Revista da Gestão Costeira Integrada 10(1):81-93 (2010)
Journal of Integrated Coastal Zone Management 10(1):81-93 (2010)

GESTÃO COSTEIRA INTEGRADA
www.aprh.pt/rgci
www.gci.inf.br

Natural and Artificial Reefs at Mar del Plata, Argentina

Recifes Naturais e Artificiais em Mar del Plata, Argentina

Federico Ignacio Isla [1]

ABSTRACT

Integrated coastal zone management techniques usually search the preferences of the owners of the coastal properties but without considering the beach users. Multipurpose artificial reefs are submerged structures built in order to diminish wave action, to modify breaker conditions, to protect the coast, and to increase marine biodiversity. Alternatives construction types are considered in relation to the surfing quality of the waves of Mar del Plata. Although detached emerged breakwaters and low-crested submerged structures have been successfully applied to protect beaches from breaking waves, the artificial surfing reefs can improve breaker conditions for recreational purposes. Both structures may increase sand accumulation at the beach if it is naturally available; if not the beaches should be artificially nourished. Based on knowledge of the littoral transport and the bottom composition of the Ensenada Mogotes, artificial submerged reefs, combined with nourishment efforts, are proposed to recover the beach called Los Acantilados. The surfing conditions can improve as a surplus to the stability of the rocky-sandy nearshore ecosystem.

Keywords: Artificial Surfing Reefs – Mar del Plata – Ensenada Mogotes - side-scan survey

RESUMO

As técnicas de gestão integrada da zona costeira são normalmente direccionadas para a protecção dos interesses dos donos das propriedades costeiras e menosprezam, ou não consideram, os interesses dos utentes das praias. Os recifes artificiais multi-funcionais são estruturas submersas construídas para mitigar ou reduzir a acção das ondas, modificar/melhorar as condições de rebentação, proteger a zona costeira (em particular, campos dunares e praias) e aumentar a biodiversidade marinha. São abordadas construções alternativas relativamente à qualidade das ondas para a prática de surf em Mar del Plata. Embora construções clássicas como quebra-mares destacados e estruturas submersas tenham revelado sucesso na protecção da praia, os recifes artificiais multi-funcionais permitem melhorar as ondas para a prática de surf e outros fins recreativos. Ambos os tipos de estruturas promovem alguma acumulação de areia na praia, se esta estiver naturalmente disponível; não existindo, a praia

1 - CONICET-Universidad Nacional de Mar del Plata, Instituto de Geología de Costas y del Cuaternario, fisla@mdp.edu.ar

** Submissão – 18 Setembro 2009; Avaliação – 18 Novembro 2009; Recepção da versão revista – 9 Novembro 2009; Disponibilização on-line - 18 Janeiro 2010*

deverá ser alimentada artificialmente. Com base no conhecimento do transporte litoral e na composição dos fundos da Mogotes Ensenada, é proposta uma solução de recifes artificiais submersos, eventualmente combinada com alimentação artificial, para recuperar a praia de Los Acantilados. As condições de surf deverão melhorar e espera-se uma contribuição positiva para a estabilidade do ecossistema arenoso existente.

Palavras-chave: *Recifes Artificiais para surf – Mar del Plata – Ensenada Mogotes – mapeamento com sonar de varrimento lateral*

1. INTRODUCTION

Mar del Plata harbour (38° 02'S; 57° 32'W) was constructed between two capes of the Tandilia Range, in a location where the continental shelf is narrower and higher wave energy. The harbour was finished in 1922. Since then Mar del Plata beaches eroded at an increasingly rates as the longshore drift from south to north was obstructed by the two jetties. Due to the availability of quartzitic rocks in the surroundings, groin fields were emplaced in order to capture this northward fine-sand drift. However, these solutions have caused serious problems as the erosive problems extended and have become critical (Isla *et al*., 2001). Cliff recession and failure episodically occurs due to the impacts of extratropical storms originating in the South Atlantic Ocean, the so-called "sudestadas" (*southeasterlies*). The Ensenada Mogotes (Figure 1) is the most endangered beach as it faces south, where the storms usually strike harder. Beach surveys performed along this littoral cell show an erosion sector to the south, an area dominated by the northwards sediment transport, and an accumulative sector at the area protected by the Pescadores Bank (Isla, 1992; Farenga *et al*., 1993; Isla *et al*., 1994). This rocky plateau is also composed of the resistant Paleozoic quartzites and constitutes a natural reef that inhibits the effect of high energy waves, without obstructing the longshore drift. Due to severe erosion problems of the southern portion of this embayment, a group of students of hydraulic engineering evaluated a groin field complemented by nourishment as the most economic solution (Algera *et al*., 2004). Based on models designed at the University of Cantabria (OLUCA, COPLA, EROS) and considering wave data provided by NOAA (National Oceanic and Atmospheric Administration) for the surrounding 100 km (Mar del Plata-Necochea), a field of 16 detached breakwaters combined with nourishment (250,000 m^3), was also proposed for the southern sector (Gyssels *et al*., 2007). Artificial reefs were also proposed for this area to the municipal authorities. Both proposals, detached breakwaters and artificial reefs, were considered by the authorities of the Buenos Aires Province in relation to their environmental impact assessments.

The present contribution analyses wave dynamics, the sand budget and nearshore information in order to justify alternative solutions that also improve the recreational facilities. In this sense, it is discussed if the decision should consider the preferences of the property owners or extended to the seasonal beach users.

2. FROM GROIN FIELDS TO BREAKWATERS

The blocking of the longshore drift caused by the harbour of Mar del Plata has led to the planning of hard structures (riprap defences and groin fields). During years, the coastal defence policy of Mar del Plata was oriented exclusively to the construction of these groin fields (Lagrange, 1980; Figure 1). At the same time that some beaches were recovered by reducing wave effects (e.g. Playa de los Ingleses, La Perla, Bristol, Camet), pluvial outfalls were diminishing the bathing quality. As the littoral blocking increased the problems of sand scarcity, new defences such as T-groins tried to induce wave diffraction (Lagrange, 1980). The availability of quarries of quartzites of excellent quality at the surroundings of Mar del Plata led to an extended use of riprap structures. In some places, groins were built too long, too high and too close (Figure 2A, Isla *et al*., 2001), being dangerous for beach users and swimmers, and recommended to be modified (Rijkswaterstaat, 1997). These constructions have been progressively increasing the erosive problems at the northern beaches becoming critic to some villages north of Mar del Plata (Isla, 2006). These effects derived from the lack of regional planning are sadly well reported in the literature (Do Nascimento and Lavenère-Wanderley, 2004). T-groynes, acting as breakwaters, accumulated artificial beaches but have led to a reduction in water quality for bathing purposes (Figure 2B).

