow wave energy pass through the seawall. At the same time, the construction of this wall on the east side of the inlet would forms a jetty, which in conjunction with the westward breakwater already present would stabilize the access channel, providing important benefits for the use of harbour facilities by the commercial fishermen and vessels. However, the optimal design for this jetty should be evaluated with a hydrodynamical model of the entire area in order to prevent potential negative interactions with tidal currents, mainly at the harbour's entrance, where several studies had demonstrated the existence of a westward littoral drift of sand (Cuadrado, et al, 2001; Ginsberg, et al., 2001). So, the magnitude of the investment and the appropriate chosen design must consider the regional socioeconomic significance of the harbour use.

Once more it is confirmed that any kind of modification to be introduced in the coastal environment should be done in agreement with previous studies of physical-geologic conditions in order to determine how the environment will behave, and then avoid future undesirable facts that will require hard and expensive solutions. There exist physical, chemical, biological and engineering parameters that, in order to avoid irreversible negative consequences, should be considered and adequately studied before introducing any kind of modification into the environment.

SUMMARY AND CONCLUSIONS

Puerto Rosales presents a higher siltation rate than other ports of Bahía Blanca Estuary due to the income of water with high suspended sediment concentrations during the tidal cycle. The erosive wave action on the neighbouring intertidal plains resuspends cohesive materials, which are transported within the water mass and only can settle at those places of low environmental energy as the harbour mooring sites and the corresponding access channel.

The great increase in siltation rate in the last two compared periods is fundamentally related to man-modifications made into the environment in 1995, which were done in order to diminish it. These modifications, which consist of the location of dredged materials (with a wrong enclosure system) and the wrecking of two vessels as a discontinue barrier on the intertidal plain, promoted an increase in the siltation rate within the harbour. This increase was caused by both: an increase of the suspended sediment concentration of the water entering during the tidal cycle into the harbour, and by a wave energy decrease after pass through a bank. However, it is expected the re-establishment of the equilibrium in the area with the course of time, progressively diminishing the siltation rate to those values prior to 1995.

The lesson learned from this case study is that the selection of the dumping site did not consider the strong wave activity that attacks the barrier, disperse the enclosed sediments, resuspend them and afterwards the tidal currents transport them to calm zones. Also the material of the hose-barrier must be carefully chosen to prevent any failure. Another lesson is that any blockage put in a coastal plain is capable of behave as a reflective wall, with the consequent modification in the coastal water.

Once more it is confirmed that any kind of modification to be introduced in coastal environment, should be done on the basis of previous studies about physic-geologic conditions in order to prevent further behaviour of the modified environment to avoid hard and expensive consequences.

The case discussed here highlights the necessity for carrying out an EIA study before implementing a harbour project and any coastal modification. This approach that integrates the behaviour of coastal structures, impacts and alternatives, provides promising information for the planners of coastal projects, decision makers and impact assessment practitioners. Upcoming activities would be a model development which quantitatively describes the anticipated impact of the given alternative. Mathematical modelling is the key for identifying future impacts of coastal protective works.

ACKNOWLEDGEMENTS

This research was supported by theAgencia de Promoción Científica y Tecnológica (PICT 03 07-14652), SGCyT UNS (PGI 24/ZH13), and CONICET (PEI N°6025 and PIP N°2611). We thank Lic. Walter Melo for the assistance in the drawings.

REFERENCES

Bertness, M. (1999). The ecology of Atlantic shorelines. Sinauer Associates, Inc. Publishers, USA.

Canter, L.W. (1966). Environmental impact assessment. Series in water resources and environmental engineering. Second edition. New York, McGraw-Hill.

Cuadrado, D.G., W.D. Melo y E.A. Gómez. (1996). Evolución de la Tasa de Sedimentación en Puerto Rosales, Estuario de Bahía Blanca. Actas VI Reunión Argentina de Sedimentología, Bahía Blanca, Argentina: 261-266.

Cuadrado, D.G. and G.M.E. Perillo. (1997). Migration of intertidal sandbanks, Bahía Blanca Estuary, Argentina. Journal of Coastal Research, 13 (1): 155-163.

Cuadrado, D.G., G.A. Federici, E.A. Gómez and M. Natali. (2000). Modification on Rosales Port sedimentation rate, Argentina. Profile 18, CD-ROM (13): 6.

Cuadrado, D.G., E.A. Gómez and S.S. Ginsberg, 2005. Tidal and longshore sediment transport associated to a coastal structure. Estuarine, Coastal and Shelf Science 62: 291-300.

Cuadrado, D.G, E.A. Gómez and S.S. Ginsberg. (2001). Sediment transport inferred by submarine bedforms. Geoacta 26: 71-80.

