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Author(s): R. A. López, P. E. Penchaszadeh, and S. C. Marcomini
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Storm-Related Strandings of Mollusks on the Northeast Coast of Buenos Aires, Argentina

R.A. López[†], **P.E. Penchaszadeh**[‡], **and S.C. Marcomini**[†]

[†]Departamento de Geología
Facultad de Ciencias Exactas y Naturales
Universidad de Buenos Aires
Ciudad Universitaria, Pab2, 1428
Capital Federal, Argentina
rlopez@gl.fcen.uba.ar, scm@gl.fcen.uba.ar

[‡]Departamento de Biología
Facultad de Ciencias Exactas y Naturales
Universidad de Buenos Aires
Ciudad Universitaria, Pab2, 1428
Capital Federal, Argentina
penchas@bg.fcen.uba.ar

ABSTRACT

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The purpose of the paper is to characterize mollusk stranding on the northern coast of Buenos Aires, and to determine the mechanisms of alteration induced by storm surges on the infralittoral macroinvertebrates as well as on the morphosedimentary feature of the beach. The most common living organisms stranded on the beach were *Adelomelon brasiliana* and their free giant egg capsules, *Amiantis purpurata, Atrina seminuda, Buccinanops duartei, Buccinanops gradatum, Buccinanops monilifer, Donax hanleyanus, Mesodesma mactroides, Mytilus edulis platensis, Tivella isabelleana,* and *Zidona dufresnei.* Shells of *Mactra isabelleana* and *Glycymeris longior* were also found.

Three mechanisms were responsible for strandings on the emerged beach: (i) storm surges related to a decrease in the wave-cut level, (ii) swell conditions with infralittoral organism remobilization in the following 7 days, and (iii) shell bar migration. The high abundance of shells found at the emerged beach is due to *Mactra isabelleana,* although no living individuals were found during the 6 years of survey. The predominance of *G. longior* shells resulted from their shape, thickness, and hardness, enriching the beach sediments. This is in contrast to other species (*D. hanleyanus, Mytilus edulis platensis,* and *Mesodesma mactroides*) whose shells cannot endure exposure to the transport and weather conditions in the swash zone and on the emerged beach.

The intact condition of shells immediately after the storm indicate that they were transported from greater depths where the death of the organisms occured. This is indicated by the simultaneous presence of live stranded individuals and empty shells of the same species (*T. isabelleana, Amiantis purpurata, Adelomelon brasiliana, Z. dufresnei, B. gradatum,* and *Mytilus edulis platensis*). Between 35% and 65% of the sand are shell fragments, mostly of deeper water species. The variation in mean grain size, sorting, and skewness among samplings is attributed to shell fragmentation, while the mode remained invariable. Most of the intact shells supplied by the storm were reworked in the swash zone. The percentage of bioclasts remained invariable for 5 months and fell within the interval of 0–0.5 phi.

ADDITIONAL INDEX WORDS: *Beach hydrodynamics, mollusks, strandings, mass mortality, storms, beach morphodynamics, grain size, ecology, storm surges.*

INTRODUCTION

Strandings and mass mortalities on the shore are frequent episodes and affect many taxa. Most available information is referred to strandings of marine mammals and turtles (Berrow and Rogan, 1997; Raga *et al.,* 1991). Literature of invertebrate strandings is limited, and usually related to isolated species. Many different causes have been suggested. Lawrence (1996) considers mass mortalities resulting from abiotic factors, occurring in a short period of time (minutes to several weeks) and killing a substantial number of individuals of a population. He describes the mass mortality of echinoderms from abiotic factors and recognized volcanism, earthquakes, storms, temperature and desiccation, salinity, hypoxia, noxiousness from phytoplankton toxins, ice, and pollutants as causes of mass mortality. Brongersma-Sanders (1957) categorized the causes of mass mortality in the sea and gave examples, emphasizing the primary importance of finding mass-mortality events in recent times to explain and interpret paleontological observations. She considered volcanism and listed an increase in temperature, covering with ash, flood waves, poisonous gases, and acidic water as injurious consequences. Earthquakes can be tectonic or volcanic; the former are the cause of the great, disastrous ones. She listed shock, uplift of the sea, flood waves, poisonous gases, and landslides as injurious consequences. Severe storms can kill benthic invertebrates by covering them with mud or casting them up on the beach. Storms can generate strong water motion to considerable depths and can affect offshore populations.

Covering by sediment, or obrution, is the main cause of mass mortality (Seilacher, 1990) listed in six occurrences in asterozoans, thirteen in crinoids, eight in echinoids, one in cystoids, and three in blastoids. Obrution events are rarely

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observed in the present, although SEILACHER (1990) reported sand-smothered echinoderms. Other causes of strandings described by LAWRENCE (1996) are related to a combination of temperature and desiccation in the intertidal zone when emersed by water levels lower or for a longer time than usual. Several authors (GLYNN, 1968; HENDLER, 1977; LAWRENCE, 1990, 1992; MAYER, 1914; SOTO, 1985; YAMAGUCHI, 1975) studied mass mortality during emersion and immersion. BRONGERSMA-SANDERS (1957) describes salinity changes as another cause of mass mortality. The range in salinity is much greater in semiseparated parts of the sea, and nearly all reports of mass mortality she found were in such areas. Hypoxic conditions are produced when oxygen supply is decreased or consumption increased. These conditions result from current changes, stratification, and eutrophication. Referring to noxious waterbloom as a cause of mass mortality in the sea, most mortalities from waterbloom result from dinoflagellates, the notorious "red tide". An example of *Echinocardium cordatum* mass mortality occurred on the coast of south Wales in August 1990 and was attributed to a bloom of *Glycimeris aureolum* (OLIVE and CADMAN, 1990). Natural mortality of the cnidarian *Vellela vellela* has been observed in Oregon (KEMP, 1986). Other strandings are associated with senescence and parasitism in some individuals so that only a fraction of the population is affected (PENN and BROCKMAN, 1995). DARBY *et al.* (2002) found stranded Florida apple snails (*Pomacea paludosa*) related to wetland drying events. They speculated that apple snails respond to decreasing water levels and potential drying events by moving toward refuges that remain under water. Stranded *P. paludosa* must contend with dry conditions and possibly survive by aestivation.

Other cases of mass mortalities have been associated with El Niño phenomenon. Strandings of pelagic crab *Pleurocondes planipes* in Mexico (AURIOLES, CASTRO, and PEREZ, 1994) and of mollusks (*Mesodesma donacium*) and brown algae of genus *Macrocystis* were observed along the coast of Peru during those events (ARNTZ, LANDA, and TARAZONA, 1985; ARNTZ and VALDIVIA, 1985). Major storms and high tides may also cause stranding. GRANT (1985) suggested two possible reasons for stranding of surf clams in Sandy Hook, Florida. First, the biological factor, peaks in populations, abundance (or overabundance) of clams at the time of the storm. Second, the coincidence of a storm with exaggerated spring tidal range (perigean spring tide). Other species stranded by storm surges include the lobster *Homarus americanus* on the coast of Prince Edward Island, Canada (MAYNARD and CHIASSON, 1988) and the scallop *Argopecten purpuratus* on the northern coast of Chile (GONZALEZ *et al.*, 2001). In Argentina two strandings of the yellow clam (*Mesodesma mactroides*) were associated with storm surge events (OLIVIER *et al.,* 1971).