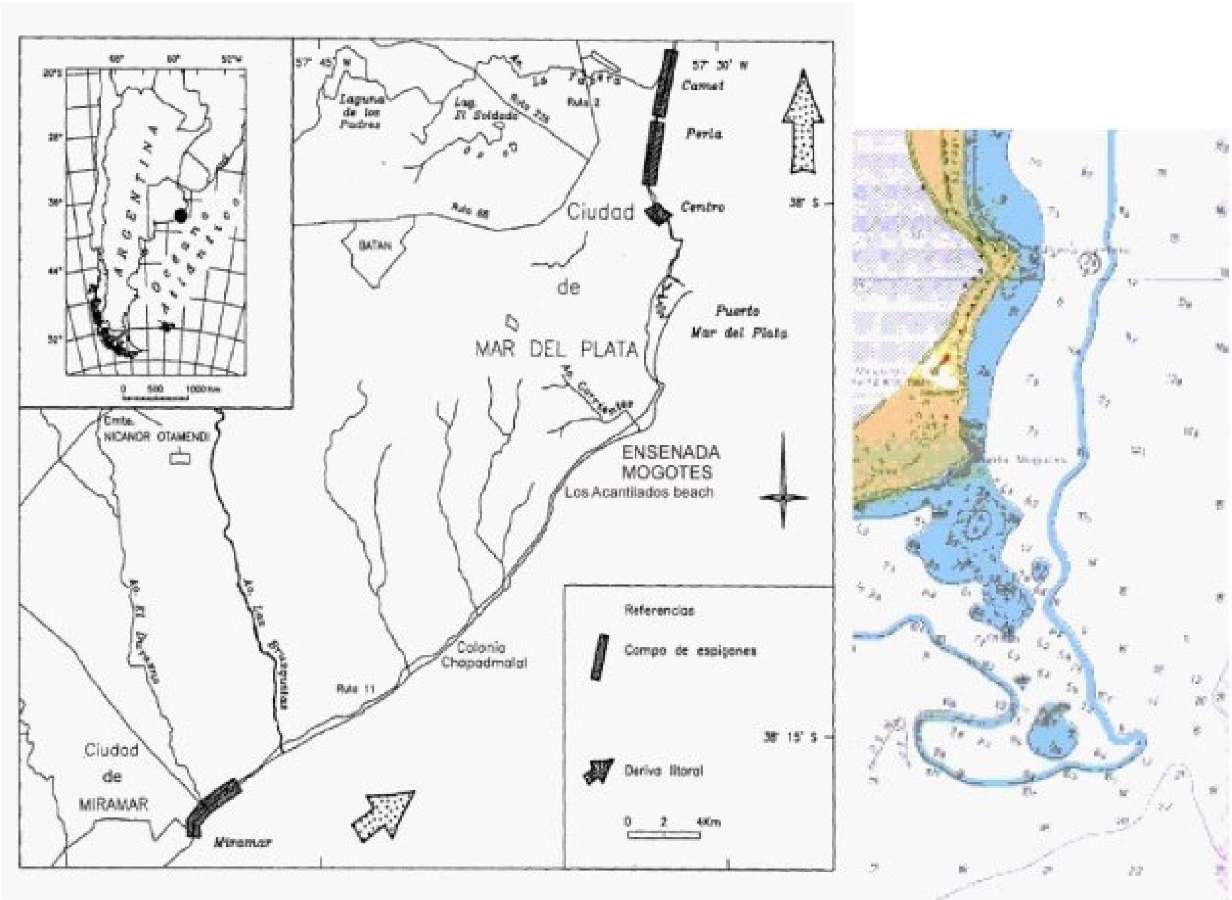

Figure 1. A. Location map and groin fields at Mar del Plata and Miramar (modified from Isla *et al*., 2001); B. Bathymetric chart of Punta Mogotes and Punta Cantera capes.

Figura 1. Mapa de localização e campos de esporões em Mar del Plata e Miramar (modificado por Isla et al., 2001); B. carta batimétrica de Punta Mogotes e cabo de Punta Cantera.

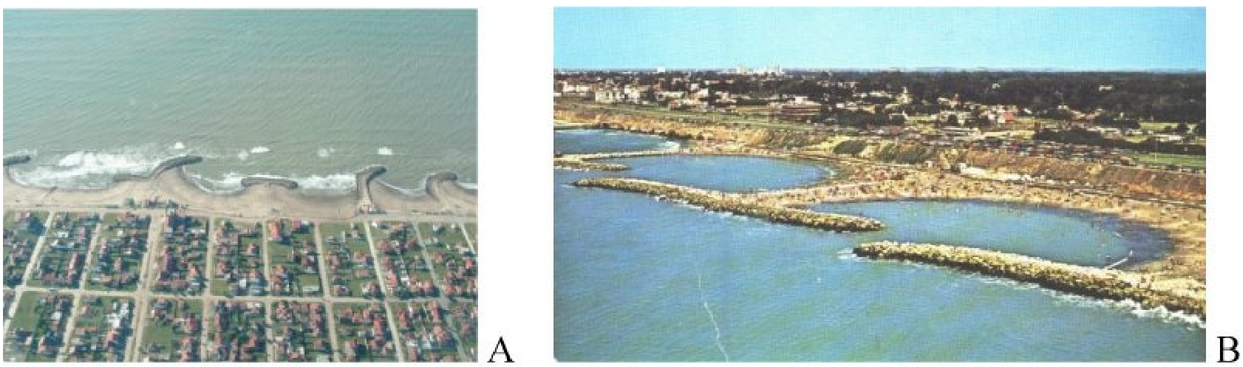

Figure 2. Hard structures north of Mar del Plata (Camet). A. Groins (straight and bended) cause longshore-drift obstruction; B. T-groins cause wave diffraction, induce sand sedimentation but impede the renewal of water at the compartments.

