

JOSELYN ARRIAGADA GONZALEZ (*), CARMEN PAZ CASTRO CORREA (*),
MARÍA VICTORIA SOTO BAUERLE (*) & GIULIANO RODOLFI

TOWARDS A CLASSIFICATION OF THE DELTA SYSTEMS IN TRANSITIONAL SEMI-ARID CHILE BETWEEN THE RIVERS COPIAPO AND ACONCAGUA

ABSTRACT: ARRIAGADA GONZÁLEZ J., CASTRO CORREA C.P., SOTO BAUERLE M.V. & RODOLFI G., *Towards a classification of the delta systems in transitional semi-arid Chile between the rivers Copiapo and Aconcagua*. (IT ISSN 0391-9838, 2010).

In the last decades countries like Chile have been faced with swift and growing territorial transformations, principally derived from the process of agricultural modernization and urban expansion, as in those zones favoured in climatic terms for the production of «specialized» agriculture where semi-arid regions have shown important comparative advantages. In this paper a proposition is presented for the incorporation of determining factors (like the morpho-edaphologic vulnerability, morfo-climatic position and the corresponding level of intervention, in conjunction with physical geographic variables) in the taxonomic classification of delta systems. In order to reach this goal, three catchments have been selected: those of the rivers Copiapó, Choapa and Aconcagua, which are representative of different phases of agricultural modernization, and of the interior and costal urban expansion, located in differing morfoclimatic environments, ranging from marginal desert, through the semi-arid, to the transitional belt in the temperate zone. According to this analysis, a discussion is proposed on the limits suggested by (Araya-Vergara, 1981) to classify estuaries, the following criteria have been taken into account: i) morfo-climatic position, ii) processes and current dynamics of inlet system, iii) current landforms, iv) geodynamic processes of the catchments, v) level of intervention into the catchments. Therefore, a new classification of the studied delta systems is here proposed: Río Copiapo: paleo delta, stabilized morphology, arid environment with high basin intervention; Río Choapa: truncated delta, dominated by waves and fluvial energy, morphologically dynamic, semi-arid environment with low basin intervention; Río Aconcagua: delta dominated by waves and fluvial energy, morphologically dynamic, semi-arid environment with high basin intervention.

KEY WORDS: Transitional semiarid Chile, Land use changes, Delta systems, Coastal Dynamics.

RESUMEN: ARRIAGADA GONZÁLEZ J., CASTRO CORREA C.P., SOTO BAUERLE M.V. & RODOLFI G., *Hacia una clasificación de los sistemas de desembocadura en Chile semiárido transicional, entre los ríos Copiapo y Aconcagua*. (IT ISSN 0391-9838, 2010).

(*) *Departamento de Geografía, Universidad de Chile* - mvsoto@uchilefau.cl; joarriag@uchile.cl; cpcastro@uchile.cl

En las últimas décadas Chile se ha visto enfrentado a rápidas y crecientes transformaciones territoriales, derivadas principalmente de los procesos de modernización agrícola y de expansión urbana, como en aquellas zonas favorecidas en términos climáticos para la producción agrícola de primores, donde el semiárido ha mostrado importantes ventajas comparativas. En este estudio se propone la incorporación de condicionantes (vulnerabilidad morfoedafológica, posición morfoclimática y grado de intervención correspondiente, en conjunto con las variables geográficas físicas) en la clasificación taxonómica de los sistemas de desembocadura. Con este fin, se han seleccionado tres cuencas, las del río Copiapó, Choapa y Aconcagua, representativas de diferentes fases de la modernización agrícola y de la expansión urbana interior y costera, localizadas en distintos ambientes morfoclimáticos, desde el desierto marginal, el semiárido, hasta la zona de transición a la zona templada. De acuerdo al análisis realizado, y a la discusión con respecto a los límites propuestos por Araya-Vergara (1981) para la aplicación de la nomenclatura de estuarios, se han considerado los siguientes criterios para una nueva clasificación: i) posición morfoclimática, ii) procesos y dinámica actual del sistema de ensenada, iii) formas actuales, iv) procesos geodinámicos de las cuencas, v) nivel de intervención de las cuencas. Por lo tanto se propone la siguiente clasificación: Río Copiapó: paleo delta, de morfología estabilizada, en ambiente árido con alta intervención en su cuenca; Río Choapa: delta truncado, dominado por el oleaje y la energía fluvial, de dinamismo morfológico, en ambiente semiárido con baja intervención en su cuenca; Río Aconcagua: delta dominado por el oleaje y la energía fluvial, de dinamismo morfológico, en ambiente semiárido con alta intervención en su cuenca.

PALABRAS CLAVE: Chile semiárido transicional, Transformaciones territoriales, Geomorfología deltaica, Dinámica Costera.

INTRODUCTION

Starting from diverse integrated analysis of basins and their costal associates, conceived as systematic geographical units whose natural and socio-economic processes affect dynamic function and that have synergetic effects from the mountainous environments to the coastlines, a proposition is presented for the incorporation of determining factors related with the anthropic modification in the highly intervened basins in the taxonomic classification of delta systems.

This is particularly significant for countries like Chile that have been faced with swift and growing territorial

transformations, principally derived from the process of agricultural modernization and urban expansion associated with the effects of globalization on their economies.

In the case of Chile, these transformations have been observed principally in those zones favoured in climatic terms for the production of «specialized» agriculture where semi-arid regions have shown important comparative advantages. The intervention of the basins, which has overtaken the morpho-edaphologic thresholds normally acceptable in terms of the use of slopes, may be generating undesirable effects related to their natural use, regardless of the positive effects that the incorporation of irrigation and an increase in vegetable coverage may generate.

In virtue of the aforementioned, this study proposes incorporating the variable of morpho-edaphologic vulnerability, morfo-climatic position and the corresponding level (grade) of intervention in conjunction with physical geographic variables. To this end, three basins have been selected: those of the rivers Copiapó, Choapa and Aconcagua, which are representative of different phases of agricultural modernization, and of the interior and costal urban expansion located in differing morfoclimatic environments, ranging from marginal desert, through the semi-arid, to the transitional belt in the temperate zone (fig. 1).