Other strandings include those related to pollution such as oil spills (DYRYNDA *et al.,* 1997). Several authors state that the risk of stranding in some species may be increased by the presence of epibionts (ANSELL, ROBB, and POWEL, 1988; GONZALEZ *et al.,* 2001; ORENSANZ, PARMA, and IRIBARNE, 1991).

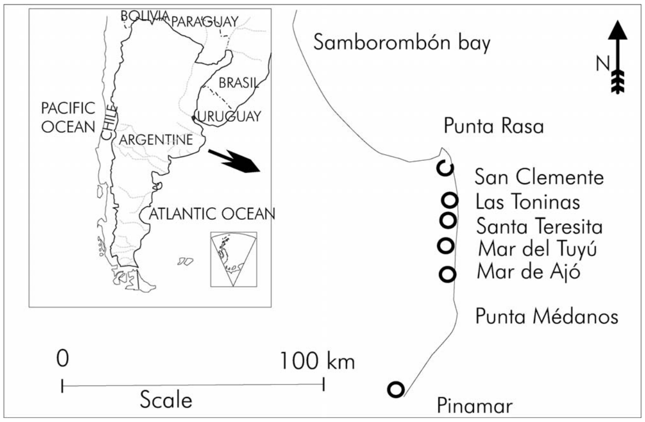

Figure 1. Location map.

The purpose of the present report is to characterize mollusk stranding on the northern coast of Buenos Aires, Argentina produced by major storms. The paper also analysed the mechanisms of alteration induced by storm surges on the infralittoral macroinvertabrates as well as on the morphosedimentary characteristics of the beach. Observations and measurements carried out between 1997 and 2003 along the coast from Punta Rasa to Punta Médanos have provided diverse information on different aspects of storm and coastal dynamics effects on the biota. Coastal monitoring included the record of macroinvertebrates in the foreshore and backshore related with storm surge events (LÓPEZ, PENCHASZADEH, and MARCOMINI, 2001). The dynamic conditions by which organisms were stranded on the emerged beach were also characterized. These were recognised by the appearance of organisms during and after storm surges, as well as by changes in the coastal morphology related to such events.

METHODOLOGY

A survey to detect the presence of infralittoral invertebrate species on the emerged beach was conducted along a coastal stretch of 100 km between 1997 and 2003. Field observations using a sighting system were performed at 11 points from the different localities comprising the Municipality of La Costa (Figure 1). After the identification of a surge event, a beach profile referring to a fixed point was obtained using a Work Station and organisms were surveyed along the emerged and submerged transverse beach profile. The spatial distribution of stranded organisms along the coast and their characteristics were recorded (permanent, sporadic, *etc.*). The number of organisms was quantified by means of photographs and calculated per unit area. Organisms were sampled and preserved in a 10% formalin–seawater solution. This same methodology was applied for empty shells thrown ashore by the storm event. The organisms recorded were classified according to their original habitats as shallow-water or deepwater dwellers. The former were related to the intertidal and swash zones up to the first longshore bar and the latter inhabit the sector between the longshore bar and the infralittoral zone. In turn, organisms from deeper habitats were subdivided into soft-bottom and hard-bottom organisms.

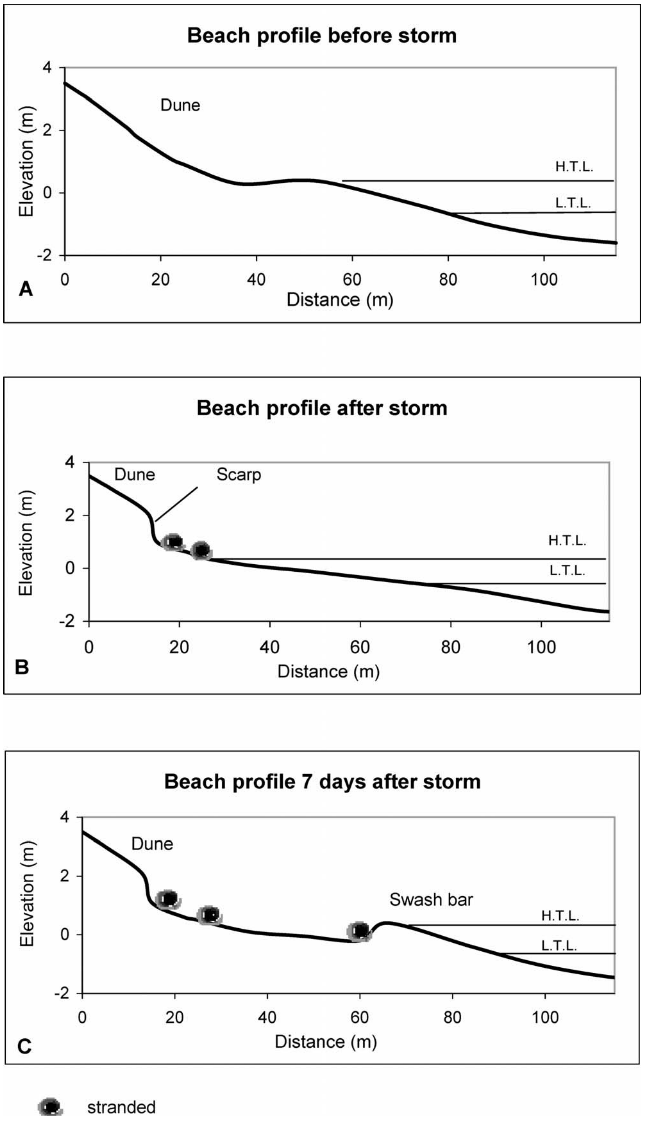

Figure 2. Changes on the transverse beach profiles and location of strandings after major storms. (A) Prestorm, (B) poststorm, (C) 7 days after storm profiles.

The mollusk shells and living organisms appearing during and after the storm surge were identified and compared. Their relationship with the shell material in the beach sand was evaluated. Meteorological data recorded over a 7-day period before the stranding were obtained. In addition, samples of sediment were taken from the swash, foreshore, and backshore areas to determine the content of shells derived from bivalve and gastropod in each grain size fraction. The grain size analysis was carried out using a Ro-tap sieving machine for 15 minutes. The scale used was the square root of two. The weight percentages of the classes were calculated along with the weight percentage of each grain size interval and histograms were made to visualise the results. Each fraction was analysed with a binocular microscope to calculate the percentages of shells and litho clasts in the samples. A storm surge that took place on 1 February 2002 was considered a control event to sample the sediments in the different beach subenvironments of Punta Médanos locality. Sampling was repeated in July of the same year to evaluate the evolution of changes caused by storm surges in the supply and reworking of shell material from deep to emerged beach sectors. All the information was processed at the Laboratory of Geology and Environmental Ecology of Coastal Areas of the Facultad de Ciencias Exactas y Naturales (University of Buenos Aires).

