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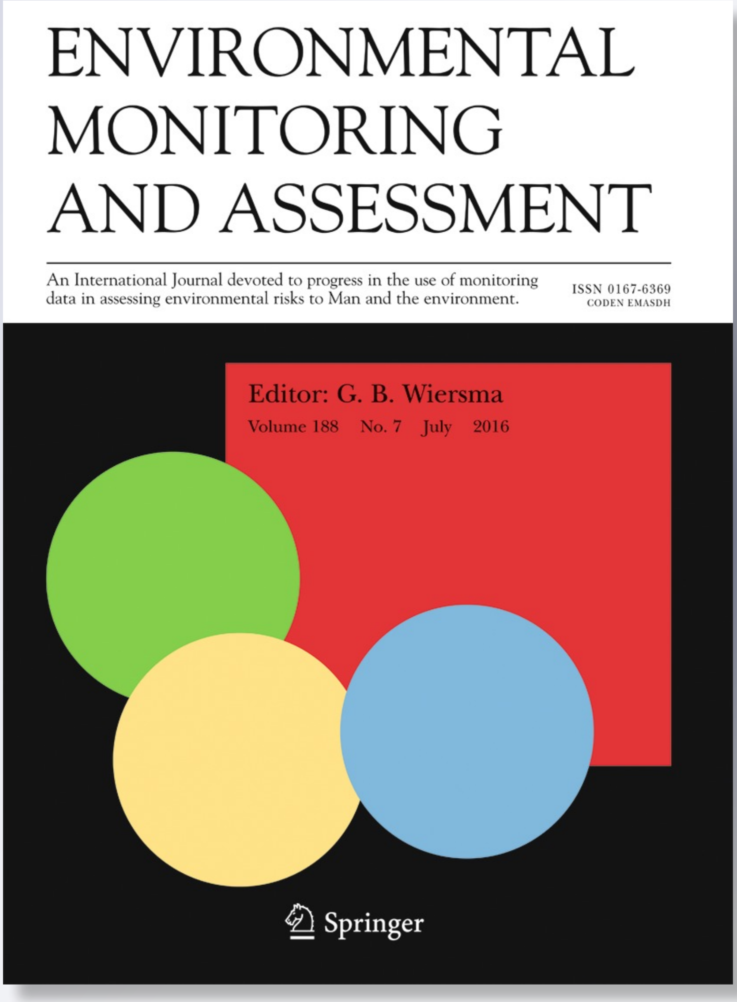

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Abstract The aim of this study was to investigate the temporal dynamics (monthly/tidal) of water temperature, salinity, chlorophyll-*a* (chlo-*a*), suspended particulate matter (SPM), particulate organic carbon (POC), and dissolved nutrients in the surf zone of Monte Hermoso sandy beach, Argentina. We also aimed to understand the underlying mechanisms responsible for the observed variability. Sampling was carried out approximately monthly (September 2009–November 2010), and all samples were collected in a fixed station during high and low tide. Water temperature showed a clear seasonal variability (July: 9 °C–December: 26.5 °C) and a thermal amplitude of 17.5 °C. Salinity ranged from 33 to 37, without a pronounced seasonality. SPM (10–223 mg L^{-1}) and POC concentrations (399–6445 mg C m^{-3}) were high in surf zone waters. Chlo-*a* (0.05–9.16 μg L^{-1}) was low and did not evidence the occurrence of surf diatom accumulations. Dissolved nutrient concentration was quite fluctuating. None of the variables seemed to be affected by tidal stage. The results showed how fluctuating the physico-chemical and biological variables can be in this particular system. The observed variability can be related with local beach conditions but also with regional processes. The study area is highly influenced by a neighbor estuary and as a consequence, could be vulnerable to their seasonal and inter-annual dynamics. All of these characteristics must be considered for further studies and planning of the uses of natural resources and should be taken into account in any environmental monitoring program conducted in a similar beach system.

Keywords Sandy beach · Surf zone · Environmental variables · Chlorophyll-*a* · Particulate organic carbon · Dissolved nutrients

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Introduction

Sandy beaches are among the most intensely used coastal ecosystems for human recreation and are decisively important to coastal regions economies. They support a high biodiversity and provide a wide range of functions and services for ecosystems including buffering and absorption of wave energy by stored sand, filtration of large volumes of seawater, breakdown of organic materials and pollutants, extensive detrital processing and nutrient recycling, nursery areas for juvenile fishes, and the provision of critical habitat and resources for declining and endangered wildlife (Defeo et al. 2009;

Dugan et al. 2015). Despite their ecological and socio-economic importance and strong potential as indicator of coastal ecosystem state, sandy beaches are under-represented in the marine literature.

The surf zone of sandy beaches represents a transition area between the dunes and the open sea, playing an important role in transporting materials and exchanging organic matter and nutrients with these adjacent environments (Carcedo et al. 2015). Surf zones are highly influenced by inputs from the coast and the ocean, thus subjected to the impacts generated in both environments (Odebrecht et al. 2010). Storms and wind-driven sand transport are the main driving forces in these ecosystems; however, beaches are also extremely sensitive to anthropogenic influences (Odebrecht et al. 2010). Numerous studies have dealt with some environmental variables (e.g., suspended particulate matter, organic matter, nutrients, photosynthetic pigments) in offshore waters and estuarine systems, but these shallow waters of recreational and ecological importance have received scant attention (Talbot and Bate 1988, 1989, 1990; Odebrecht et al. 1995, 2010, 2014; Rezende 1995; Rezende and Brandini 1997; Rörig and Garcia 2003; Rörig et al. 2006). Monitoring coastal environmental variables can contribute to the knowledge the state of marine environments and also provide a significant contribution to the strategy for coastal and marine sustainable development. The study and comprehension of the temporal dynamic of physico-chemical variables are the baseline for the understanding of ecosystem functioning.