THE CURRENT DELTA CLASSIFICATION SYSTEM IN CHILE

The knowledge of the geomorphology and dynamics of delta environments of the country is recent and, in the majority of cases, fairly general. The studies by Araya Vergara (1981) and Paskoff (1970) can be singled out. In this sense, Araya Vergara established that the phenomenon of deltas should be studied as parts of a system; an idea adhered to in this document. Said author points out the importance of considering the form of the land in which the study is developed, thereby seeking a geomorphological concept. In this way he defines the expression «delta estuary» as a delta developed within an estuary, thus the inclusion of the concept of «ria», which corresponds to the international geomorphologic term, is deemed appropriate.

For this reason, the aforementioned author proposed denominating the inland deltas formed in valleys flooded by the sea as «estuary deltas or rias».

Araya Vergara (1981) identifies the following delta zones in Chile in function of their morpho-climatic position:

- a) the zone of the distal deltas that correspond to the morph-climatic influence of the desert, with the summer contributions derived from high-altitude lighting
- b) the zone of the *rias progradadas* (zones of deltas in a ria) that coincide with the semiarid conditions of Norte Chico, from the River Copiapo (27°20'S) to the River Maipo (33°47'S) inclusively. They correspond to paleo-rias defined by Paskoff (1970) that show a higher sediment level attributed to the rivers of semiarid zones

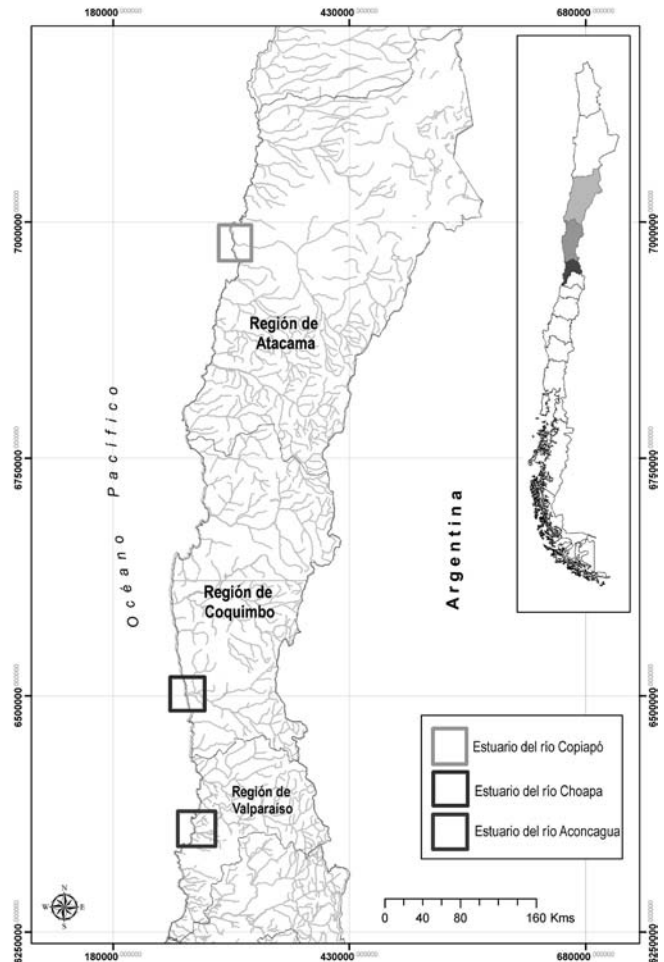


FIG. 1 - Sketch map of the studied sites.

- c) the zone of the estuary deltas that are located in the area of transition between the semiarid and sub humid, from the mouth of the River Rapel (34°s) to the mouth of the River Bio-Bio (37°S) inclusively, where the fluvial energy is important in generating wide inland canals and contributing an abundance of material to the delta even though the marine energy is significant and impedes progradation towards the sea
- d) finally, the zone of rias connected with the humid and very humid conditions in the Lake District region.

The morphological classification of delta systems by Araya Vergara (1970, 1978 and 1981) establishes zones according to the identification of essential forms such as delta banks and meandering, lateral cuspidal ridges, coastal lagoons, and delta lagoons. In the delta systems under analysis, Copiapo, Choapa and Aconcagua, one can recognize those morphological characteristics that highlight the evolution of said systems in the context of a transitional morpho-climatic domain from desert to semiarid.

The taxonomy by Araya Vergara (1982) classifies these systems as deltas in a *ria* from the River Copiapo to the

River Maipo in Chile's central zone, therefore grouping the three basins selected for this analysis in the same class. However, the strong intervention in the basins has generated new conditions at their mouths, which means that a new classification should be incorporated into the taxonomy. With this in mind, it is suggested that this new reclassification should consider the dynamics of the systems in the last couple of decades where they are found in differing stages of productive restructuring and in different morpho-climatic positions, establishing a greater number of classes in the area of Central Chile under study.

RELEVANT ASPECTS OF THE STUDY AREA

The basins being analysed are located in the regions of Atacama, Coquimbo and Aconcagua. Atacama constitutes the northern limit of the system of transversal valleys (East-West) located between the basins of the rivers Copiapo and Aconcagua. In this coastal zone a marked tectonic condition exists and very wide coastal plains which are connected to an elevated coastal mountain range. The rivers Copiapo and Huasco are the only Andean systems that flow into the sea. One can observe an important variation between those rivers that come from the Andean range, with a pluvio-nivo-glacial regime and those that are born in the coastal mountain range that present a very low flow due to their seasonal rainfall and episodic downpours (fig. 1).

The basin of the River Copiapo is in an environment that is closer to desert than semi-arid, and it is the area that has undergone a greater and longer productive intervention since the end of the 1970s. The associate coastline, where the port of Caldera is located, presents forms that bear witness to older climates of greater humidity (fig. 2).

In relation to the semi-arid dominance as such, the most representative characteristics can be found in the Coquimbo region, with prominent transversal valleys and mountain range rivers of a clearly exoreic regime. The rivers Elqui, Limari and Choapa can be highlighted as the most important, despite being in a zone of very low flow dependant on a nivo-glacial mountain range (fig. 3).