RESULTS AND DISCUSSION

Beach Profile Ecology and Dynamics

Beaches in the northeast of Buenos Aires province from Punta Rasa to Punta Médanos (Figure 1) are exposed to wave action. There are two prevailing directions of incident waves, from the south and SSE, and they produce a northward littoral drift current. The volume of sand drift ranges from 300,000 m^3/y to 1,000,000 m^3/y (CAVIGLIA, POUSA, and LANFREDI, 1991). The tidal regime is semidiurnal with diurnal inequalities showing a mean amplitude from 1.37 m (spring tides) to 0.78 m (neap tides) (SERVICIO DE HIDROGRAFÍA NAVAL, 2001). The extreme values range from 0 to 240 cm for high tides and from −40 to 160 cm for low tides (PERILLO, 1979). Spring tides combined with storms reach the dune base and cause erosional escarpments.

The beaches varied in width from 40 to 80 m and had a mean slope of 0.028 (1°36′). No stable berms were observed (seasonal bars were recognized in some cases, Figure 2A) except at the southern limits of the study area where well-developed berms were found (Punta Rasa and Punta Médanos). The swash bars, frequently observed at the foreshore, ranged from 15 to 25 m in width and 25 to 50 cm in height. Two daily breaker lines could be distinguished next to the shore, one at a distance between 80 and 100 m from the mean tide line and the other between 140 and 160 m. The most frequent breaker was the spilling type. The mean wave height was 0.70 m, the maximum wave height was 2 m, and the mean wave period was 8.4 seconds (SPERONI, DRAGANI, and MAZZIO, 1999). According to WRIGHT and SHORT (1984), the studied beach is of intermediate type, with an adimensional fall velocity of 2.38. According to SUNAMURA (1988), the beach corresponds to the intermediate type with bars and channels. The sandy substratum predominated in the submerged beach, with scarce and discontinuous consolidated shell banks outcropping at a depth of 6 m.

The distribution of living organisms along the cross-profile of the beach is shown in Figure 3. The typical intertidal species that were displaced upshore by storm surges and suffered mortality, occasionally massive, were the yellow clam *M. mactroides,* the surf clam *Donax hanleyanus,* and the snail *Olivancillaria auricularia* (MARCOMINI *et al.,* 2002; PENCHASZADEH and OLIVIER, 1975). Although these bivalves perform vertical migrations with the water level, this mechanism can be exceeded during strong storms and bivalves are carried to upper beach areas from where they are not able to return. In addition to performing vertical migrations, the yellow clam is a shallow burrower during its juvenile stage (up to 5 cm deep). However, the adult yellow clam can be buried

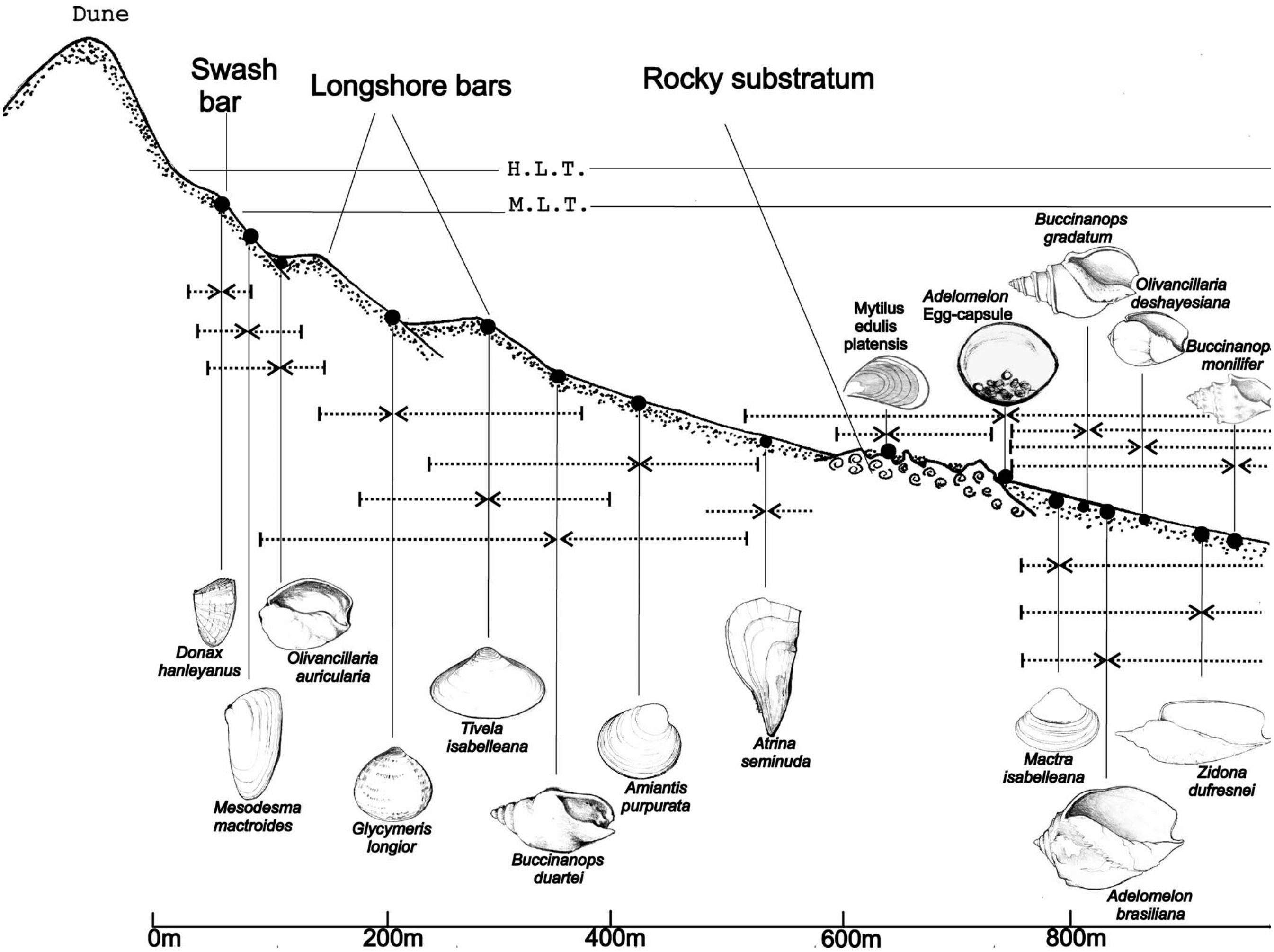

Figure 3. Scheme showing the beach profile from the backshore to the submerged beach up to 6 m depth. Zonification/sectorization of species and habitats.