Monte Hermoso (MH) is a 32 km long dissipative beach situated in the SW coast of Buenos Aires Province, Argentina (38° 59′ 33″ S; 61° 15′ 55″ W). Despite their cultural and socio-economic importance, this urban center does not have any kind of long-term monitoring program of environmental variables. The spatial and temporal dynamics of physico-chemical and biological variables have been extensively studied in the adjacent estuary, the Bahía Blanca Estuary (BBE) (e.g., Piccolo and Perillo 1990; Cuadrado et al. 2002; Perillo et al. 2004; Delgado 2013; Menéndez et al. 2015). However, to our knowledge, considerable gaps also exist in the processes involved in the ecological coupling between the exposed sandy shores and the adjacent estuarine system. The current study focuses on temporal (seasonal/tidal) dynamics of some environmental variables (water temperature, salinity, chlorophyll-*a,* suspended particulate matter, particulate organic carbon, dissolved nutrients) in the surf zone of MH sandy beach. The specific aims were (i) to describe the dynamic of each variable at a seasonal and tidal scale (high tide/low tide) and (ii) to evaluate a possible relationship between this sandy beach and the adjacent estuarine system (BBE). This baseline monitoring program can be of relevance for further ecological studies in the region. Moreover, it will enhance our understanding of the surf zone ecosystems and may be useful for future environmental monitoring programs performed in similar, sandy beach systems.

Materials and methods

Study area

The southwest coast of Buenos Aires Province, Argentina presents an open and straight shoreline with a E-W orientation (Fig. 1). MH is a dissipative sandy beach characterized by a low slope and supported by extensive sand dunes (Fig. 1) (Delgado et al. 2012). The area is characterized by a mesotidal regime with semidiurnal tidal cycles. The tidal amplitude varies between 2.32 and 3.35 m for neap and spring conditions, respectively,

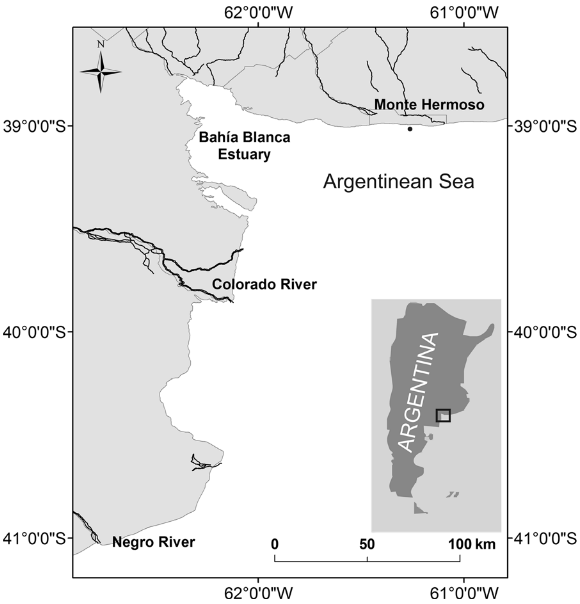


Fig. 1 Map of the study area and location of the fixed sampling site, the surf zone of Monte Hermoso sandy beach. In the *lower right corner*: general location of the sampling site in Argentina

with a mean value of 3.10 m (Servicio de Hidrografía Naval 2009). Mean wave height in the study area oscillates between 0.25 and 1.5 m associated to wave periods between 0 and 16 s (Delgado et al. 2012). Maximum wave heights occur in spring and minimum in winter months.

MH coastal waters are highly influenced by the plume of the BBE (38° 45′–30° 40′ S; 61° 45′–62° 30′ W) (Fig. 1). This temperate estuary covers an area close to 2300 km^2 and is formed by a series of NW-SE tidal channels separated by extensive inter-tidal flats, low marshes, and islands (Piccolo and Perillo 1990). The region has a temperate climate characterized by warm summers, cold winters, and moderate springs and autumns (Delgado et al. 2012). Mean temperatures oscillate between 14 and 20 °C, and the annual mean precipitation is 650 mm (Campo de Ferreras et al. 2004). The prevailing wind directions are from the N, NW, and NE, but the strongest winds come from the S, SE, and SW, especially in spring and summer, with mean speeds fluctuating between 22 and 24 km h^{-1} (Delgado et al. 2012). Winter is the season that presents more calm days and also the lowest wind speeds (SMN 1992).