Figura 2. Estruturas pesadas a norte de Mar del Plata (Camet). A. Esporões (simples e compostos): causam obstrução à deriva litoral; B. Esporões em T: causam difracção das ondas e induzem acumulação de areia, mas impedem a renovação da água entre compartimentos.

3. FROM BREAKWATERS TO ARTIFICIAL REEFS AND LOW-CRESTED STRUCTURES

Reef breakwaters were usually recommended to reduce sediment transport at harbour entrances (Carver and Bottin, 1997). One of the firsts offshore breakwaters was constructed in1968 to assure the access of the Ventura Harbour (California); later it was subject to several changes (Hughes and Schwichtemberg, 1998). At the beginning of the nineties, the Coastal Engineering Research Center (CERC) considered nearshore berms to attenuate wave energy for coastal protection (Pollock *et al.*, 1993; Allison and Pollock, 1993; Williams *et al.*, 1993). In 1997 rapidly installed breakwaters (RIB) were proposed to protect the Outer Banks of North Carolina (Fowler *et al.*, 1997). To predict tombolos or salient formation several practical rules are applied, supplemented by physical model tests (Zyserman and Johnson, 2002). However, several attempts failed as a regional coastal-defence solution (Edwards, 2006).

In regard to detached breakwaters designed for beach protection, several formulas were proposed (Table 1) considering distance from the coast (X), lengths of the breakwaters (L), distance between them (G), distance between tombolos (D), wave angle (wa), wave steepness (ws) and coastal slope (m).

For detached breakwaters located 275 m offshore, segments of 220 m length and gaps of 300 m were recommended; the empirical relationships suggested X/L = 1.25 and G/L = 1.5 (Thomalla and Vincent 2004). However, for the Ensenada Mogotes shorter breakwaters (L = 60 m) with gaps of only 70 m (Gyssels *et al.*, 2007) means X/L relationships of 4.16 and G/L about 1.16. This means that the segments will be too short and too close in relation to the empirical formulas proposed for the North Sea.

During this century artificial reefs have been proposed in order to benefit recreation, conserve the aesthetic value, and therefore improving the economy; i.e. the so-called "artificial surfing reefs" (Mead, 2003). Some surfing reefs have focused to induce the breaker over the structure (conventional surfing reefs); others are planned to cause wave refraction towards a certain place where waves breaks landwards of the reef (wave-focusing reef; West *et al.*, 2003). Projects should consider a depth of the structure to assure wave breakers, but also a depth that gives security to surfers (Ten Voorde *et al.*, 2008). Although some failed in their objectives, others have been successfully applied (Scarfe *et al.*, 2009). The purpose is to increase the steepness of the wave at the breakers, and to improve the wave angle to increase the "surfable" distance (Mead, 2003). One of the main benefits of them is that they do not obstruct the longshore drift (Figure 3). They show better performance when the coast is subject to oblique wave attack (Ranasinghe and Turner, 2006).

Table 1. Comparison of parameters considered for empirical formulas to plan detached breakwaters (references in the text).
Tabela 1. Comparação dos parâmetros considerados nas fórmulas empíricas para o projecto de quebra-mares destacados (referências no texto).

	X	L	G	S	D	wa	Ws	M
Suh and Dalrymple, 1987		o	o	o				
Pope and Dean, 1986	o	o	o		o			
Ahrens and Cox	o	o						
Mc Cormick, 1993	o	o				o	o	o
King *et al.*, 2000	o	o	o					
Thomalla and Vincent, 2004	o	o	o					

Figure 3. Benefits and problems compared in relation to costal defence solutions.
Figura 3. Comparação de benefícios e problemas de soluções de defesa costeira.

4. SETTING

A subhumid template climate characterizes Mar del Plata city. Mean annual temperature is 13.9 °C with Precipitations of 864 mm/year (data from Camet Airport, Mar del Plata). The coast has a microtidal regime (tidal range is between 0.6 a 0.91 m) with daily inequalities. In response to differing beach orientation along the coast wave energy vary significantly along the coast conditioning reflective, intermediate and dissipative morphodynamic regimes (Short, 1978; 1980). Open-ocean wave height is about 0.90 m (period of 9.5 s) although maximum wave heights of 2.30 m were estimated (Lanfredi *et al.*, 1992). Annual sand drift has been estimated between 400.000 to 700.000 m^3/yr, based on wave statistics of 1967-68 (Caviglia *et al.*, 1992). Applying the UNIBEST Longshore transport model, potential drifts, calculated specifically for the Ensenada Mogotes, can vary from 250,000 to 1,230,000 m^3/yr (Algera *et al.*, 2004). The longshore transport capacity discriminated along the embayment increases in Los Acantilados beach to an amount of 740,000 m^3/yr (Algera *et al.*, 2004). Storms episodically strike and altered significantly the volumes moving across-shore and alongshore. Based on tide-gauge records from Mar del Plata, the storm erosion potential index (SEPI) was estimated for the last 20 years (Figure 4). The more erosive storms therefore occurred in 1997 (April), 1994 (June) and 1999 (December; Fiore *et al.*, 2009).

The cliffs of the south of the embayment are composed of sandy silts with indurated levels of caliche (Chapadmalal formation), comprising ages of Pliocene to Pleistocene. The recession of these cliffs average 0.5 m/year (Isla and Cortizo in press). Towards the north, Punta Mogotes, Punta Cantera and Banco Pescadores are uplifted blocks of Paleozoic quartzites (Balcarce formation). The coastal plain is slightly undulated and crossed by creeks (Corrientes, Lobería, Chapadmalal). Natural beaches are narrow accumulations of sand, in many places presenting abrassion platforms composed of siltstones. Beaches of Ensenada Mogotes are composed of medium to very fine sand (Isla, 1992; Farenga *et al.*, 1993). Coarse sand has been sampled at the breakers and surf zone, and towards the Punta Mogotes salient (Isla *et al.*, 1994; Algera *et al.*, 2004). Los Acantilados beach is