up to 30 cm deep in the mid-littoral zone, particularly during spring tide. Subtidal species found living on the beach were the snail *Olivancillaria deshayesiana,* which prefers to burrow in shallow infralittoral sandy bottom, is generally smaller than 3 cm, and has a broad foot about three times the shell diameter when extended that provides a strong anchor in the substratum; *Buccinanops duartei,* which is found in the breaker zone and offshore and has a less developed but very active foot that allows it to dig rapidly in sandy substrata; *Buccinanops monilifer* and *Buccinanops gradatum* inhabit deeper waters (6–15 m) and are larger (up to 5 cm and up to 8 cm, respectively); the black snail *Adelomelon brasiliana* is a shallow burrower found between 5 and 15 m deep and can weigh up to 500 g. Its shell of up to 15 cm long is generally colonized by the big sea anemone *Antholoba achates.* This may have a negative hydrodynamic effect on the snail, since its chance of being carried out to the beach during storm surges seems to be increased. The eggs of *Adelomelon brasiliana* are enclosed within giant and almost spherical egg capsules, with a volume of up to 140 ml, and are laid free on the bottom (PENCHASZADEH *et al.,* 1999). After a storm surge event, these egg capsules are frequently found on the beach where they are subject to predation by shorebirds or to desiccation, leading to a massive mortality of embryos (PENCHASZADEH, BOTTO, and IRIBARNE, 2000). Another snail found alive in the beach area was *Zidona dufresnei.* Although this species develops large populations at greater depths (50 m), it can occur from the mid-subtidal zone (at 6–8 m deep) onward (GIMENEZ and PENCHASZADEH, 2003). This snail has a well-developed foot, but its burrowing capacity is exceeded during very strong storms.

Among the subtidal bivalve molluscs, live specimens of *Amiantis purpurata* and *Tivella isabelleana,* which are shallow infralittoral burrowers, were the most frequent species found on the beach. In contrast, *Atrina seminuda* was less abundant, possibly because it is attached to the substratum by byssal threads and stranding occurs only after very strong storm surges.

Figure 4. Stranded organisms after the storm event.

The mussel *Mytilus edulis platensis* is found in the area on consolidated substrata of submerged holocene beach ridges. This species is attached to hard bottoms through bunches of byssal threads, and like *Atrina seminuda,* it can only be torn loose by very strong storms. The clam *Glycymeris longior* was rarely seen alive stranded on the beach. However, its shells were very abundant on strandings associated with longshore bars because of their high resistance.

Extreme Events

The temporal changes along the beach profiles coincided with those established by KOMAR (1976), who recognized changes associated with swell and storms. These cycles may occur over short periods (hours or days) or long periods, but the profile is in a permanent state of change. The morphological variations in the beaches associated with changes in the hydrodynamic conditions (waves and storms) revealed an annual cycle in those coastal sectors that retained their natural conditions (MARCOMINI and LÓPEZ, 1997). Erosive conditions prevailed during spring–summer, when the action of storm surges was more frequent and intense. In autumn–winter the sand input came from south to north in the direction of the littoral drift, producing swash bars that subsequently formed seasonal bars.

The mean conditions of the coastal dynamics behaviour alternated randomly with extreme situations due to paroxysmal events caused by storms. These storms were associated with winds from the southwest, south, southeast, and east, which increased the sea level up to 1.5 m above normal. On the other hand, the extreme event, represented by an increase in the sea level, height, and wave period, was produced during spring tides. In this scenario, low-slope beaches of northeastern Buenos Aires were totally covered by the sea, which reached the base of the dunes. In response to the energy increase, there was major mobilization of sediments from the different beach sectors and part of the coastal dune. As a result, the backshore beach level decreased up to 0.9 m (MARCOMINI and LÓPEZ, 2001). There was escarpment of the frontal sector of the foredune, while the slope of the foreshore decreased and sand bars were produced offshore. Waves subsequent to the storm moved the sand bars back onshore and they emerged on the foreshore in a few days. In addition, sand transport by littoral currents occurred down to -7 m depth instead of the usual 0 and -2.8 m depth. As a result, organisms and shells appeared in different sectors of the emerged beach during and after the storm. Once removed from their subtidal habitats, individuals died rapidly. Frequently, large numbers of organisms formed extensive strandings composed of one or more species.

Figure 5. Input of swash bars to the emerged beach. The bar sediments are composed mainly by *M. isabelleana* and *G. longior* fragmented shells.

Three mechanisms for strandings on the emerged beach were identified. The first mechanism occurred during the storm and was due to the decrease in the wave-cut base level. Organisms removed from their habitat and sediments were carried by traction and saltation transport to the highest beach level reached by the storm. They formed, together with fragments of tree branches and other remains, the storm regolith (Figure 2B). This explains the presence of clusters of *M. edulis platensis, Amiantis purpurata, D. hanleyanus,* juvenile *Mesodesma mactroides* (<2 cm in length), *Adelomelon brasiliana* (<10 cm in length), *Z. dufresnei* (<10 cm in length), and *Atrina seminuda.*

The second mechanism occurred after the storm. Numerous organisms that had been dislodged at depths where wave bases normally interact with the bottom were transported to the emerged beach. During the 7 days subsequent to the extreme event, organisms in different sectors of the emerged beach were continuously found in regolith lines (Figure 4) at a height determined by the high tides after the storm (Figure 2B). These species were clusters of *M. edulis platensis, Amiantis purpurata, T. isabelleana, Adelomelon brasiliana, Adelomelon* egg capsules, *Z. dufresnei, Buccinanops globulosum, Buccinanops gradatum,* and *O. deshayesiana.*

The third mechanism also occurred after the storm, sand, and shell bars that had been formed in the surf zone by erosion of sediments from the emerged beach after storms were moved onshore through wave action (Figure 5). One or two of these swash bars, which emerged at the foreshore during the following days, remained there for months. In some cases they were a barrier preventing the vertical migration of *D. hanleyanus.* These stranded clams lose contact with the sea and organisms died (Figure 2C).

Figure 6. Strandings recognized after storms along the foreshore (A) and backshore (B).