MH is a small coastal town with an economy mainly based on the exploitation of marine and coastal resources, firstly touristic activities and secondly, artisanal fishery (Rojas et al. 2014). It has evolved into an important touristic center with a significant population increase during the last years, since it is one of the most selected tourist destination of Argentina (Vaquero et al. 2007). According to the last National Census of Population and Housing (INDEC 2010), Monte Hermoso has a total of 6495 inhabitants. However, during summers, its population increases by more than 60,000 people (up to 1000 %) (Rojas et al. 2014). On the other hand, the region constitutes an ecological worldwide unique system because of the existence of archeological footprints (Perillo and Iribarne 2003). Indeed, part of the beach was established as a Geological, Paleontological, and Archaeological Provincial Reserve and is currently in the last stages to be declared a world heritage by UNESCO (Rojas et al. 2014).

Collection of samples

Surf zone waters of MH sandy beach were sampled approximately monthly from September 2009 to November 2010. Field sampling was conducted at a single station located in the middle of the surf zone (38° 59′ 22.8″ S–61° 18′ 42.1″ W) within 30 m from the shoreline. Samples were collected in waters ranging from 0.7 to 1.2 m in depth during the daylight hours on two occasions: high and low tide (HT, LT). Surf zone water temperature, salinity, and pH were measured in situ using a digital multisensor Horiba U-10 (0.5 m depth). At the same time, water samples for determination of chlorophyll-*a* (chlo-*a*), particulate organic carbon (POC), suspended particulate matter (SPM), and dissolved inorganic nutrients (nitrate, nitrite, ammonium, phosphate, and silicate) were collected from the surf water and transported to the laboratory in dark and cooled conditions.

Analytical methods

POC concentration (mg C m^{-3}) was determined following the methodology proposed by Strickland and Parsons (1968), using a UV-Vis spectrophotometer (Jenway 6715 UV-Vis; cuvette path-length 1 cm). Water samples (500 ml) were filtered through previously muffled (450–500 °C; 1 h) Whatman glass fiber grade C membranes (GF/C, 47 mm diameter and 1.2 μm), and the filters with the retained material were frozen and stored at −20 °C until determination. Chlorides were removed with a treatment with phosphoric acid (Strickland and Parsons 1968). SPM (mg L^{-1}) was determined with vacuum filtration of water (250–300 ml) on pre-weighed 0.45 μm filters. Thereafter, the filters were dried at 60 °C to constant weight for the estimation of SPM concentrations.

The chlo-*a* and phaeopigments concentration (μg L^{-1}) were determined spectrophotometrically (cuvette path-length 5 cm) following the methods described in APHA (1998). Water samples (250 ml) were filtered through Whatman GF/C membranes, which were immediately frozen and stored at −20 °C. Pigment extraction was done in 90 % acetone for about 20–24 hs, placing the tubes in a fridge (4 °C) and in complete darkness. The cells were also mechanically disrupted using a tissue grinder (APHA, 1998). Phaeopigment concentration was determined using the equations of Lorenzen (1967).

Collected water was also filtered through Whatman GF/C for the study of dissolved inorganic nutrients and frozen (−20 °C) in plastic bottles until they were analyzed (Clesceri et al. 1998). Ammonium was immediately fixed by the addition of specific chemical reagents (Clesceri et al. 1998), kept in the dark, and then frozen.

Nitrate (Treguer and Le Corre 1975a), nitrite (Grasshoff et al. 1983), ammonium (Richards and Kletsch 1964, modified by Treguer and Le Corre 1975b), phosphate (Eberlein and Kattner 1987), and silicate (Technicon 1973) concentrations were determined using an automatized and five-channel upgraded Technicon AII Autoanalyzer.

Statistical analysis

Permutational univariate analysis of variance (PERMANOVA) was applied to test for significant differences of environmental variables (Anderson et al. 2008). Tests were applied to non-transformed data and based on Euclidian distances between samples, considering all the factors as fixed and with unrestricted permutation of raw data. Water temperature, salinity, SPM, POC, chlo-*a*, phaeopigments, and dissolved inorganic nutrients were tested with a two-way design (season/tide). PERMANOVA tests were applied with PRIMER-E v7 software.

Results and discussion

Mean water temperature in MH surf zone was of 16.5 ± 4.9 °C, with a thermal amplitude of 17.5 °C. This variable revealed a marked seasonal variation (pseudo-F = 9.93, $p < <0.01$; Fig. 2a), typical of temperate coastal waters (e.g., Marques et al. 2009; Menéndez et al. 2012, 2015). The lowest value was registered in June 2010 (9 °C, HT), whereas the highest one was in December 2009 (26.5 °C, LT) (Fig. 2a). Water temperature presented significantly higher values during the summer (post hoc *t* test, $p < 0.05$), showing no statistical differences for the remaining seasons. In relation to tidal phases, similar values were observed between HT and LT (pseudo-F test = 0.0009, $p = 0.983$); the maximum daily amplitude was 4 °C in August 2010 (Fig. 2a). In our region, sea surface temperature is highly coupled with air temperature variations, evidencing a strong heat exchange between the sea and the atmosphere (Perillo et al. 2004; Delgado 2013; Delgado et al. 2016). This interaction is assumed by the heating and cooling processes, which seem to occur first near the coast (in waters <2 m) and later on the offshore (Delgado 2013; Delgado et al. 2016). Additionally, MH coastal zone is highly influenced by the presence of the water plume coming from the BBE, which is characterized by very warm summers (26 °C) and cold winters (7 °C) (e.g., Piccolo and Perillo 1990; Menéndez et al. 2015; Delgado et al. 2016).