In turn, of the three basins selected, the basin of the River Choapa presents the least amount of intervention, whereby the process of change of use and of agricultural use of spaces of morpho-edaphologic risk is commencing.

At the same time, the transition towards a more temperate dominion corresponds with the large Aconcagua valley. An important increase in the flow of the rivers can be observed correlative to a morpho-climatic position where the rainfall system starts to be more significant. Two important river estuary systems are highlighted, those of the River Aconcagua and the River Maipo, and of a lesser hierarchy, the basins of the rivers Petorca and La Ligua, of limited but constant flow. All of the aforementioned estuaries exhibit associated dune fields oriented towards the north (fig. 4).

The basin of the River Aconcagua in an environment of greater humidity has incorporated the process of modern-

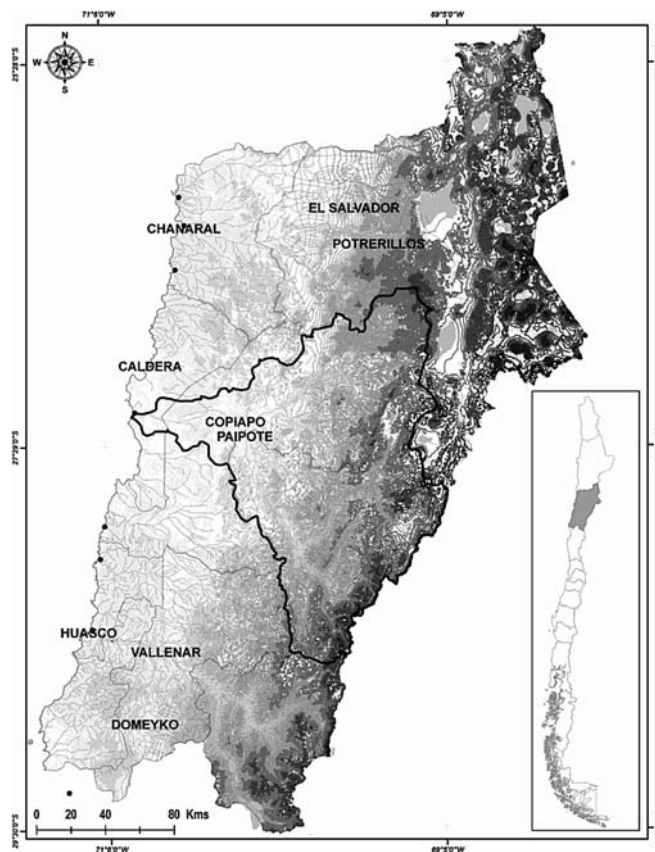


FIG. 2 - Topographical configuration of the Region of Atacama and the basin of the River Copiapo, with a large Andean front.

ization prior to River Copiapo basin. However, it has suffered an accelerated process of change of soil use and an expansion of its agricultural borders, along with a significant process of expansion of its urban areas, which, in some cases, has generated conurbations.

These three basins were selected given that they are representative of different phases of agricultural modernization and of the inland and costal urban expansion in distinct morpho-climatic environments (marginal desert, semi-arid and a transition to temperate environment) which allow the comparison of the physical geographical impact that has taken place in function of the natural determining factors in the basins and their level of vulnerability to degradation.

THE MORPHO-CLIMATIC POSITION OF THE SELECTED BASINS

The basins of the River Aconcagua and the River Choapa are of a similar size, close to 10,000 km², whilst the River Copiapo is more than double the size, with over 18,000 km². However, the River Copiapo has an extremely low flow of 1.3 m³ per second, inferior to that of the Aconcagua which has an annual average of 79 m³ per sec-

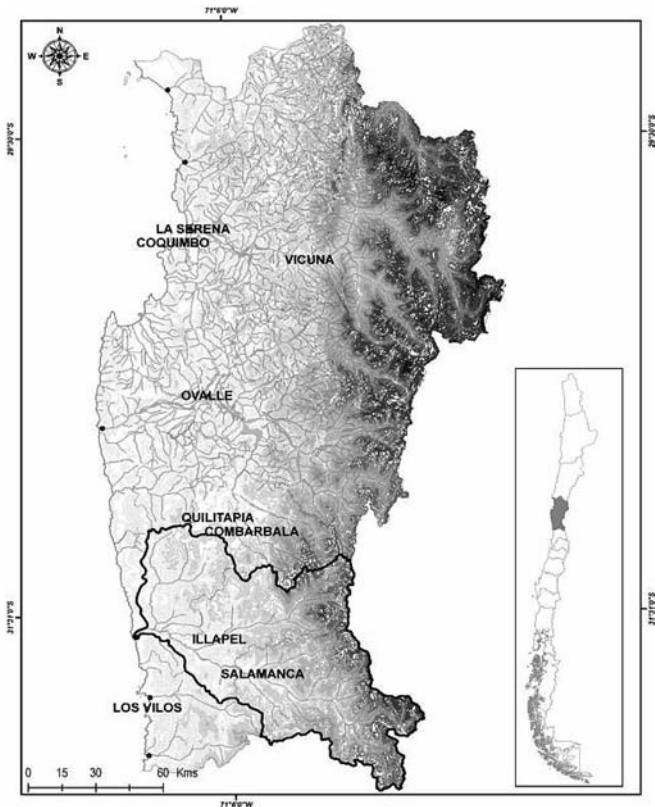


FIG. 3 - Topographic configuration of the Coquimbo Region and the basin of the River Choapa. The cities of Ovalle and La Serena are associated with the rivers Limari and Elqui. Strictly speaking they correspond to the transversal valleys.

ond. The River Choapa, in an intermediate position, has a flow of 8.3 m^3 per second, which clearly demonstrates the different climatic position of each zone and the dependence of the rivers Copiapo and Choapa on being fed by high altitude snowfall.

The climatic classification considers the position of the River Copiapo as desert, that of the Choapa as cold temperate highland, warm steppe and coastal steppe, and that of the Aconcagua as Mediterranean temperate with a prolonged dry season, the later clearly associated with the characteristics of Central Chile.