Table 1. *Description of the stranded organisms.*

Class	Subclass	Family	Species	Organism	Valves	Characteristics
Gastropoda	Caenogastropoda	Olividae	*Olivancillaria auricularia* Lamarck 1810	X	X	Characteristic snail inhabiting intertidal sandy beaches in Central North Province of Buenos Aires; it has an extended white foot.
			Olivancillaria deshayesiana Duclos 1857	X	X	Inhabits sandy bottoms behind the breaker zone at depth varying between 4 and 8 m.
		Nassariidae	*Buccinanops duartei* Klappenbach 1961	X	X	Found along the beach profile between the intertidal and the breaker zone (4 m). Without eyes, a scavenger and predator.
			Buccianops gradatum Deshayes 1844	X	X	Snail with a thick shell, characteristic of deep waters (8–22 m) and sandy bottoms.
			Buccinanops monilifer Valenciennes 1834		X	Inhabits the breaker and offshore zones, between 4 and 20 m. Characteristically with two red bands and tuberculate shell.
		Volutidae	*Adelomelon brasiliana* Lamarck 1811	X	X	Inhabits sandy bottoms between 5 and 22 m depth. Big sea anemones (*Antholoba achates*) are frequent attached to its shell. The egg capsules of *Adelomelon* are frequent at the same depths.
			Zidona dufresnei Donovan 1823	X	X	This snail inhabits deep bottoms (50 m) but can live in lower densities in shallow waters (6–12 m).
Bivalvia		Donacidae	*Donax hanleyanus* Philippi 1842	X	X	Inhabits the intertidal of sandy beaches. It is a surface borrower (5 cm). They show densities up to 2000 indiv./m^2
		Mesodesmatidae	*Mesodesma mactroides* Deshayes 1854		X	This clam is the most conspicuous of the sandy intertidal beach in the north of Buenos Aires province. They inhabit the swash zone, burying up to 30 cm from surface. They have seasonal vertical migrations and displace to the breaker zone during winter and to the swash zone during summer. Massive death has been reported with no concluding cause.
		Glycymdae	*Glycymeris longior* Soweby 1833		X	Inhabits from wave breaker zone to the offshore up to 18-m depths. Its shell is the thickest of all clams in the area.
		Veneridae	*Tivella isabelleana*	X	X	Inhabits sandy bottoms from the breaker zone up to 4 m.
			Amiantis purpurata Lamarck 1818	X	X	Recognized on sandy bottoms between the breaker zone up to 18-m depth. It has an ardéis-pink shell with white annual growth rings. UIT short siphons is surface borrowing.
			Mactra isabelleana D'orbigny 1846		X	Sublittoral to 25 m.
		Pinnidae	*Atrina seminuda* Lamarck 1819	X	X	Sublittoral digging in the sediments attached with byssus filaments.
		Mytilidae	*Mytilus edulis platensis* D'orbigny 1846	X	X	Lives on hard rock substratum or covering piles of piers, at different depths. The strandings came from isolated submerged outcrops of consolidated beach ridges at 6-m depth.

Characteristics of Animal Strandings

Strandings consisted of two components, living organisms and bivalve and gastropod shells. The macroinvertebrate fauna from the mid- and infralittoral zones are shown in Table 1. After a time, stranded living organisms accumulated in two well-defined areas, the dune base and the high-tide zone. As the former was produced during the maximum storm peak, organisms reaching this height were not transported back by subsequent high tides. Under this condition, organisms were buried by wind instead of being transported by waves. These deposits were distributed almost homogeneously along the entire coast. Their width ranged between 0.5 and 1 m, with densities ranging from 6 to 20 individuals per m^2, except for *Mytilus,* which appeared in clusters with a variable number of individuals.

The stranding observed in the high-tide zone after the storm was composed of animals that had been transported by poststorm waves and tides. They accumulated in the fringe reached by poststorm high tides. The width of these deposits ranged between 0.5 and 5 m. Two stranding fringes could be detected occasionally, one in the mid-sector of the backshore and the other at the upper limit of the foreshore. These were related to high tides occurring immediately after the storm and to normal high tides taking place after the storm, respectively (Figure 6). These two fringes, which could be observed almost continuously along the coast, showed remarkable density differences. Highest densities were found

Table 2. *Features of the storms that provoked the stranded.*

Storm Occurence (Day or Period)	Wind Direction	Sea Level During Storm Surges	Organism Stranded
October 2, 1997	SE		*Adelomelon* free giant egg capsules
March 23–26, 1998	S	2.26–2.44	*Adelomelon* free giant egg capsules
December 04–06, 1998	S	2.61	*Adelomelon* free giant egg capsules
March 14, 1999	E		*Amiantis purpurata* and *Tivella isabelleana*
June 28–29, 1999	SE	2.10	*Tivella isabelleana*
July 13–15, 1999	SE	2.35	*Tivella isabelleana*
October 01, 1999	SSW	2.5	*Adelomelon brasiliana, Adelomelon* free giant egg capsules, *Amiantis purpurata, Buccinanops duartei, Buccinanops gradatum, Buccinanops monilifer, Mytilus platensis, Tivella isabelleana,* and *Zidona dufresnei*
May 4–5, 2000	S, SE	2.2	*Amiantis purpurata*
June 23–24, 2001	S, SSW	2.65	*Adelomelon brasiliana, Adelomelon* free giant egg capsules, *Amiantis purpurata, Atrina seminuda, Buccinanops duartei, Buccinanops gradatum, Buccinanops monilifer, Mytilus platensis, Tivella isabelleana*, and *Zidona dufresnei.*
September 14–15, 2001	SW	2.25–2.45	*Adelomelon* free giant egg capsules
September 29–30, 2001	E		*Tivella isabelleana*
November 1–2, 2001			*Donax hanleyanus*
February 01–02, 2002	SW	2.20–2.70	*Adelomelon* free giant egg capsules
August 08–10, 2002	S, SW	2.30	*Adelomelon* free giant egg capsules
May 19–23, 2003	S, SE	2.35	*Adelomelon brasiliana, Adelomelon* free giant egg capsules, *Amiantis purpurata, Atrina Seminuda, Buccinanops duartei, Buccinanops gradatum, Buccinanops monilifer, Mytilus platensis, Tivella isabelleana*, and *Zidona dufresnei.*
December 28, 2003	SE	2.62	*Adelomelon* free giant egg capsules

in areas with local decrease on the littoral drift sediment transport like those surrounding fishing docks (Mar de Ajó, La Lucila, Mar del Tuyú, and Santa Teresita) or along accresive coasts associated with longshore bars (Punta Médanos and the coastal stretch between San Clemente del Tuyú and Punta Rasa).


Figure 7. Stranding of *Adelomelon* free giant egg capsules.

One or more species occurred in the 16 stranding events surveyed from 57 storm records between 1997 and 2003 (Table 2). Strandings of only *Adelomelon* egg capsules were found for seven events (Figure 7) with densities ranging from 5 to 100 egg capsules per m^2; *Tivella isabelleana* were found for three events with densities from 4 to 15 individuals per m^2. *Amiantis purpurata,* restricted to the locality of San Clemente del Tuyù, was found at one event with densities from 4 to 12 individuals per m^2.