Salinity in the surf zone was high and ranged between 33 and 36.7 (Fig. 2b). There were no substantial differences between HT and LT (pseudo-F = 0.025, $p = 0.88$; Fig. 2b). Salinity values registered in this study were similar to those reported by Delgado (2013) and Delgado et al. (2016) in MH inner shelf waters (3–11 m) from March 2010 to February 2011. The entire coastal area is highly influenced by continental freshwater supplies, mainly the Negro and Colorado Rivers and the plume of the BBE (see Fig. 1) (Cuadrado et al. 2002; Lucas et al. 2005; Delgado 2013; Delgado et al. 2015). Changes of the annual discharges due to rainfall variability are the reason of inter-annual salinity variations in the whole region (Lucas et al. 2005). The decrease of rainfall during 2007–2008 was responsible for the diminution of freshwater inputs into the area and, consequently, for the increase of salinity in 2009 and 2010, leading to very high salinity values in the entire inner shelf and, particularly, in our study area (Delgado 2013; Delgado et al. 2015, 2016). During 2009–2010, salinity seasonal variation was pronounced in the inner shelf and it was associated to the estuarine signal of the Negro and Colorado rivers (Delgado et al. 2015). However, this was not the case in the surf zone (pseudo-F = 0.16, $p = 0.924$), which evidenced that other local processes—like particular surf zone hydrodynamics, local currents, and morphology of the coast—could influence the salinity seasonal dynamic. In addition, it was not observed a clear relationship between salinity and precipitations during the study period (Fig. 2c).

The southwest coast of the Buenos Aires Province is characterized by a zone of high nearsurface suspended sediments, which is variable in width, degree of contact with the shore, and the concentration of sediments (Perillo and Cuadrado 1990). In accordance with this, SPM levels were high during the present study and varied between 10 (June 2010, HT) and 223 mg L^{-1} (November 2010, LT) (Fig. 3a). Concerning seasons, there were no significant differences in SPM concentrations between them (pseudo-F = 0.28, $p = 0.862$). The high sediment concentration can be related in part to the turbulence generated by the waves when they break. According to Perillo and Cuadrado (1990), the