The average rainfall in the coastal zones of the three basins is also very different. From 18 mm per year at the mouth of the Copiapo to 370 mm in that of the Aconcagua, with the Choapa on an intermediate figure of 130 mm per year. These values, with a strong incidence in the morphology of the basin systems, show that it is not possible to classify the three basins within the same taxonomy.

A DESCRIPTION OF THE DELTA MOUTH SYSTEMS

River Copiapo: The estuary (delta) of the Copiapo constitutes the northern limit of the system of transversal val-

leys which is located between the rivers Copiapo and Aconcagua (I.G.M, 1985a). From a hydrological point of view, the delta of the Copiapo is characterized for being an exoreic river basin. The area is within a wide unit of coastal plains, corresponding to pleistocene terraces made up of marine-coast and fluvial-estuarine sequences.

Apart from terraces there are also strong winds. In this sense, Araya-Vergara (2001) points out that the erg of the Atacama desert has been shaped by sand from pleistocene coasts but with holocenic evolution whereby the dune maintains a geo synergetic relationship with an river basin that has perennial flow towards the sea, in an arid desert environment, with dynamic activity. Likewise, Paskoff & alii (2003) state that although the Atacama dunes are living forms, they constitute remnants given that the original river, the source of their supply, has dried.

The geographical context in which the specific problem of the Copiapo estuary is placed suggests a relationship with a hydrographic basin subject to deep and accelerated changes in land use and intensity of land use. This has generated a rise in the physical vulnerability of the territory associated with the transformations in the shape of the landscape, presenting a larger potential availability of

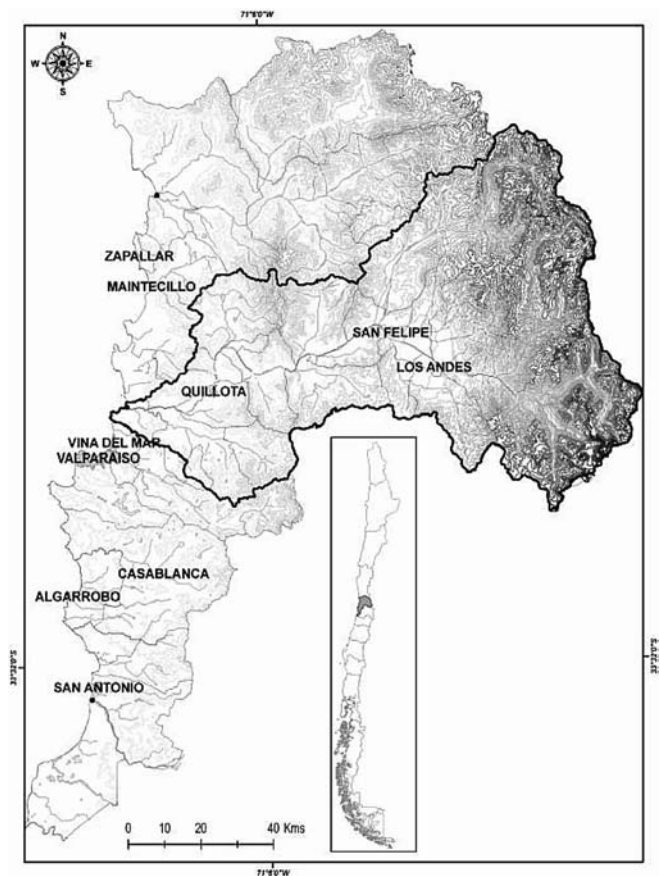


FIG. 4 - Topographic configuration of Aconcagua Region and of the basin of the forenamed river. The city of San Antonio is associated with the River Maipo corresponding to the southernmost transversal valleys in Chile.

mass in the system which could be transferred during the El Niño climate pattern (Castro & alii, 2009).

Choapa River: the estuary of the Choapa River is located in the Andean-coastal system (Börgel 1983, in M.G.I., 1985b), where it is possible to identify coastal plains and transverse valleys. From a climate feature perspective, the field of research is focused on the so-called «steppe climate with abundant cloudiness».

The estuary of the Choapa River shows changes in the use of land; however, these alterations are significantly lower compared to those of Copiapo River. In the case of Choapa, changes from agriculture and traditional goat breeding to fruit growing have been identified.

Aconcagua River: there is a system of three generation terraces located on its mouth. The highest of these terraces is 120 m high and the lowest is 4-5 m high (Caviedes, 1967). Precipitation in this zone occurs mostly between May and August and is defined by a marked interannual variability. Average annual precipitation between 1958 and 1985 was 369,1 mm. From a hydrological perspective, the Aconcagua is a fast flowing river, fed by snow and precipitation, belonging to the Chilean semi-arid zone.

CONSEQUENCE OF PRODUCTIVE RESTRUCTURING

However, benefits from agricultural modernization may have important environmental consequences such as morphoedaphological degradation, a problem associated with multiple and synergical effects.

In this sense, in order to prevent an erosion process, it is important to analyze the impact of the occupation of lands for fruit growing purposes in slopes that exceed the morphodynamic limits for productive activities. This may cause undesired environmental problems such as degradation; mass wasting; increase of sedimentation in irrigation canals, streams and rivers; accretion in the estuary zone and increase of sedimentary accumulation in beaches and dunes, among others.

Some of the important changes that took place may be reflected in the processes of Copiapo and Aconcagua. In the first case, there has been an increase in vegetation cover associated with vine monoculture and not with natural vegetation, located in the valley floor zone and in terraces, cones and glacis. In the second case, fruit monoculture in the Aconcagua has reached high slopes.

In Copiapo, despite the low rates of precipitation, there are low percentages of erosion; however, during El Niño-Southern Oscillation (ENSO) years, these percentages increase to high levels. This situation has similar patterns in all the drainage basins studied, where mid to low rates of erosion are measured during the winter and high levels of this phenomenon are registered as a consequence of concentrated and erosive precipitation during ENSO years.