Species most frequently found together in strandings were *Adelomelon brasiliana, Adelomelon* egg capsules, *Z. dufresnei, B. gradatum, T. isabelleana,* and *Amiantis purpurata. Atrina seminuda* was occasionally present with densities of 4 to 20 individuals per m^2. *Adelomelon brasiliana* (approximately 40% of individuals) was the most frequent species and *Z. dufresnei* (60%) was the least frequent species. Combinations of these species less frequently observed in different events were *T. isabelleana–Amiantis purpurata* and *Adelomelon brasiliana–Z. dufresnei–B. gradatum* (Figure 8).

The higher mortality of *D. hanleyanus* was related to the migration of swash bars to upper beach areas. The death of clams occurred in different ways, burial by a large swash bar

Figure 8. Features and composition of the strandings. (a) *Adelomelon brasiliana,* (b) *Zidona dufresnei,* (c) *Buccinanops gradatum,* (d) *Antholoba achates,* and (e) *Amiantis purpurata.*

Table 3. *Statistical parameters of the beach subenvironments pre- and poststorm.*

	7 days after storm	5 months after storm
Swash Zone		
Mean	0.39	0.54
Mode	0	0
Sorting	1.63	0.95
Skewness	0.06	0.32
% of clam	64.73	64.82
Foreshore		
Mean	1.69	1.24
Mode	1.5	1.5
Sorting	0.74	0.80
Skewness	−0.20	−0.05
% of clam	34.45	52.23
Backshore		
Mean	1.47	1.54
Mode	1.5	1.5
Sorting	0.90	0.84
Skewness	−0.31	−0.20
% of clam	35.75	36.18

migration (individuals with siphons <2 cm long) or deposition on the backshore after storm surge and exposure to subaerial conditions for long periods. Although *Donax* strandings were locally distributed, covered a narrow area, and appeared on beach stretches not exceeding 400 m long, they involved hundreds of thousands of individuals.

No stranded *Mesodesma mactroides* were found in any events, although the distribution of this species overlaps with that of *D. hanleyanus.* This is probably due to the fact that the yellow clam has a higher burrowing capacity (more than 30 cm deep) and can move longer distances during its intertidal vertical migrations than *D. hanleyanus.*

Relationship between Bioclasts and Beach Sediment Composition

There were two types of sources for bioclastic material, one derived from the reworking of submerged holocene banks (Parker *et al.*, 1990) and the other from the current fauna. Abundant shells of different species were observed after the migration of swash bars onto emerged beach. The most frequent shells were *Mactra isabelleana* (74%) and *G. longior* (26%). Shells were intact or fragmented. They come from deep-sea environments where they had possibly died and been transported by local currents and storms (Figure 5).

Grain size analysis of a poststorm bar located in the swash zone at Punta Médanos showed that 64.73% of the sample was composed of shells. This is 80% greater than shell material from the foreshore and backshore (34.45% and 35.75% respectively, Table 3). The sample was taken 7 days after the storm that occurred on 1 January 2002, when waves reached up to 2.70 m because of a “sudestada” event. The sample taken from the bar was poorly sorted (1.63 φ) and those from the foreshore and backshore were moderately sorted (0.74 and 0.90 φ). The histogram representing the grain size distribution of the swash zone (Figure 9) shows a mean grain size of 0.30 φ and a symmetrical skewness (0.06 φ). There is high polymodality with a main mode at 0 φ (13.37%) with 80% of bioclasts, and two secondary modes at 1.5 (12.52%) and −2 φ (9.22%). The latter corresponded entirely to bioclasts, most of which were scarcely fragmented. The samples collected from the foreshore and backshore showed modes at the 1.5 φ interval with bioclast contents of approximately 50% in both cases. Mean grain size was 1.69 and 1.47 φ for the foreshore and backshore, respectively, and their grain size distributions were negatively asymmetric (−0.20 φ).

Five months after the storm event, and without the occurrence of any other important event, the transport of a swash bar to the foreshore was clearly evident. An increase in bioclastic concentration in the sand bar was detected associated with the displacement of the swash bar as consequence of the wave reworking of shells. Samplings were taken in different beach subenvironments. Between 8 January 2002 and 16 July 2002, the calcareous composition of the samples remained invariable both in the swash zone (64.82%) and at the backshore (36.16%). In contrast, the bioclast content at the foreshore showed an increase (52.23%).

None of the subenvironments showed changes in the mode. In the swash zone, the relation between bioclasts and lithoclasts in the mode remained invariable (80%/20% of bioclasts), but an increase in the bioclast content was observed for the mode interval when compared with the rest of the intervals (from 18% to 35%). The curve is mesokurtic, shows a high positive skewness (0.32 φ), and a mean grain size of about 0.54 φ.

The foreshore sediments immediately after the storm showed a relation of bioclasts/lithoclasts of 46%/54% for the mode class. Five months later the relation changed to 52%/48%. The reworking of the stranded shells increased, in consequence, the bioclast/lithoclast ratio of the foreshore. The interval distribution of sediment in the foreshore was nearly symmetrical (−0.05 φ) and leptokurtic, and that in the backshore did not show changes in skewness and kurtosis with respect to the previous sampling. The sediments from the swash zone were better sorted, varying from poorly sorted to moderately sorted (0.95 φ). Those from the foreshore and backshore did not show significant variation.

CONCLUSIONS

Shell fragments were more numerous than stranded live organisms in a proportion of 10 : 1, probably because the latter were heavier and showed active resistance to removal through attachment mechanisms. Most shells found at the emerged beach sectors were *Mactra isabelleana*; fewest were *Glycymeris longior.* During the 6-year survey no live individuals of these species were found stranded after storm events. The increase in the concentration of *G. longior* shells in the sand was due to their planar shape and the great thickness and hardness of their shells, which allows them to persist over time. This contrasts to other species whose shells cannot withstand transport and weather conditions in the swash zone and at the emerged beach (*D. hanleyanus, M. edulis platensis,* and *Mesodesma mactroides*). The three storm-related mechanisms causing strandings were related to a temporal sequence: during, immediately after, and after the storm.