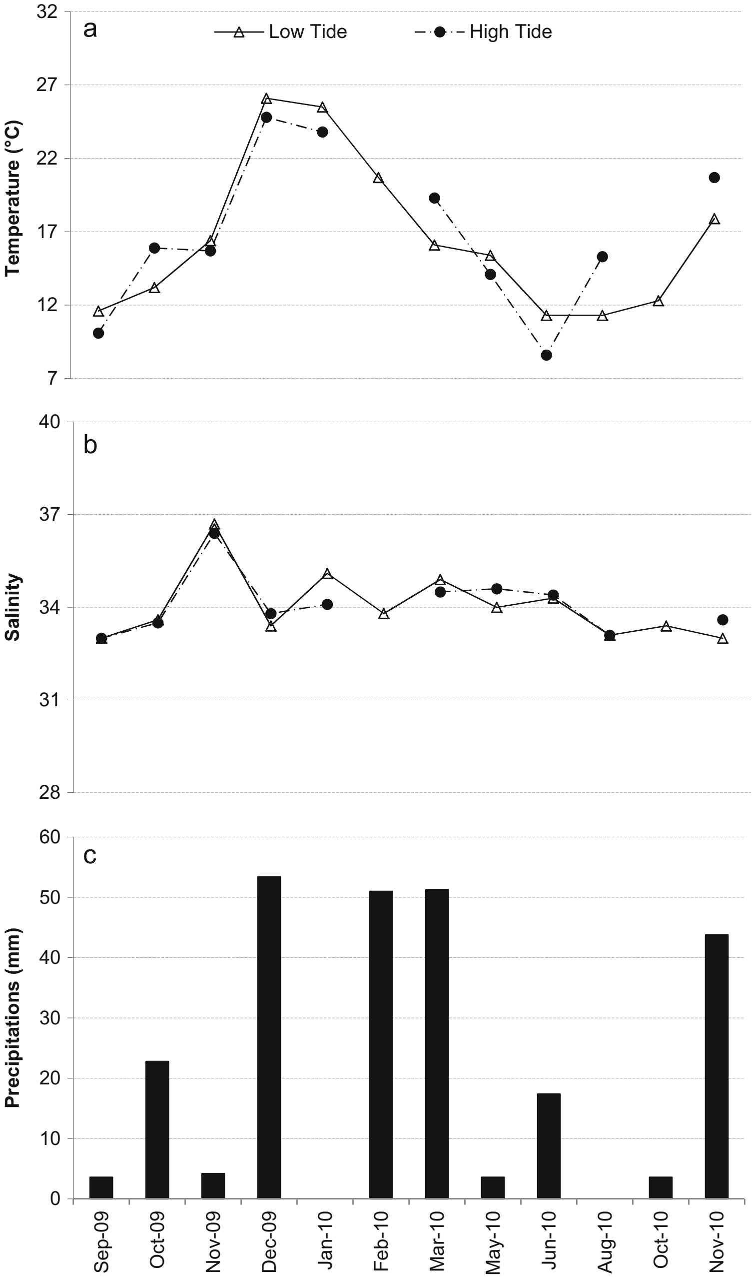
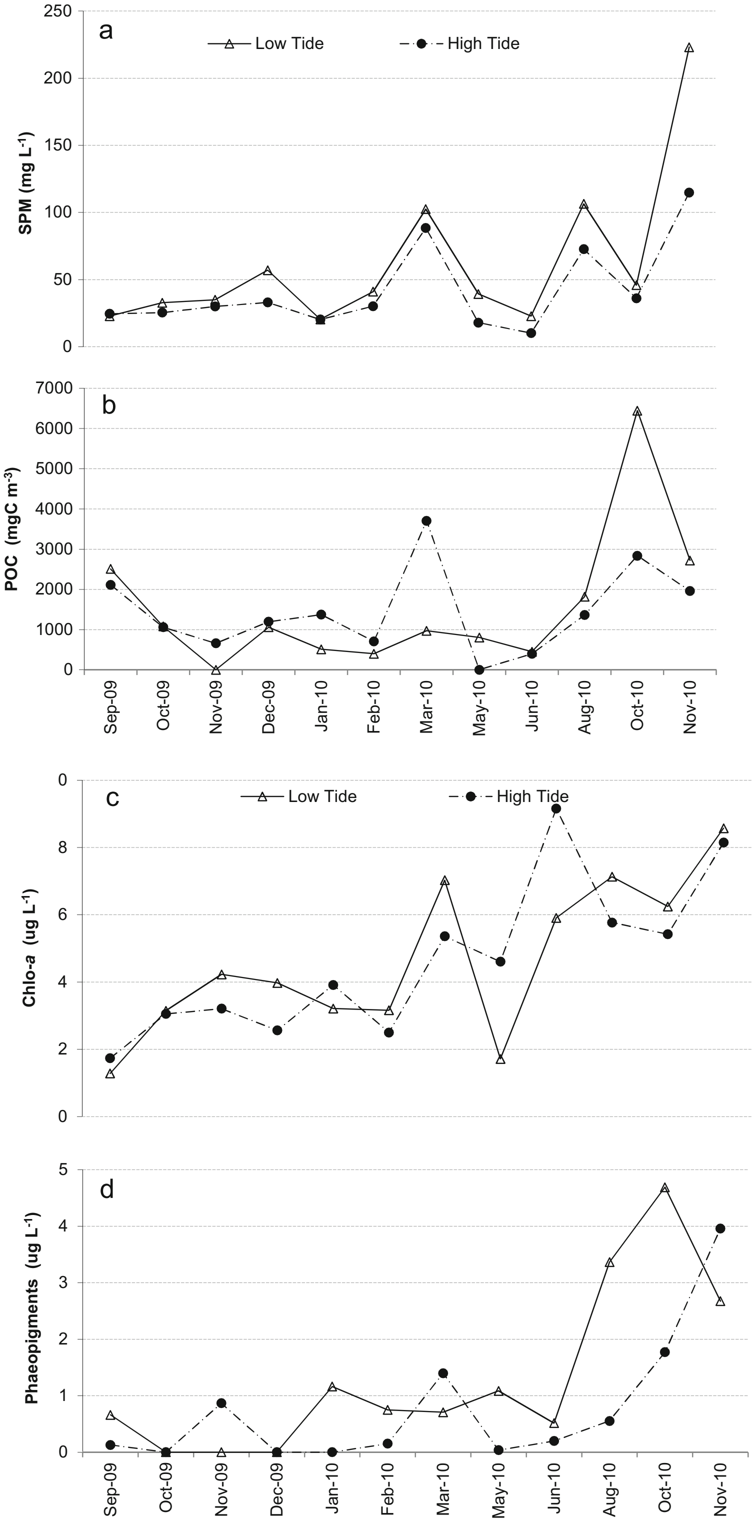


Fig. 2 Temporal variations of **a** water temperature, **b** salinity, and **c** precipitations during high tide and low tide in the surf zone of Monte Hermoso sandy beach, Argentina

suspended sand particles—highly concentrated in the surf zone—seemed to be autochthonous of MH beach. On the other hand, the BBE outflow, which deflected toward the northern coast by Coriolis force, represents an important source of fine sediments in the adjacent beaches (Perillo and Cuadrado 1990; Menéndez et al. 2015; Delgado et al. 2016). Over a short time-scale, SPM showed similar concentrations between HT and LT (pseudo-F = 0.361, *p* = 0.525), although slightly higher values were always registered during LT (Fig. 3a). Possibly a mechanism that resuspends and maintains the sediments in suspension in the surf zone is more relevant during low water conditions.

Similar to SPM, the amounts of POC were high in MH surf waters. Concentrations ranged from 399 to 6445 mg C m^{-3}, and they were quite fluctuating during