SPACE-TIME VARIATIONS OF ESTUARY SYSTEMS

Deltaic System of the Copiapo River

1979 - The estuarial system had classic features: the proximal area showed the meandering form of the river, indicating the influence of this type of environment. In the middle part, cuspidated lateral banks were identified, showing marine influence, as it indicated a competition between fluvial and marine currents. In the distal part, the system expanded towards the mouth, indicating the presence of an estuarial lagoon. The fluvio-marine terrace is currently conformed by a marsh zone, a coastal lagoon decreasing in size (wetland) that may have been an extensive lagoon. The estuarial channel continued up to the mouth, where it was blocked by an extensive sand spit, which extended from south to north. The wetland covered most of the north part, suggesting the fierce competition that took place in the Copiapo estuarial system.

In 1981, using data from 1979 as reference, the analysis of aerial photographs revealed that there were no important changes in the estuarial system.

In 2008, it was observed a decrease in the fluvial energy and its contribution to the deltaic system. For that reason, the analysis of the forms was based on the differences of vegetation and the change of texture of aerial images. The proximal area showed the meandering form of the river. The estuary was blocked by the sand spit, just as in previous years; however, this spit is overflowed under ENSO conditions, as in 1997 (fig. 5).

The analysis of waves, through the classification of wave dominated beaches (Short, 1999), allows understanding the dynamics of the nearby coast; it also represents the behaviour of the transport of sediment across the coast.

The analysis of aerial photographs revealed the presence of rips in 1971, 1981 and 2007, indicating a strong transverse component of waves, consistent with the patterns of intermediate beach (transverse bars and rips). In 1996 longitudinal intermediate features prevailed (fig. 6).

Deltaic system of the Choapa river

1978 - The deltaic system of the Choapa River is characterized by its large extension. There was a diffluent channel in the proximal area, suggesting fluvial influence, as it revealed the existence of extensive lateral fluvial banks. In the middle area there was an alternation of middle and lateral fluvial banks. It is important to point out the presence of abandoned channels in both the fluvial terraces and the lateral estuarial banks. In the distal part, it was located a fluvio-marine terrace of 2 km long. The fluvial channel was constituted by a meander, which then turned into a series of channels. Its estuary was semi-blocked by a north-south spit bar. There was an estuarial lagoon and, heading to the south, coastal dune systems, most belonging to the transverse type, were found.

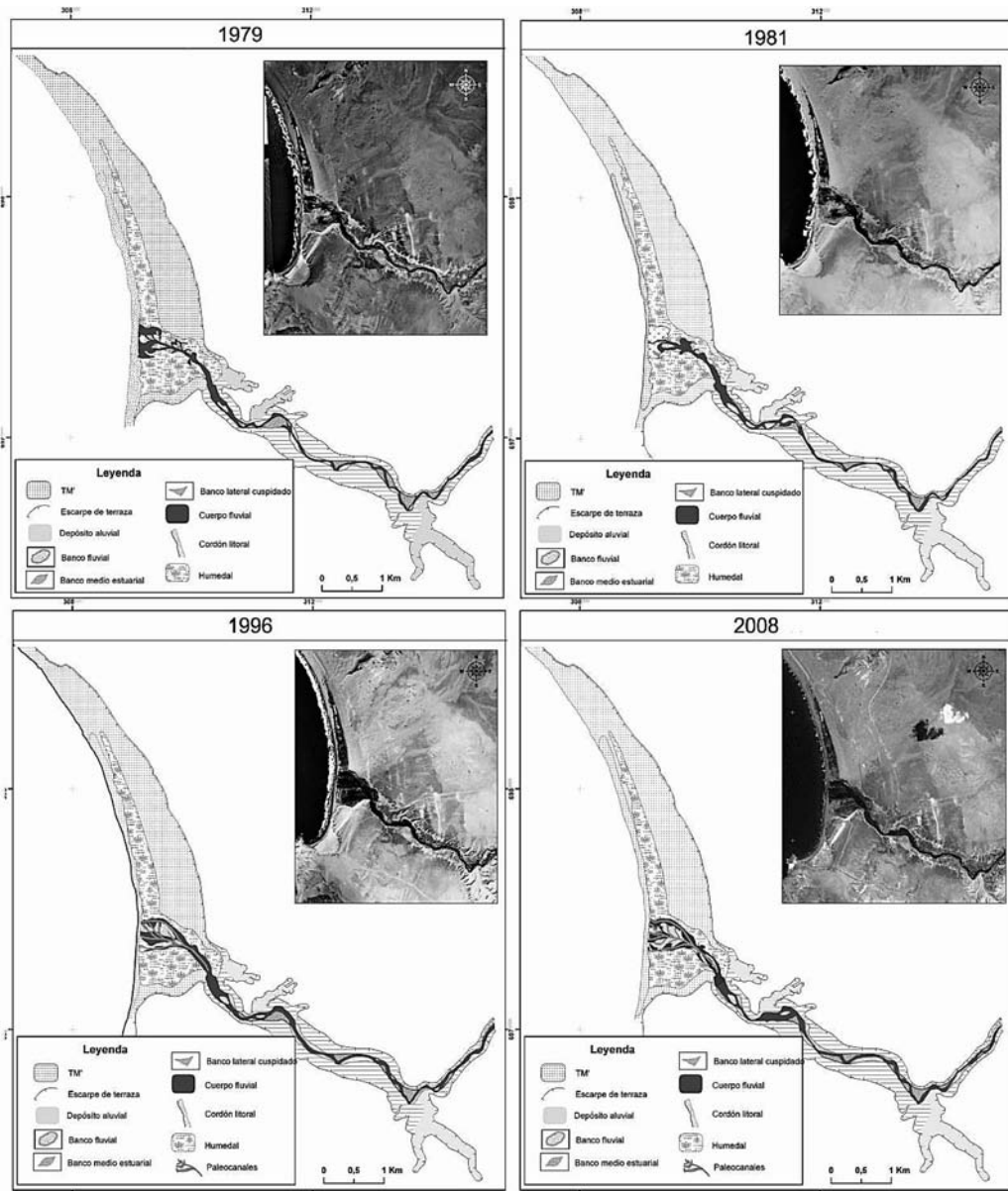


FIG. 5 - Evolution of the Copiapo delta.