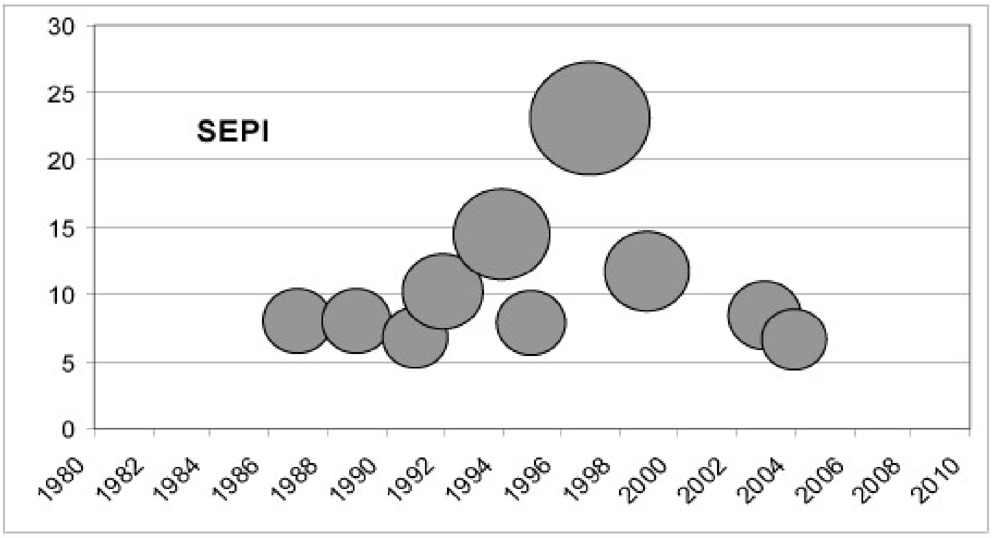

Figure 4. Storm erosion potential index for different storms that struck in Mar del Plata (modified from Fiore *et al*., 2009).
Figura 4. Índice de erosão potencial para diferentes temporais que ocorreram em Mar del Plata (modificado por Fiore et al., 2009).

dominated by very fine and fine sands (Gyssels *et al*., 2007), with coarser fractions sampled close to the breakers. However, along the embayment grain size can vary from 0.2 to 5.2 mm (Algera et al. 2004). During the summer 2002-2003, the southernmost beach of this embayment, Los Acantilados, did not recover from the erosive winter. Since then, it became matter of special concern and studies (Algera *et al*., 2004; Gyssels *et al*., 2007).

Punta Cantera and Punta Mogotes are located northwards of the Ensenada Mogotes littoral cell. The Pescadores submerged bank is the largest of several blocks located in front of Punta Mogotes. It extends from depths of 20 m to 6 m (below the hydrographic datum that is 0.91m below mean sea level). However, a block closer to the coast can emerge during low tide. This particular area has been chosen for preservation as habitat of a colony of *Arctocephalus australis* (Dassis *et al*., 2007). These blocks are inducing a tombolo that remained stable during many years (Figure 5B), although this area was subject to intense sand extraction during the end of the last century (Farenga *et al*., 1993). By the mean of the sand budget from several beaches within this embayment, a littoral cell was defined with erosion at the south and accumulation at the Punta Mogotes tombolo (Figure 5B).

5. METHODS

Beach profiles and samples for grain-size analyses were collected in 1986 (Isla, 1992). Side-scan sonar surveys were performed using a Klein 422 tow-fish model (with a K-Wing depressor) whose signal was triggered by a 350A transceiver, and echoes printed in an EPC (GSP 1086 model) graphic printer. The vessel moved at a velocity between 4 and 5.5 knots. A GPS (Trimble Ensign XL) connected to a PC located the vessel every 60 s. Bottom sediments were collected with a Snapper grab sampler.

At lab, sediment samples were dried and sieved at 0.5 phi intervals. Weights were estimated in order to calculate statistical parameters following the Folk and Ward (1957) parameters.

6. RESULTS

6.1 Wave dynamics

In Mar del Plata, the highest waves come from the south with characteristic heights around 1.5 m and 7 s period (Table 2). According to breaker waves measured between 1967 and 1968 (Sunrise Technical Consultants 1971), 50% of them are of less than 1.0 m, and 46.45% between 1 and 2 m (Figure 6), only 3.54% waves were higher than 2 m. The waves from

Figure 5. A. Punta Cantera operates as a headland or point break (in the sense of Scarfe *et al.*, 2009) that causes wave diffraction with a peel angle improved for surfing; B. Pescadores Bank acts a natural reef causing wave refraction and protecting the tombolo of Punta Mogotes. Waves from the south arrived obliquely and transport sand towards the tomobolo

Figura 5. Punta Cantera funciona como um promontório, ou ponto de rebentação (no sentido de Scarfe et al., 2009), que causa a difracção das ondas com um "peel angle" melhorado para o surf; B. O banco "Pescadores" actua como um recife natural, provocando refracção das ondas e protegendo o tômbolo de Punta Mogotes. As ondas do sul propagam-se obliquamente e transportam areia em direcção ao tômbolo.

the S were higher and with longer periods (Table 2) occurring mostly during spring (Figure 6 A). Waves from the SE were more common, with a second mode from the NE (Figure 6 B).

The continental shelf of Mar del Plata is dominated by storms coming from the south. For a storm lasting 12 hours, a maximum wave height of 5.1 m is expected in 50 years, and of 5.6 m in 100 years. Although a storm statistics is available for the last 20 years (Fiore *et al.*, 2009; Figure 2), the combined effect of two storms in a short period has been considered as capable of causing higher potential erosion (Schnack *et al.*, 1998; Lee *et al.*, 1998). In a coast dominated by storms, the sand budget of each year depends on the impact of the strongest storm (Robertson *et al.*, 2008). The parameter defined as closure depth (d_{ct}; Coastal Engineering Research Centre, 1984; Dean, 2002) is related to the significant period (Ts) and the significant wave height of the highest waves that occurred at least 12 hours during one year ($H_{s(12h,t)}$). The closure could therefore vary significantly every year.

$$d_{ct} = 2{,}28 H_{s(12h,t)} - \frac{68{,}5 H^2_{s(12h,t)}}{g T^2_{s(t)}}$$

where
g = gravity acceleration,

Considering the wave data provided by Alkyon Hydraulic Consultancy and Research, the closure depth for Mar del Plata is about 7.9 m. In other words, there is no sand movement triggered by waves below 8 m (Algera *et al.*, 2004).