Fig. 3 Temporal variations of **a** suspended particulate matter (SPM), **b** particulate organic carbon (POC), **c** chlorophyll-a (chlo-*a*), and phaeopigments **d** concentrations during high tide and low tide in the surf zone of Monte Hermoso sandy beach, Argentina



the sampling period (pseudo-F = 1.85, $p = 0.162$) (Fig. 3b). POC values were similar between tidal phases, except during March 2010 (>HT) and October 2010 (>LT) (Fig. 3b); however, no statistical differences were detected between HT and LT (pseudo-F = 0.14, $p = 0.706$). Similar high POC concentrations were recorded in other beach systems (Talbot and Bate 1988; Kotwicki et al. 2005). Previous studies in Sundays River Beach, South Africa demonstrated that the live fraction (surf diatoms and other phytoplankton cells) was not the major C source (Talbot and Bate 1988). Most of POC present in the surf zone was in the form of detritus (55–85 %) and not live material (13–43 %). Thus, even during surf diatom accumulations, detritus may compose ~50 % of the total POC (Talbot and Bate 1988). This may be happening in our study area, as phytoplankton biomass was low. Accordingly, Yamaguchi et al. (2003) indicated that POC flux does not always reflect the phytoplankton primary production. Often the high turbidity observed is due to allochthonous matter. In MH sandy beach, the autochthonous fraction of detritus could be due to the phytoplankton community, considering that macrophytes are not present in the beach-surf ecosystem. The allochthonous contribution can be of terrigenous origin, which probably originated from the vegetated dunes. A longshore transport of this eolian-derived material could eventually result in a partial accumulation in the surf zone. The proximity of the BBE, characterized by extensive tidal flats and islands partially covered by halophytes such as *Sarcocornia perennis* and *Spartina alterniflora*, could eventually be responsible of large contribution of additional organic matter into this system. The latter was personally observed in some sampling days in MH beach. On the other hand, the low phytoplankton biomass reported in this study supports that alternative sources would keep the high levels of organic matter into the surf zone ecosystem.

Chlo-*a* in MH surf zone was low, highly variable, and did not show a clear seasonal pattern (pseudo-F = 2.14, $p = 0.122$) (Fig. 3c). It ranged from 0.05 to 9.16 μg L^{-1}, with the highest values in June 2010 (HT) and the lowest ones in October 2010 (HT). Phaeopigments were also quite variable (pseudo-F = 0.72, $p = 0.547$), with concentrations ranged between 0.13 (September 2010, HT) and 4.69 μg L^{-1} (October 2010, LT) (Fig. 3d). In any case, there were significant differences between HT and LT (pseudo-F = 0.03, $p = 0.871$ for chlo-*a*; pseudo-F = 1.20, $p = 0.294$ for phaeopigments). Chlo-*a* concentrations in the present work coincided with those registered in Cassino Beach (southern Brazil) during periods characterized by calm weather and therefore, by an absence of brown patches of diatoms (Odebrecht et al. 1995). Moreover, they were low compared to other beaches in which surf diatom accumulations occur (concentrations up to 1647 μg L^{-1}) (Odebrecht et al. 1995, 2010, 2014; Rörig and Garcia 2003). The amounts of chlo-*a* registered in MH did not evidence the accumulation of diatoms in the surf zone. This can be related to the sampling design adopted in this beach. The low frequency of field samplings together with the fact that they were always made with calm weather—owing to the difficulty to access to the study area in other weather conditions—might explain the low chlo-*a* levels detected (and the absence of diatom accumulations) in the surf zone of MH.