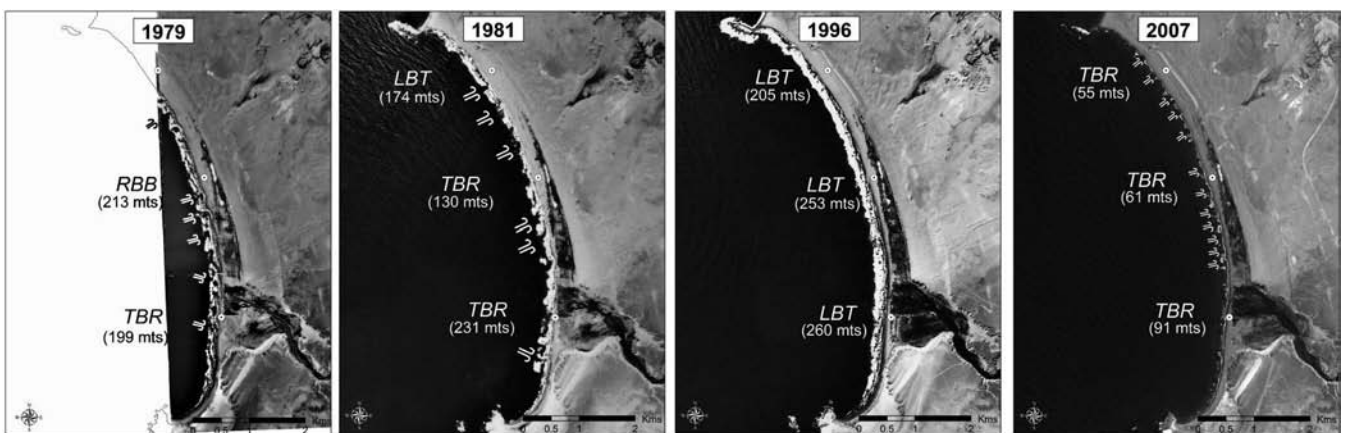


FIG. 6 - Analysis of the littoral of the Copiapo delta.

1997 - The estuarial lagoon had increased in size since 1978 and the spit bar was blocking the estuarial system, a phenomenon observed only in 1997. The coastal dune system showed barchans and fewer numbers of transverse dunes. These characteristics were consistent with an increase in aeolian activity, suggesting the reduction of transverse dunes during the period 1978-1997.

2001 - There is a meandering channel in the distal area, just as in previous years. The middle part, however, revealed some differences: a great number of middle banks indicated an increment of sediment load. This situation continued up to the limit of the middle area, where the fluvial channel returned to its meandering form. Abandoned channels suggested stream flow reduction. Braiding patterns appeared in the mouth area. The estuarial zone

was semi-blocked by the north-south spit bar. It is important to mention the situation of the southern area of the estuary, where the reduction process of dunes continued; few sequences of transverse dunes were identified.

Patterns observed in 2008 were similar to those registered in 2001 (fig. 7).

After four years of study, temporal analysis of wave dominated beach showed a prevalence of transverse shoals. The relative position of the coastline is transversal to the direction of swell movement. This means that swell energy impacts perpendicular to the coastline, generating transverse rips and bars in proximal, middle and distal zones. During the years of study, a reflective shoal zone was identified in the inlet of the southern area of the estuary. This phenomenon created low energy conditions that gave shape to a shoal front.