6.2 Bottom survey

The side-scan sonar provided a geophysical record from the bottom between depths of 7 and 12 m. Sonographs permitted to map Pliocene siltstones with caliche indurated levels to the south of the embayment (Figure 7A), and orthoquartzites towards the north (Pescadores Bank). Sand patches were limited to the centre of the embayment. Grab samples, collected from the nearshore of the Alfar and Los Acantilados beaches, provided very-well sorted, very fine sand (mean grain size of 3.53 and 3.47 phi units). These samples confirmed the grain-size composition sampled previously (Algera *et al.*, 2004; Gyssels *et al.*, 2007).

Table 2. Wave climate from Mar del Plata (Hs: Significant wave height; Ts: Significant wave period) and summary (modified from Algera *et al*., 2004).

Tabela 2. Clima de ondas de Mar del Plata (Hs: altura da onda significativa; Ts: período da onda significativa) e resumo (modificado por Algera et al., 2004).

	N	NE	E	SE	S	SW	Total
Winter (Jun-Aug)							
Number of days	19	11	10	9	27	15	91
Hs average (m)	1,0	1,1	1,3	1,4	1,5	1,4	1,3
Ts average (s)	6,0	5,9	6,8	7,3	7,0	6,3	6,4
Spring (Sep-Nov)							
Days	15	16	13	12	24	11	91
Hs average (m)	0,9	1,0	1,4	1,3	1,6	1,4	1,3
Ts average (s)	5,5	6,0	6,4	6,6	6,6	6,2	6,2
Summer (Dec-Feb)							
Days	17	22	11	8	24	9	91
Hs average (m)	1,1	1,3	1,3	1,4	1,6	1,5	1,3
Ts average (s)	5,8	5,9	6,2	6,9	6,3	6,3	6,1
Autumn (Mar-May)							
Days	18	13	8	11	26	15	91
Hs average (m)	1,0	1,2	1,3	1,5	1,6	1,4	1,3
Ts average (s)	5,4	6,1	6,5	6,9	6,6	5,9	6,1

SUMMARY	NE	S	SW
Days	180	140	45
Hs average (m)	1,2	1,5	1,4
Ts average (s)	6	7	6

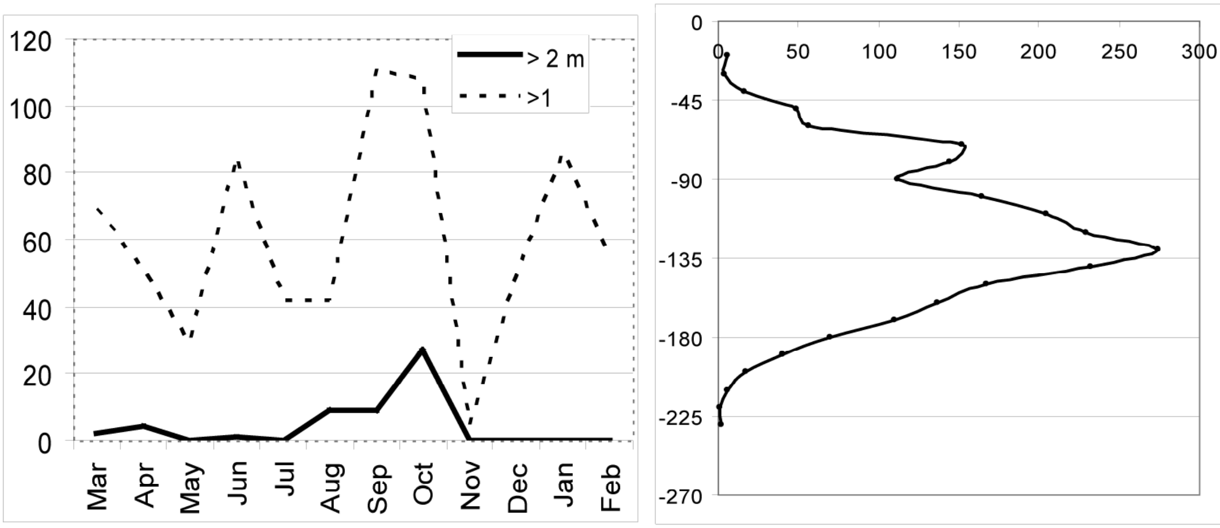

Figure 6. A. Wave height variations along the 1967-1968 period; B. Frequency distribution of wave orientations during the 1967-68 period (data collected by Sunrise 1967-68).

Figura 6. Variação da altura da onda ao longo do período 1967-1968; B. Distribuição de frequências de orientação da onda durante o período de 1967-68 (dados compilados por Sunrise 1967-68).