Federici, G.A, D.G. Cuadrado, E.A.Gómez y M. Natali. (2000). Influencia de la Alteración Ambiental en la Tasa de Sedimentación en Puerto Rosales, Estuario de Bahía Blanca. Resúmenes IV Jornadas Nacionales de Ciencias del Mar, Puerto Madryn, Argentina: 62.

Federici, G.A, E.A. Gómez, D.G. Cuadrado y M. Natali. (2001). Acción de las olas en la sedimentación de Puerto Rosales, Argentina. Actas en CD IX Congreso Latinoamericano de Ciencias del Mar, San Andrés, Colombia: 4.

Fettweis, M. and D. Van den Eynde. (2003). The mud deposits and the high turbidity in the Belgian-Dutch coastal zone, southern bight of the North Sea. Continental Shelf Research 23 (7): 669-691.

Frey, R. and P. Basan. (1985). Coastal salt marshes. In: Davis R., Jr. (ed), Coastal sedimentary environments. Springer-Verlag, New York. pp. 225-291.

Frihy, O. (2001). The necessity of environmental impact assessment (EIA) in implementing coastal project: lessons learned from the Egyptian Mediterranean Coast. Ocean & Coastal Management 44: 489-516.

Ginsberg, S.S, D.G. Cuadrado and E.A. Gómez. (2001). Sea bottom characteristics related to tidal currents at Rosales Port, Bahía Blanca Estuary, Argentina. Abstracts in CD Joint IAPSO-IABO Assembly. Symposium IB01: Regional estuarine and coastal systems of the Americas.

Gómez, E.A. (1989). Dinámica morfológica del sector externo al Canal Bermejo, influencia en el calado del Canal de Acceso. In: Centro Naval delegación Bahía Blanca (eds.), La Ría de Bahía Blanca y sus posibilidades portuarias de aguas profundas, pp. 19-42.

Gómez, EA, D.G. Cuadrado y W.D. Melo. (1994). Posible causa de sedimentación en Puerto Rosales. Resúmenes IX Coloquio de Oceanografía, Bahía Blanca, Argentina.

Gómez, E.A., W.D. Melo and D.G. Cuadrado. (1998). Evaluation of environmental conditions at Rosales Harbour, Bahía Blanca, Argentina. In: C.-D.Reuther, Hamburg and H.Miller (eds.), Zentralblatt für Geologie und Paläontologie, Teil I, Ed. (3-6), pp.

663 - 670. Germany.

Green, J. (1968). Estuarine vegetation. In: P. Dales (ed). The biology of estuarine animals. Sidgwick & Jackson, London. pp. 47-64

Landin, H.C. (1991). Growth habits and other considerations of smooth cordgrass, Spartina Alterniflora Loisel. In: T.F. Munford, Jr Peyton, J.R. Sayce and S. Harbell (eds.), Spartina Workshop Record. Washington Sea Program, pp. 15-20. University of Washington, Seattle.

Le Hir, P., W. Roberts, O. Cazaillet, M. Christie, P. Bassoullet and C. Bacher. (2000). Characterization of intertidal flat hydrodynamics. Continental Shelf Research, 20: 1422-1459

Melo, W.D., D.G. Cuadrado y E.A. Gómez. (1997). Importancia de las condiciones ambientales en la planificación territorial del área de Puerto Rosales. Actas Primeras Jornadas Nacionales de Geografía Física, Bahía Blanca, Argentina: 147-154.

Mitchell, S.B., J.S. Couperthwaite, J.R. West and D.M. Lawler. (2003). Measuring sediment exchange rates on an intertidal bank at Blacktoft, Humber Estuary, UK. The Science of the Total Environment. In press.

Nedeco-Arconsult. (1983). Estudio de dragado al canal de acceso al Puerto de Bahía Blanca. Technical Report. Bahía Blanca.

Perillo, G.M.E. and D.G. Cuadrado. (1991). Geomorphologic evolution of El Toro Channel, Bahía Blanca Estuary (Argentina). Marine Geology, 91: 401-412.

Silva, J.R. and P. Le Hir. (2001). Response of stratified muddy beds to water waves. In: W.H. McAnally and A.J. Metha (eds.), Coastal and Estuarine Fine Sediments Processes, pp. 95-108. Elsevier Science, The Netherlands.

Stanley, D.J, A.G. Warne. (1993). Nile delta: recent geological evolution and human impact. Science, 260: 628-34.

Tafireño-Silva, E. (2002). North-South educational partnership on marine science: the Latin American experiences and perspectives. Ocean & Coastal Management, 45: 649-666

Toorman, E.A. (2001). Cohesive sediment transport modelling: European perspective. In: W.H. McAnally and A.J. Mehta (eds.), Coastal and Estuarine Fine Sediments Processes, pp. 1-18. Elsevier Science, The Netherlands.

Winterwerp, J.C. (2002). On the flocculation and settling velocity of estuarine mud.. Continental Shelf Research, 22: 1339-1360

(Received: November, 4, 2004. Accepted: September, 9, 2005)