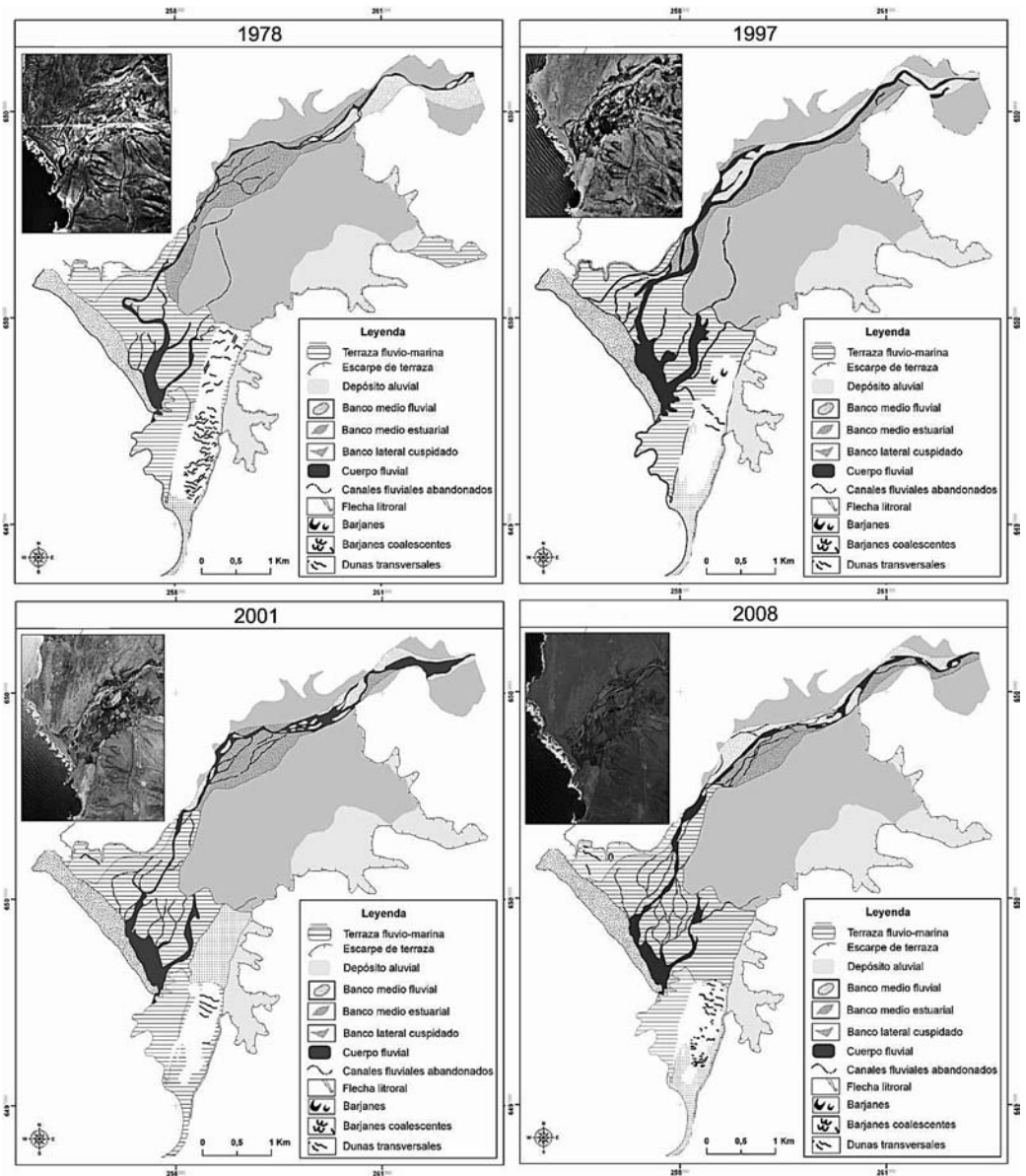


FIG. 7 - Evolution of the Choapa delta.

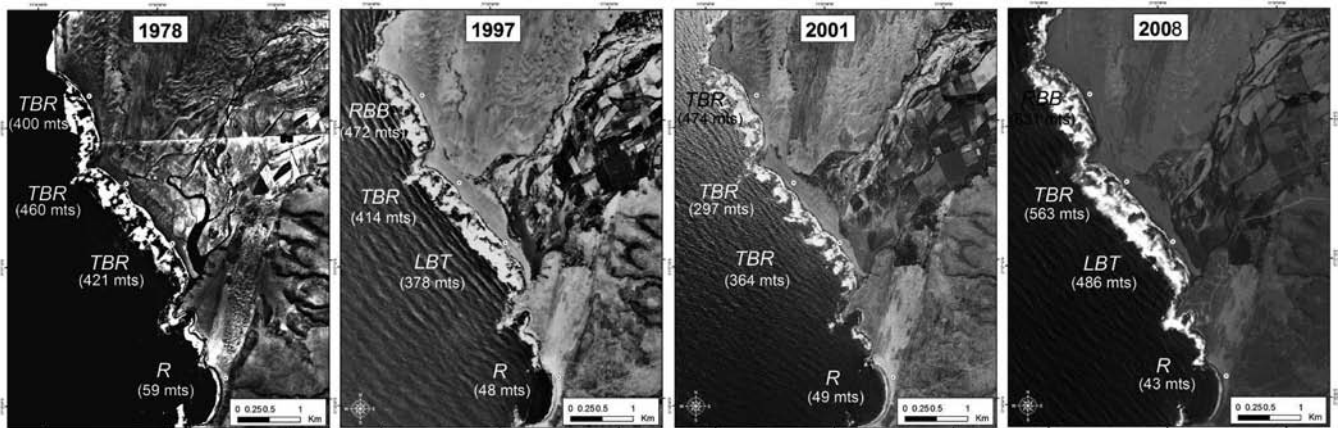


FIG. 8 - Analysis of the littoral of the Choapa delta.

The situation of this inlet has not varied greatly, except in 1978, when registered the lowest variation (60 m) (fig. 8).

Deltaic System of the Aconcagua River

The research of Cortés (2002) was useful to analyze the dynamics of the Aconcagua estuarial system. According to the study, the evolutionary trend observed between 1877 and 1996 suggests that the Aconcagua deltaic system is prone to suffer morphological variations, being the progressive sedimentation in the estuarial zone one of the most important characteristics. This is a deduction from

the growth of the coastal sand bars and their incidence to the change in posterior sandbanks.

The shore of estuarial banks is convex and shows a depositional trend. Spit bars and banks belonging to the inner and middle zones are the most unstable elements. This system, according to (Cooper, 1994, 2004), was classified as an estuary dominated by fluvial processes and waves (fig. 9).

FINAL COMMENTS

According to this analysis, it may be stated that today the estuarial system of the Copiapo River has modest dy-

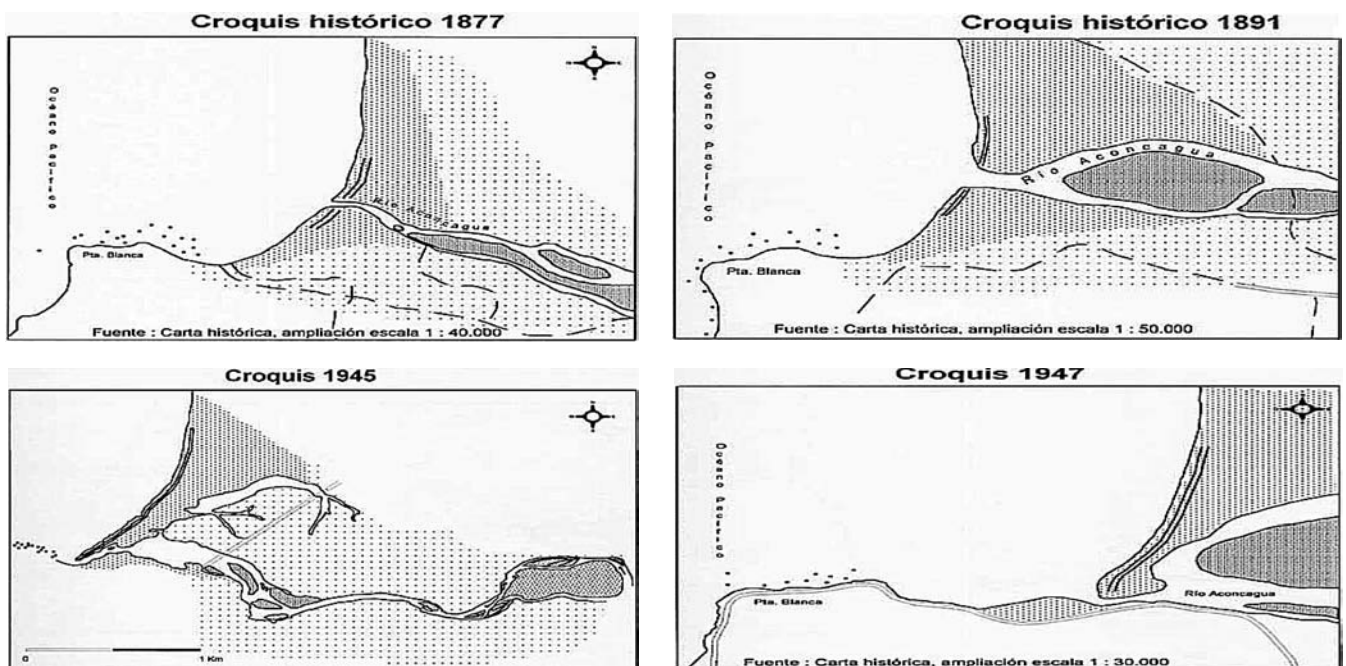


FIG. 9 - Evolution of the Aconcagua delta.