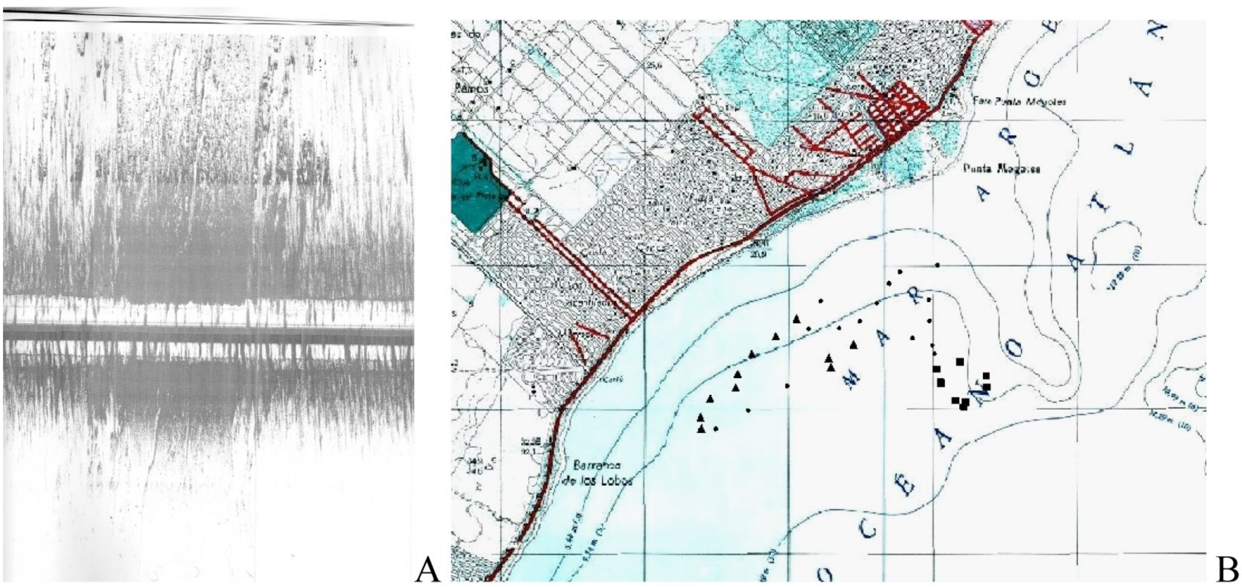

Figure 7. A. Side-scan sonar record showing a transition between a sandy bottom (light colors) and outcrops of siltstones with caliche crusts (dark colors); B. Map of the bottom of the Ensenada Mogotes based on grab simples and side scan sonar records (squares are quartzitic rocks; triangles, caliche outcrops, and dots signify a sand cover).

Figura 7. Registo com sonar de varrimento lateral mostrando uma transição entre um fundo de areia (cores claras) e o afloramento de siltitos com crostas "caliche" (cores escuras); B. Mapa da parte inferior da Mogotes Ensenada baseado em simples suportes e registos com sonar de varrimento lateral (os quadrados são rochas quartzíticas; triângulos, afloramentos "caliche" e pontos significam uma cobertura de areia).

6.3 Multi-purpose submerged reefs for Los Acantilados beach

Considering that hard structures (groins, breakwaters) proposed for the south of the embayment can cause impacts at the beaches of the north (Algera *et al*., 2004; Gyssels *et al*., 2007), a different solution is here proposed. These beaches are, at the same time, the most attractive for surfing activities. Most "point breaks" of Mar del Plata (Punta Gruta, Cabo Corrientes) were spoiled by groins constructed during the XX century. This proposal considers the strategic preservation of the surfing conditions for future generations (Scarfe *et al*., 2009b). Artificial surfing reefs (Mead, 2003; Scarfe *et al*., 2009a) can improve surfing conditions by many ways:

1. Increasing wave steepness. To improve breaker wave height (Hb) convex profiles were suggested (Mead, 2003) and Narrow Neck (Gold Coast, Australia) fits this requirement. However, Pratte´s Reef (El Segundo, California) failed as it was too small and emplaced at only 30 m from the beach (Borrero and Nelsen, 2003).
2. Improving breaker type. Although spilling and plunging breakers are available for surfing, surfers prefer plunging breakers with circular or elliptic profiles. The vortex ratios (Mead, 2003) have been related to the seabed gradient, and have also been related to peel angles and skill levels (Scarfe *et al*., 2009a)
3. Diminishing the wave peel angle. Small artificial reefs were conceived to reduce the peel angle, increasing therefore the distance of the breaker (Henriquez, 2005; Van Ettinger, 2005; Ranasinghe *et al*., 2006). A distance between the apex of the structure and the shoreline greater of 1.5 times the natural surf zone has been recommended (Ten Voorde *et al*., 2009).
4. Fixing rip currents. The fixing of a stable rip current is one of the most important issues to consider in submerged reef design (Van Ettinger, 2005). The failure of some artificial reefs was caused by the concentration of wave energy that impedes surfers to get to the breakers.

7. DISCUSSION

Traditional methods of coastal protection obstruct the longshore transport in order to accumulate sand. Although the initial inversion is paid by a stable beach, bathing quality decreases and sometimes the "solution" caused worse problems downdrift. Examples of these mistakes have been reported from Ilheus (Brazil; Do Nascimento and Lavenère-Wanderley, 2004), Santa Clara del Mar (Argentina; Isla, 2006), Arboletes, Punta Manzanillo, Bahía de Cispatá (Colombia; Correa *et al*., 2007), and Quarteira (Portugal; Cruz de Oliveira *et al*., 2008).

In the last years, submerged breakwaters and low-crested structures (LCS) have been considered as aesthetically better when the tourist value is the main objective (Johnson *et al*., 2005). These structures are planned to be built armoured but significant erosion was detected at the toes of the structures produced by an increase in rip-currents energy (Martinelli *et al*, 2006). In this sense, there are significant discrepancies about the gap distances: 20-40 m for European LCS and 90-110 m for those planned at USA (Lamberti *et al*., 2005). These structures have been repeatedly built in coasts of tourist value but where waves are not of special attraction.

Similar discrepancies can be reported in relation to the X/B relationships of detached breakwaters constructed at the North Sea (Thomalla and Vincent, 2004) and those constructed at the Mediterranean Sea (Bricio *et al*., 2008).Experiences from beaches of fetch-limited waves (i.e. Adriatic, Baltic Sea) should not be extrapolated to other coasts with different emplacement conditions, drift magnitudes or swell dynamics (Lamberti *et al*., 2005). Wave-refraction analysis and numerical modelling are specifically recommended before a decision (Zyserman and Johnson, 2002; Johnson *et al*., 2005; Zanuttigh, 2007).

Mar del Plata has the better waves of Argentina for surfing purposes, as it is located at the minimum width of the continental shelf, with less friction effects. The main benefit of surfing reefs is that they can filter larger waves, permitting short-period waves to maintain recreational conditions. Ensenada Mogotes has a stable nearshore profile composed of resistant rocks dipping gently towards the south (Figure 7B). These conditions justified the construction of a multipurpose artificial reef, as there is no risk of sinking of the structure. Large reefs are subject to erosion at their bases and therefore can be slowly sinking on nearhsore zones dominated by sand. Geotextile sand bags were preferentially chosen for reef construction as they are more easily removed, if necessary.

In regard to controversies related to the economically affordable solution, it is also recommended to consult neighbours and beach users. As the economic benefit of surfing breaks to coastal communities can be disregarded in Integrated Coastal Zone Management programs, this issue should be included in Evaluation of Impact Assessments protocols (Scarfe *et al*., 2009b). Surfing conditions are very fragile and should be considered as another issue to preserve for future generations.