Sedimentologic analyses showed: (i) in 5 months, the bioclast content at the foreshore increased to more than 50%

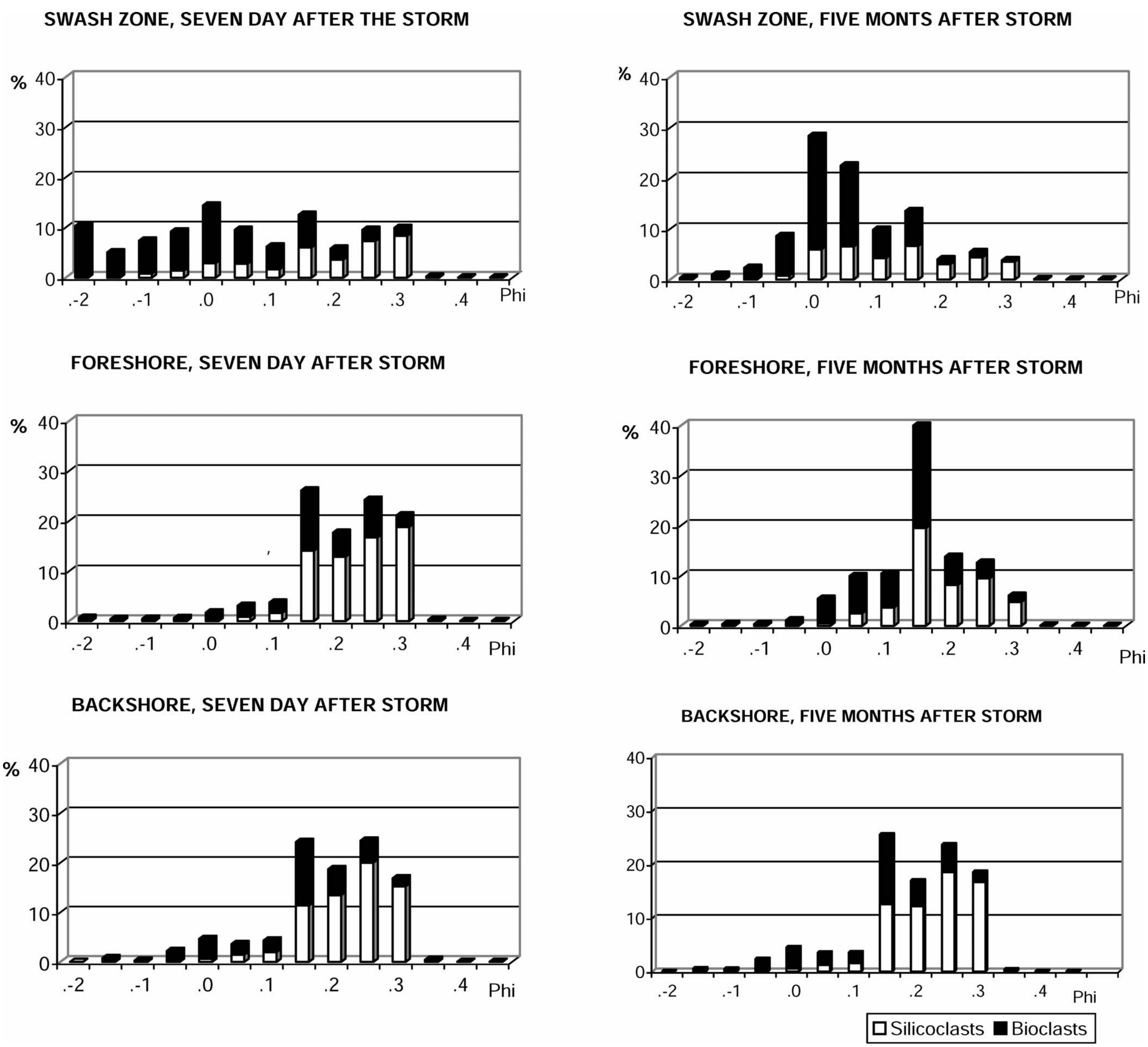

Figure 9. Grain size distribution and shellclasts *vs.* lithoclasts relations for the different beach subenvironments before and after the storm event.

because of the input of poststorm swash bars with high shell content. (ii) The low amount of fragmented shells immediately after the storm indicates that the material derived from deep sectors where there was no reworking of organisms probably died there. This is suggested by the simultaneous presence of live stranded individuals and empty shells of the same species, as found for *T. isabelleana, Amiantis purpurata, Adelomelon brasiliana, Z. dufresnei, B. gradatum* and *M. edulis platensis.* (iii) Between 35% and 65% of the sand at the emerged beach resulted from shell fragmentation. Intact shells were mainly supplied by storms since the recorded species live in deep habitats. Therefore their transport to the shore was due to storm events rather than to the littoral dynamics. (iv) The variation in mean grain size, sorting, and skewness among samplings while the mode remained invariable is attributed to shell fragmentation. (v) Most of the intact shells supplied by the storm were reworked in the swash zone. The percentage of bioclasts remained invariable for 5 months.

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LITERATURE CITED

Ansell, A.D.; Robb, L., and Powel, H.T., 1988. Algal-induced dislodgment as a cause of bivalve mortality on some Scottish beaches. *Journal of the Marine Biological Association U.K.,* 68, 219–233.

Arntz, W.; Landa, A., and Tarazona, J., 1985. "El Niño": Su impacto en la fauna marina. *Boletín del Instituto del Mar,* Special Issue No. 18, 1–222.

Arntz, W.E. and Valdivia, E., 1985. Incidencia del fenómeno "El Niño" sobre los mariscos en el litoral peruano. *In*: Arntz, W., Landa, A., and Tarazona, J. (eds.), "El Niño": su impacto en la fauna marina. *Boletín del Instituto del Mar,* Special Issue No. 18, 91–101.

Aurioles, D.; Castro, M.I., and Perez, L., 1994. Annual mass strandings of pelagic red crabs, *Pleurocondes planipes* in Bahía Magdalena, Baja California Sur, México. *Fishery Bulletin,* 92(2), 464–470.

Berrow, S.D. and Rogan, E., 1997. Review of cetaceans stranded on the Irish coast. *Mammal Review,* 27(1), 51–76.

Brongersma-Sanders, M. 1957. Mass mortality in the sea. *In*: Hedgpeth, J.W. (ed.), *Treatise on Marine Ecology and Paleoecology. I. Ecology.* New York: The Geological Society of America, pp. 941–1010.

Caviglia, F.L.; Pousa, J.L., and Lanfredi, N.W., 1991. A determination of the energy flux constrant from dredge records. *Journal of Coastal Research,* 7(2), 543–549.

Darby, P.C.; Bennetts, R.E.; Miller, S.J., and Franklin Percival, H., 2002. Movements of Florida apple snails *In*: *Relation to Water Levels And Drying Events Wetlands,* 22(3), 489–498.

Dyrynda, E.A.; Law, R.J.; Dyrynda, P.E.J.; Kelly, C.A.; Pipe, R.K.; Graham, K.L., and Ratcliffe, N.A., 1997. Modulations in cell-mediated immunity of *Mytilus edulis* following the Sea Empress oil spill. *Journal of the Marine Biological Association U.K.,* 77(1), 281–284.

Giménez, J. and Penchaszadeh, P., 2003. Size at first maturity in *Zidona dufresnei* (Caenogastropoda, Volutidae) of the southwestern Atlantic Ocean (Mar del Plata, Argentina). *Journal of the Marine Biological Association of the United Kingdom,* 83, 293–296.

Glynn, P.W., 1968. Mass mortalities of echinoids and other reef flat organisms coincident with midday low water exposure in Puerto Rico. *Marine Biology,* I, 226–243.