namics, as it shows conditions of stabilization of essential forms, mainly in the proximal and middle areas. In the distal part, the wetland (former estuarial lagoon) reveals variations related to low fluvial contribution and exceptional climatic phenomena, such as ENSO events, resulting in an increase in both stream flow and river sedimentation. Another indicator of stabilization is the spit bar, transformed into a sand spit, that blocks the system.

This condition may also be associated with changes in land use that take place in the drainage basin of the Copiapo River, as the water used for irrigation and mining purposes is reducing the stream flow of the river. The intensive agricultural use of the basin entails destabilization of slopes, accelerating the erosion process and creating more sediment that may be transported to the estuary during exceptional precipitation events.

In relation to the estuarial system of the Choapa River, conditions, especially in the distal zones, are similar to those systems of central Chile. There is an estuarial lagoon surrounded by a stable spit bar. In the middle area it is possible to find fluvial and estuarial banks, which appear one after another. In the proximal zone, the meandering form of the river is clearly identifiable.

It can be said that the Choapa system carries more sediment, meaning that the fluvial course shifts from meandering to braided in the distal area. As a consequence, the fluvial system, during the last 30 years, has continuously contributed mass to the coast. A change in the direction of the estuary is observed.

As its essential elements are stabilized and show climatic conditions associated with a past humid tropical environment, the Copiapo delta is classified as a *paleoestuary*. Its cuspidated lateral banks indicate that fluvial component was as important as marine component in the formation of this system.

The characteristics of the Choapa delta seem to be similar to those systems of central Chile, such as the Aconcagua and the Maipo. These systems have seasonal dynamics in the behaviour of essential forms, where fluvial energy and contribution are important.

In view of the foregoing, a discussion is proposed on the limits suggested by Araya-Vergara (1981) to classify estuaries. This debate should take into account the following criteria:

- Morpho-climatic position
- Processes and current dynamics of inlet system
- Current forms
- Geodynamic processes of basins
- Level of intervention of basins

Proposed classification

Copiapo: Paleo delta, stabilized morphology, arid environment with high basin intervention.

Choapa: Truncated delta, dominated by waves and fluvial energy, morphologically dynamic, semi-arid environment with low basin intervention.

Aconcagua: Delta dominated by waves and fluvial energy, morphologically dynamic, semi-arid environment with high basin intervention.

REFERENCES

- ARAYA VERGARA J.F. (1970) - *Contribución al estudio de los procesos estuariales en las desembocaduras de los ríos Rapel y Maipo*. Informaciones Geográficas, 20, 17-38.
- ARAYA VERGARA J.F., CASTRO C. & ANDRADE B. (1978) - *Análisis de la turbidez fluvial en el mar mediante teledetección y control terrestre*. Congreso de Percepción Remota, Santiago, Ed. Instituto Geográfico Militar, Santiago.
- ARAYA VERGARA J.F. (1981) - *El concepto de delta en ría y su significado en la evolución litoral (ejemplo de Chile Central)*. Informaciones Geográficas, 28, 19-42.
- ARAYA VERGARA J.F. (1982) - *Análisis de la localización y de los procesos y formas predominantes de la línea litoral de Chile*. Informaciones Geográficas, 29, 35-55.
- ARAYA VERGARA J.F. (2001) - *Los ergs del desierto marginal de Atacama*. Investigaciones Geográficas, 35, 27-66.
- ARRIAGADA J. (2009) - *Geomorfología estuarial comparada en la zona semiárida de Chile. Casos de Copiapó y Choapa*. Tesis para optar al grado de Magíster en Geografía, mención Recursos Territoriales. Facultad de Arquitectura y Urbanismo, Universidad de Chile, Santiago; 100 pp. (Unpublished).
- CASTRO C.P., SOTO M.V., FERNÁNDEZ R., MAERKER M. & RODOLFI G. (2009) - *Impacto en la geodinámica actual del valle de Nantoco, cuenca del Río Copiapó, asociado a la reconversión productiva*. Revista de Geografía Norte Grande, 42, 81-99.
- COOPER J.A. (1994) - *Sedimentary processes in the river-dominated Mvoti estuary, South Africa*. Geomorphology, 9, 271-300.
- COOPER J.A. (2001) - *Geomorphological variability among microtidal estuaries from the wave-dominated South African coast*. Geomorphology, 40, 99-122.
- CORTÉ C. (2002) - *Observaciones dinámicas y geomorfológicas en el estuario del Aconcagua, Chile Central*. Memoria para optar al título de geógrafo, Universidad de Chile, Santiago, 73 pp. (Unpublished).
- INSTITUTO GEOGRÁFICO MILITAR (1985a) - *Geografía de la III región*. Santiago, 206 pp.
- INSTITUTO GEOGRÁFICO MILITAR (1985b) - *Geografía de la IV región*. Santiago, 425 pp.
- PASKOFF R. (1970) - *Recherches geomorphologiques dans le Chili Semi-aride*. Bordeaux, 1970, 420 pp.
- PASKOFF R., CUITIÑO L. & MANRÍQUEZ H. (2003) - *Origen de las arenas dunares de la región de Copiapó, Desierto de Atacama, Chile*. Revista Geológica de Chile, 30(2), 355-361.
- SHORT A.D. (1999) - *Waves-dominated beaches*. In: Short A (ed). «Handbook of beach and shoreface morphodynamics», Wiley & Sons, Chichester, 173-191.

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