8. CONCLUSIONS

1. The natural reef of Punta Mogotes has proven its efficiency filtering larger waves and inducing sediment accumulation and beach stability.
2. Groins and detached breakwaters can cause the obstruction of longshore drift at Ensenada Mogotes and therefore could increase erosion problems.
3. Artificial reefs, combined with beach nourishment, are recommended as they induced less impact and are easily removed, if necessary.
4. Surfing conditions and breakers preservation should be also considered in EIA protocols.

ACKNOWLEDGEMENTS

The author wishes to thank those who helped during the samplings and surveys. The survey with side-scan sonar was performed on the coastguard vessel Río Luján (Prefectura Naval Mar del Plata). Gustavo Huici, Surfrider Foundation Argentina, encouraged this study at several stages. A. Algera, B. Burger, W. Hartog y Q. De Rijke (Technische Universiteit of Delft, The Netherlands) provided useful information during their stay in Mar del Plata (2004). Ramón González improved the manuscript.

REFERENCES

Ahrens, J. P. and Cox, J., 1990. Design and performance of reef breakwaters. Journal of Coastal Research SI, 7:61-75.

Allison, M. C. and Pollock, Ch. B., 1993. Nearshore berms: an evaluation of prototype designs. In Magoon, O. T, Wilson, W. S., Converse, H. and Tobin, L. T. (eds.) Coastal Zone ’93, Proc. 8th. Symposium on Costal and Ocean Management, ASCE, 2938-2950.

Borrero, J. C. and nelsen, Ch., 2003. Results of a comprehenseive monitoring program at Pratte’s Reef. In Black, K.P. and Mead, S. T. (eds.) Artificial surfing reefs 2003: The 3rd. International Conference, Raglan, New Zealand, CD publication, 83-98.

Bricio, L., Negro, V. and Diez, J. J., 2008. Geometric detached breakwater indicators on the Spanish Northeast coastline. Journal of Coastal research 24, 5, 1289-1303.

Carver, R. D. and Bottin, R. R., 1997, Reef breakwater design for Burns Waterway Harbor, Indiana, U.S.A. Journal of Coastal Research 13(4):1267-1281.

Caviglia, F. J., Pousa, J. L. y Lanfredi, N. W., 1992. Transporte de sedimentos: una alternativa de cálculo. II Congreso de Ciencias de la Tierra, Memorias, Santiago, Chile, 413-422.

Coastal Engineering Research Center, 1984. Shore protection manual. Department of the Army, Vol. 1, Vicksburg, Miss.

Correa, I. D., Acosta, S. and Bedoya, G., 2007. Análisis de las causas y monitoreo de la erosión litoral en el Departamento de Córdoba. Universidad Eafit, Departamento Geología, Medellín, 128 pp.

Cruz de Oliveira, S., Catalâo, J., Ferreira, O. And Alveirinho Dias, J. M., 2008. Evaluation of cliff retreat and beach nourishment in Southern Portugal using photogrammetric techniques. Journal of Coastal Research 24, 4C, 184-193.

Dassis, M., 2005.utilización del habitat costero de Mar del Plata por lobos marinos de dos pelos: Su análisis a partir de Sistemas de Información Geográfica. Unpublished thesis, Universidad Nacional de mar del Plata, Mar del Plata, 74 pp.

Dean, R. G., 2002. Beach nourishment: theory and practice. World Scientific, Singapore, 399 pp.

Do Nascimento, L. and Lavenère-Wanderley, A. A., 2004. Effect of Shore Protection Structures (Groins) on São Miguel Beach, Ilhéus, Bahia Brazil. Journal of Coastal Research SI 39, 858-862.

Edwards, B. L., 2006.Invesigation of the effects of detached breakwaters at Holly Beach and Grande Isle, Louisiana. Unpublished thesis, Louisiana State University, 117 pp.

Farenga, M. O., Adamini, R. and Isla, F. I., 1993. Evaluación de playas de intensa extracción de arena: Ensenada Mogotes, Mar del Plata, Argentina, 1987-1990. Revista Thalassas, Univ. de Santiago de Compostela - Univ. de Vigo, 10, 41-47.

Fiore, M., .D'Onofrio, E. E., Pousa, J. L., Schnack, E. J. and Bértola, G. R., 2009. Storm surge and coastal impacts at Mar del Plata, Argentina. Continental Shelf Research.29, 1643-1649.

Folk, R. and Ward, W., 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology 27 (1): 3-26.

Fowler, J. E., Pollock, Ch. E., Resio, D. T. and Turk, G. F., 1997. Development of a rapidly installed breakwater (RIB) system. The CERCular. CERC-97-3, 1-4.

Gyssels, P., Ragessi, M., Rodriguez, A., Cardini, J., and Campos, M., 2007. Aplicaciones de modelos numéricos a un estudio de prediseño de un sistema de diques exentos en el litoral argentino. Mecánica computacional XXVI, 1252-1271

Henriquez, M., 2005. Artificial surf reefs. Unpublished Rept., Delft University of Technology, Delft, 63 pp.

Hughes, S. A. and Schwichtemberg, B.R., 1998. Current-induced scour along a breakwater at Ventura Harbour, CA. Experimental study. Coastal Engineering 34, 1-2, 1-22.

Isla, F. I. 1992. Balance sedimentario y estacionalidad en 8 playas de Mar del Plata. Revista Thalassas, Univ. Santiago de Compostela y Univ. de Vigo, 11: 11-21.

Isla, F. I., 2006. Erosión y defensa costeras. En Isla, F. I and Lasta, C. A. (eds.) Manual de Manejo costero para la Provincia de Buenos Aires, EUDEM, Mar del Plata, 125-147.

Isla, F. I., Bértola, G. R., Farenga, M. O. and Cortizo, L. C., 2001. Variaciones antropogénicas de las playas del sudeste de Buenos Aires, Argentina. Revista Pesquisas en Geociéncias, Universidade Federal do Rio Grande de Sul, 28, 1, 27-35.

Isla, F. I. and Cortizo, L. C, in press. Cliff erosion as sediment input to Argentine continental shelf. Geologica Acta, 19 pp.

Isla, F. I., Witkin, G., Bértola, G. R. and Farenga, M. O. 1994. Variaciones morfológicas decenales (1983-1993) de las playas de Mar del Plata. Revista de la Asociación Geológica Argentina 49 (3-4): 55-70.