González, S.A.; Wolfgang, B.; Stotz, W.B., and Aguilar, M., 2001. Stranding of scallops related to epiphytic seaweeds on the coast of northern Chile. *Journal of Shellfish Research,* 20(1), 85–88.

Grant, D., 1985. Mass strandings of surf clams. *Underwater Naturalists,* 15(3), 23–27.

Hendler, G., 1977. The differential effects of seasonal stress and predation on the stability of reef-flat echinoid populations. *Proceedings, Third International Coral Reef Symposium.* I, pp. 217–223.

Kemp, P.F., 1986. Deposition of organic matter on a high-energy sand beach by mass stranding of the cnidarian *Vellela vellela* (L.). *Estuarine Coastal Shelf Science,* 23(4), 575–579.

Komar, P.D., 1976. *Beach Processes and Sedimentation.* Englewood Cliffs, N.J.: Prentice Hall, 544p.

Lawrence, J.M., 1990. The effect of stress and disturbance on echinoderms. *Zoological Science,* 7, 17–28.

Lawrence, J.M., 1992. Analysis of characteristics of echinoderms associated with stress and disturbance. *In*: Yamagisawa, T.; Yasumasu, I.; Oguro, C.; Suzuki, N., and Mootokawa, T. (eds.), *Biology of Echinodermata.* Rotterdam: Balkena, pp. 11–26.

Lawrence, J.M., 1996. Mass mortality of echinoderms from abiotic factors. *Equinoderm Studies,* 5, 103–137.

López, R.A.; Penchaszadeh, P., and Marcomini, S.C., 2001. Extraordinary events affecting the sandy beach coast of northern Buenos Aires province (Argentina). *Proceedings of the* Ocean Odyssey. Buenos Aires, Mar del Plata. CD.

Marcomini, S.C. and López, R.A., 1997. Influencia de la urbanizacion en la dinámica costera de Villa Gesell, Provincia de Buenos Aires, Republica Argentina. *Revista de la Asociación Argentina de Sedimentologia,* 4(2): 79–96.

Marcomini, S.C. and López, R.A., 2001. Método de evaluación de vulnerabilidad de playa. Caso tipo: las toninas. *III Reunión Nacional de Geología Ambiental y Ordenación del Territorio y I Reunión de Geología Ambiental y Ordenación del Territorio del Area del Mercosur.* ISBN 987-544-003-5 Buenos Aires, Mar del Plata, pp. 1–6.

Marcomini, S.C.; Penchaszadeh, P.; López, R.A., and Luzzatto, D., 2002. Beach morphodynamics and clam (*Donax hanleyanus*) densities in Buenos Aires, Argentina. *Journal of Coastal Research,* 18(4), 601–611.

Mayer, A.G., 1914. The effects of temperature upon tropical marine animals. *Papers Tortugas Laboratory,* 6, 1–24.

Maynard, D.R. and Chiasson, I., 1988. Storm related mortality of lobsters, *Homarus Americanus,* on the northeastern shore of Prince Edward Island, Canada. *Journal of Shellfish Research,* 7(1), 169.

Olive, J.S. and Cadman, P.S., 1990. Mass mortalities of the lugworm on the south Wales coast: a consequence of algal bloom?. *Marine Pollution Bulletin,* 21, 542–545.

Olivier, S.R.; Capezzani, D.A.A.; Carreto, J.I.; Christiansen, H.E.; Moreno, V.J.; Aispun De Moreno, J.E., and Penchaszadeh, P., 1971. Estructura de la comunidad, dinámica de la población y biología de la almeja amarilla *(Mesodesma Mactroides* Desh. 1854) en Mar Azúl (Pdo de General Madariaga, Buenos Aires, Argentina. Proyecto Desarrollo Pesquero FAO, Technical Report, 27, 1–90.

Orensanz, J.M.; Parma, A.M., and Iribarne, O., 1991. Population dynamics and management of natural stocks. *Developments in Aquaculture and Fisheries Science,* 21, 625–713.

Parker, G.; Violante, R.A.; Costa, P.; Marcolini, S.; Paterlini, C.M., and Cavallotto, J.L., 1990. Evolución de la región costera del este bonaerense durante el Pleistoceno Superior. *Quaternary Shorelines: Evolution, Processes and Future Changes,* 51.

Penchaszadeh, P.; Botto, F., and Iribarne, O., 2000. Shorebird feeding on stranded giant egg capsules of *Adelomelon brasiliana* (Volutidae) in coastal Argentina. *Journal of Shellfish Research,* 19(2), 321–326.

Penchaszadeh, P.; Lasta, M.; Miloslavich, P., and Souza, P.J.S., 1999. Spawn in member of the genus *Adelomelon* (Caenogatropoda: Voluptidae) from the Atlantic coast of South America. *The Nautilus,* 113(2), 78–83.

Penchaszadeh, P. and Olivier, S.R., 1975. Ecología de una población de "Berberecho" (*Donax hanleyanus*) en Villa Gesell, Argentina. *Malacofauna,* 15(1), 133–149.

Penn, D. and Brockman, H.J., 1995. Age-biased stranding and righting in male horseshoe crabs, *Limulus polyphemus. Animal Behaviour,* 49(6), 1531–1539.

Perillo, G.M., 1979. Cálculo del volumen de sedimentos de la playa frontal en el área de Punta Médanos, Provincia de Buenos Aires. *Acta Oceanográfica Argentina,* 2, 31–55.

Raga, J.A.; Raduan, A.; Balbuena, J.A.; Aguilar, A.; Grau, E., and Borrel, A., 1991. Varamientos de cetaceos en las costas españolas del Mediterraneo durante el período 1982–1988. *Miscelania Zoológica,* 15, 215–226.

Seilacher, A., 1990. Taphonomy of fossil Lagerstatten: overview, *In*: Briggs, D.E.G. and Crowter P.R. (eds.), *Palaeobiology: A Synthesis.* Oxford: Blackwell Scientific Publications, pp. 266–270.

Servicio De Hidrografia Naval, 2001. Tabla de Mareas 2001.

Speroni, J.O.; Dragani, W.C., and Mazzio, C.A., 1999. Observaciones costeras en Mar de Ajo, Pcia de Buenos Aires, descripción del ambiente litoral. Servicio de Hidrografía Naval, Tecnical Report No. 102/99, 19p.

Soto, R., 1985. Efectos del fenómeno el Niño 1982–1983 en ecosistemas de la I Región. *Investigaciones Pesqueras,* 32, 353–391.

Sunamura, T., 1988. Beach morphologies and their change. *In*: Horikawa, K. (ed.), *Nearshore Dynamics and Coastal Processes.* Tokyo: University of Tokyo, pp. 136–157.

Yamaguchi, M., 1975. Sea level fluctuations and mass mortalities of reef animals in Guam, Marina Islands. *Science,* 214, 749–755.

Wright, L.D. and Short, A.D., 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology,* 56, 93–118.