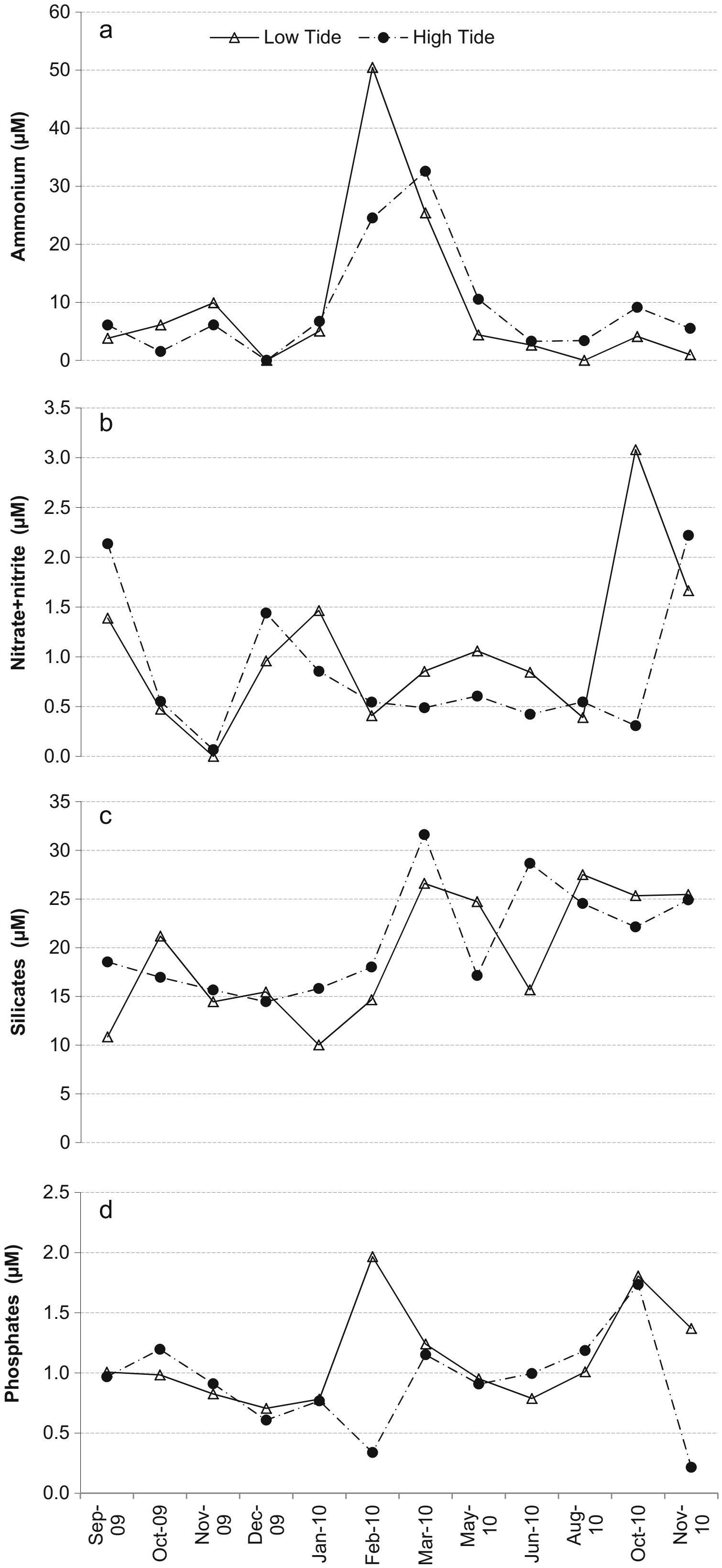
Monthly fluctuations of microalgae are related to the dynamics of exposed high-energy sandy beaches, which are largely controlled by meteorological short-term processes (Rörig and Garcia 2003; Rörig et al. 2006; Odebrecht et al. 2010). Short-term sampling programs (daily/weekly) carried out at Cassino Beach showed that the passage of southern polar fronts provides the physical setting for diatom accumulations (Odebrecht et al. 2010). High wave energy generated by southerly winds and turbulence resuspends and concentrates the cells in the surf zone (leads to extreme values of chlo-*a*), emphasizing that the frequency of accumulations in the surf zone may not be regarded as seasonal (Rörig and Garcia 2003; Odebrecht et al. 2010). The main factor promoting diatom accumulation is the effect of wind due to its influence on wave height (Talbot et al. 1990). Thus, the increase of cell concentration after storms is caused by wave-generated resuspension of diatom deposited on the sediment of the nearshore (Lewin 1978; Talbot and Bate 1989). A similar condition was observed in other surf zone as Sundays River Beach, where the increased wave energy related to storm events with onshore winds was responsible for the nearshore resuspension of epibenthic stocks and large accumulations of diatoms in the inner surf zone (Talbot and Bate 1988, 1989). The persistence of such biomass accumulation varies according to the occurrence of the winds that support this condition and the concentrations of nutrients which favors cell growth and maintenance of the in the surf zone (Odebrecht et al. 2010). In conclusion, the sampling strategy (monthly frequency and calm weather conditions) was not enough to capture all surf zone dynamics in MH sandy beach; however, it was suitable to recognize large-scale temporal variations of chlo-*a* concentrations.

Dissolved inorganic nutrients varied largely in MH surf zone (Fig. 4a–c). Statistical analysis did not show significant differences between seasons for $NO_3^- + NO_2^-$ (pseudo-F = 0.60, $p = 0.62$), PO_4^{3-} (pseudo-F = 0.21, $p = 0.87$), or dissolved silica (DSi) (pseudo-F = 0.76, $p = 0.56$); however, this revealed a marked seasonal variation for NH_4^+ (pseudo-F = 7.36, $p < 0.05$; Fig. 4a). NH_4^+ summer concentrations were significantly different from spring (post hoc *t* test, $p < <0.01$) and those observed in autumn from the winter ones (post hoc *t* test, $p < 0.05$). In any case, there were significant differences between tidal phases (all nutrients with $p > 0.25$). Dissolved inorganic nitrogen (DIN) concentration was dominated by ammonium. Mean NH_4^+ concentration (mean 9.79 ± 12.1 μM; 0.95–50.47 μM) was almost ten times higher than $NO_3^- + NO_2^-$ (mean 0.94 ± 0.71 μM; 0.07–3.08 μM) (Fig. 4a, b). The highest NH_4^+ levels were detected in late summer (February and March 2010) during both HT and LT. Nitrogen, rather than phosphorous or silicon, seems to be the limiting nutrient in the surf zones of eastern North Pacific (Lewin 1978), southern Brazil (Niencheski et al. 2007; Odebrecht et al. 2010, 2014) and South Africa (Campbell and Bate 1997, 1998). In this study, nitrate + nitrite concentrations were lower to those registered in Cassino Beach during the period 1992–2007, while ammonium values were of similar magnitude (Odebrecht et al. 2010). Total DIN concentration was higher to that registered in the surf zone of Pontal do Sul (Rezende 1995) and in Cassino Beach (Rörig and Garcia 2003). In the same way, the mean nitrate concentration found in MH was slightly higher than the registered by Gayoso and Muglia (1991) in Pehuen Co, a temperate sandy beach close to our study area. In surf zones of southern Brazil, the highest ammonium and nitrate + nitrite values have been related to meteorological extremes: the maximum values of ammonium were recorded during low precipitation conditions and the maximum nitrate concentrations during high ones (Odebrecht et al. 2010). The opposite happens in this study, where the maximum concentrations of ammonium were registered during February and March 2010 which coincide with high precipitations (Fig. 2c). However, this is not the case in other sampling days with high precipitations conditions, therefore, other factors must be influencing. In other beaches worldwide, high amounts of ammonium have been related to an increased anthropogenic activity (municipal wastewater, industrial wastewater, and agricultural runoff) around river mouths close to surf zones (Wolmarans 2012). However, in this study the levels of ammonium, dominant form of nitrogen, are much lower than those recorded in municipal wastewater according to EPA (2003).