Johnson, H.K., Karambas, T. V., Avgeris, I., Zanuttigh, B, González-Marco, D., Cáceres, I., 2005. Modelling of waves and currents around submerged breakwaters. Coastal Engineering 52:949– 969.

King, D. M., Cooper, N. J, Morfett, J. C, and Pope, D. J., 2000. Application of offshore breakwaters to the UK: a case study at Elmer Beach. Journal of Coastal Research 16, 1, 172-187.

Lagrange, A. A., 1993. Mar, playas y puerto. Fundación Bolsa de Comercio de Mar del Plata, Mar del Plata, 556 pp.

Lamberti, A., Archetti, R., Kramer, M., Paphitis, D., Mosso, C. and Di Risio, M., 2005. European experience of low crested structures for coastal management. Coastal Engineering 52:841–866.

Lanfredi, N. W., Pousa, J. L., Mazio, C. A. and Dragani, W. C. 1992. Wave-power potential along the coast of the Province of Buenos Aires, Argentina. Energy 17(11): 997-1006.

Lee, G., Nicholls, R. J. and Birkemeier, W. A., 1998. Storm-driven variability of the beach-nearshore profile at Duck, North Carolina, USA, 1981-1991. Marine Geology 148, 163-177.

Martinelli, L., Zanuttigh, B. and Lamberti, A., 2006. Hydrodynamic and morphodynamic response of isolated and multiple low crested structures: Experiments and simulations. Coastal Engineering 53, 363 – 379.

Mc Cormick, M. E., 1993. Equilibrium shoreline response to breakwaters. Journal of Waterways, Ports, Coastal and Ocean Engineering 119(6):657-670.

Mead, S. T, 2003. Surfing science. Proc. 3rd. International. Surfing Reef Conf., Karioi Centre, Raglan, NZ.

Pollock, Ch. E., Allison, M. C. and Williams, G. L., 1993. Designing nearshore berms to optimize wave attenuation. Dredging Research DRP 93-3, 4-8.

Pope, J. and Dean, J. L., 1987. Development of design criteria for segmented breakwaters. Porc. 20th.

Intnal. Conference on Coastal Engineering, ASCE, Taiwan, 2144-2158.

Ranasinghe, R. and Turner, I. L., 2006. Shoreline response to submerged structures: A review. Coastal Engineering 53, 65-79.

Ranasinghe, R., Turner, I. L. and Symonds, G., 2006. Shoreline response to multi-functional artificial surfing reefs: a numerical and physical modelling study. Coastal Engineering 53:589-611.

Rijkswaterstaat, 1997. Port and coastal study Mar del Plata. Final report. Document WB1062-4-96045, 127 pp.

Robertson, W., Zhang, K. Finkl. Ch. W. and Whitman, D., 2008. Hydrodynamic and geologic influence of event-dependent depth of closure along the South Florida Atlantic coast. Marine Geology 252, 156-165.

Scarfe, B. E., Healy, T. R. and Rennie, H. G., 2009b. Research-based surfing literature for coastal management and the science of surfing: a review. Journal of Coastal Research 25, 3, 539-557.

Scarfe, B. E., Healy, T. R. and Rennie, H. G. and Mead, S. T., 2009b. Sustainable-management of surfing breaks: Case studies and recommendations. Journal of Coastal Research 25, 3, 684-703.

Schnack, E.J., Pousa, J.L. and Isla, F.I., 1998. Erosive processes on the sandy coastline of Argentina. Vechtaer Studien zur Angewandten Geographie und Regionalwissenschaft, Band 20:133-136.

Short, A. D., 1978. Wave power and beach-stages: a global model. Proc. 16 th. Coastal Engineering Conference, ASCE, Hamburg, 1145-1162.

Short, A. D., 1980. Beach response to variations in breaker height. Proc. 17th. Intnal Coastal Engineering Conference, ASCE, Sydney, 1016-1035.

Stauble, D. K. and Tabar, J. R, 2003. The use of submerged narrow-crested breakwaters for shoreline erosion control Journal of Coastal Research 19(3): 684-722.

Suh, K. and Dalrymple, R. A., 1987. Offshore breakwaters in laboratory and field. Journal of Waterways, Ports, Coastal and Ocean Engineering 113(2): 105-121.

Sunrise Technical Consultants Co, 1971. Estudio mediante ensayo hidráulico sobre modelo del Puerto de Mar del Plata y sus alrededores. Harmi, Chou-Ku, Tokio, Japan, 7 volumes.

Ten Voorde, M., Antunes do Carmo, S. S. and Neves, M. G., 2009. Designing a preliminary multifunctional artificial reef to protect the Portuguese coast. Journal of Coastal Research 25, 1, 69-79.

Ten Voorde, M., Neves, M. G. and Carmo, J. S. A., 2008. Estudo preliminar da geometria de um recife artificial para protecção costeira e para a prática de surf na costa oeste portuguesa. Revista da Gestão Costeira Integrada 8(1): 65-79.

Thomalla, F.y Vincent, Ch. E., 2004. Designing offshore breakwaters using empirical relationships: a case study from Norfolk, United Kingdom. Journal of Coastal Research 20(4):1224-1230.

Van Ettinger, H. D., 2005. Artificial surf reef design. Dutch swell conditions. Unpublished Report., Technische Universiteit Delft , Delft, 65 pp.

West, A. S., Cowell, P., Battjes, J. A., Stive, M. J. F., Doorn, N. and Roelvink, J. A., 2003. Wave-focusing surfing reefs. A new concept. In Black, K.P. and Mead, S. T. (eds.) Artificial surfing reefs 2003: The 3rd. International Conference, Raglan, New Zealand, CD publication, 360-370.

Williams, G. L., Pollock, Ch. B. Hands, E. B., Davis, J. E. and Glenboski, L., 1993. Berm placement planning study at Breton Island, Louisiana. En Laska, S. and Puffer, A. (eds.) Coastlines of the Gulf of Mexico. Proc. 8th. Symp. On Costal and Ocean Management, ASCE, 144-158.

Zanuttigh, B., 2007. Numerical modelling of the morphological response induced by low-crested structures in Lido di Dante, Italy. Coastal Engineering 54: 31–47.

Zyserman, J. A. and Jonson, H. K., 2002. Modelling morphological processes in the vicinity of shore-parallel breakwaters. Coastal Engineering 45:261-284.