Subterranean groundwater discharges were mentioned as the primary nutrient source for maintenance of surf diatom biomass in southern Brazil (Niencheski et al. 2007; Odebrecht et al. 2014) and South Africa (Campbell and Bate 1991, 1998). Although there is no accurate information from the MH area, in general, it may be noted that the flow of groundwater in the area has a dominant orientation NNW-SSE toward the seacoast (Paoloni et al. 2005; Sequeira 2005). Municipal solid wastes without pretreatment are deposited in a landfill opencast located at the north of the urbanization, and 44 % of the items comprising the urban area use septic tank. Thus, the influence of the direction of groundwater discharge on landfill and septic tanks can be a source of nutrients in the surf zone area. The great variability observed in dissolved nutrient levels in MH surf zone could be due to the adsorption effect with other particles, an effective process in a short-time scale. It is well known that particles in the water column may alter the availability of dissolved inorganic nutrients since many elements can be adsorbed to the particle surface and transferred to the bottom by sedimentation (Odebrecht et al. 2010). Even though nutrients did not show a clear tidal pattern, high concentrations during LT could indicate a release of nutrients into the water column from the sediment. Conversely, low concentration during LT may be associated to the loss of them from the water column to the sediment (Yin and Harrison 2000).

PO_4^{3-} concentrations were highly fluctuating during all the study period and ranged from 0.22 to 1.97 μM (mean 1.04 ± 0.39 μM) (Fig. 4d). In February 2010, concentration was up to 1.97 μM during HT while decreased to 0.33 during LT. A similar behavior was observed in November 2010 (Fig. 4d). Phosphate concentrations in MH surf waters were similar to those registered in other similar surf beach ecosystems (Rörig and Garcia 2003; Odebrecht et al. 2010), but higher than that the reported by Gayoso and Muglia (1991) in Pehuen Co. Phosphate peaks observed in February 2010 (LT) and October 2010 (HT/LT)

Fig. 4 Temporal variations of **a** ammonium, **b** nitrate + nitrite, **c** silicates, and **d** phosphates concentrations during high tide and low tide in the surf zone of Monte Hermoso sandy beach, Argentina



coincided with high concentrations of ammonium and nitrate + nitrite, respectively. As in the case of ammonium, the registered phosphate values were lower than those recorded in municipal wastewater according to EPA (2003). As PO_4^{3-}, silicate concentrations were quite fluctuating (Fig. 4c). Minimum and maximum DSi concentrations were 10.2 μM (January 2010, LT) and 31.6 μM (March 2010, HT), respectively (Fig. 4c). These concentrations (mean 20.57 ± 6.05 μM) were generally low in the first half of the study (Fig. 4c). Mean DSi concentration was higher to that mentioned for Pontal do Sul (4.43–10.47 μM) (Rezende 1995) and for Pehuen Co (29.4 μg L^{-1}) (Gayoso and Muglia 1991) but lower than in Cassino Beach coastal waters (28.5 μM) (Rörig and Garcia 2003). In addition, silicate concentrations in MH surf zone were always higher than silicate Ks for diatoms uptake (<7 μM) (Dugdale et al. 1981; Odebrecht et al. 2010), which lead us to propose that silicate amounts would not limit the growth of diatoms in this beach (Odebrecht et al. 2010).

In conclusion, this study presents for the first time a comprehensive analysis of the temporal (seasonal/tidal) dynamics of some environmental variables in the surf zone waters of MH sandy beach. The results demonstrated how fluctuating the physico-chemical and biological variables can be in this particular system. Water temperature was the only variable that exhibited a pronounced seasonal variability. Salinity was always high in the surf zone waters, and it seemed to be influenced not only by regional but also by local processes. SPM was very high in the study area which corroborate that the southwest coast of the Buenos Aires Province represents a zone of high nearsurface suspended sediments. POC was also very high in surf waters, whereas chlo-*a* levels were low and did not evidence the occurrence of surf diatom accumulations. It is worth noting that for the study of this variable, it is necessary to check the sampling frequency (to detect the occurrence of surf accumulation). Dissolved nutrient concentrations were quite fluctuating and only ammonium showed significant differences between months. None of the variables seemed to be affected by tidal stage (HT or LT); therefore, the tide does not represent an important source of variation. The observed temporal variability of water temperature, salinity, SPM, POC, chlo-*a*, and nutrient concentration can be related not only with local beach conditions but also with regional processes. Also, the study area is highly influenced by the neighbor BBE and as a consequence, could be vulnerable to their seasonal and interannual dynamics. The BBE could provide significant inputs of organic matter, suspended particulate matter, and nutrients into the adjacent beach, providing part of the conditions where biological communities can growth. These conditions may in turn affect the presence and variability in abundances of fish species in the study area, in which artisanal fishery represents one of the main economic activities. All of this variability could have significant consequences in the food webs and uses of the ecosystem and must be considered for further studies and planning of the uses of natural resources in the study area. Also, they should be taken into account in any environmental monitoring program conducted in a similar temperate system.

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