*Journal of Foraminiferal Research*, v. 48, no. 3, p. 210–222, July 2018

# RECENT BENTHIC FORAMINIFERS FROM THE SOUTH ATLANTIC SHELF OF ARGENTINA

Emiliana Bernasconi[1,*], Mario Mansilla[2] and Gabriela Cusminsky[1]

ABSTRACT

**The aim of this study was to determine foraminiferal associations from recent sediments of Argentina's continental shelf (39–41ºS, 59–61ºW; 11–70 m) and assess their relationship to physicochemical parameters. From 20 samples, all dominated by sandy sediments (>80% sand), 44 species of foraminifers were identified, most commonly *Buccella peruviana*. Recovered foraminiferal tests were generally well preserved, with morphologies indicating predominantly epifaunal, free-living detritivores from well-oxygenated waters. Multivariate analyses showed a strong correlation between foraminiferal assemblages and four zones related to physicochemical parameters. Zone I included the offshore samples from depths of 40–70 m where waters were slightly colder and more saline. Zone II samples were all collected from depths of 30–40 m that were intermediate in temperature. Zone III occurred at 20–40 m depth where sediments were characterized by some gravel content. Zone IV included the inshore sites (<20 m) offshore from the Rio Colorado delta. This work contributes to the knowledge of foraminifers on Argentina's continental shelf, complementing earlier studies of foraminiferal distributions and ecology from the region.**

## INTRODUCTION

Interest in Recent foraminifers and foraminiferal assemblages of the Austral Southwest Atlantic Ocean extends back nearly two centuries. Pioneering studies by d'Orbigny (1839) and by Cushman & Parker (1931) were extended by Heron-Allen & Earland (1932) to analyses of sediments from the Malvinas Islands (Falkland Islands) and adjacent zones. Extensive studies by Boltovskoy described benthic foraminifers from the region, for example, in the Gulf of San Jorge (Boltovskoy, 1954a, b) and the Bay of San Blas (Boltovskoy, 1957), providing details of assemblages from the Rio de la Plata estuary and its zone of influence. Boltovskoy (1966, 1976) recognized zoogeographic provinces for the South American region, while other studies used foraminifers as indicators of different water masses (Boltovskoy, 1962, 1979, 1981; Boltovskoy et al., 1980, 1996), assessing the paleoceanography of the South Atlantic Ocean from the Miocene to the present. Kahn & Watanabe (1980) and Boltovskoy & Totah (1985) studied benthic foraminifers as indicators of the Malvinas Current (Falklands Current).

Studies analyzing recent foraminifers include Alperín et al. (2008), using classical taxonomic classification, and Alperín et al. (2011), applying the "taxon free" criterion (classification of foraminifers into morphogroups). Both papers recognized different environments and water masses in the Southern Ocean. Cusminsky et al. (2006) and Calvo Marcilese et al. (2013) characterized the Bahía Blanca estuary based on research on modern sediments.

The goal of our study was to investigate the distribution and composition of modern benthic foraminiferal assemblages and to evaluate their correlation with physicochemical parameters to assess environmental variations in the sector to the southeast of the Buenos Aires Province. This work contributes to the knowledge of foraminifers on the continental shelf of Argentina and complements earlier studies of foraminiferal assemblages in this region.

## STUDY AREA

The study area (39–41ºS, 59–62ºW) is located on the Argentine Shelf off the coast of the Buenos Aires Province in the South Atlantic Ocean (Fig. 1A). The pattern of ocean currents influences the distribution of water masses, affecting the geographic distribution of marine organisms. In this context, Boltovskoy (1976) recognized a foraminiferal biogeographical province (i.e., the Argentine Province), which is located from 32–33°S in the north, to the Cape Horn area to the south (56°S). This province is characterized by the predominance of *Buccella peruviana* f. *campsi* (Boltovskoy) along with species endemic to this province, such as *Notorotalia clathrata* Brady, *Quinqueloculina arctica* Cushman, *Recurvoides contortus* Earland, and several unilocular species (Boltovskoy, 1976).

The Argentine Province includes three subprovinces: the North Patagonian Subprovince (32º–33ºS to 41ºS, Valdés Peninsula), the South Patagonian Subprovince located along the coast between 41ºS and 52ºS (Río Gallegos), and Malvinas Subprovince, which occupies the south part of the outer shelf at about 52ºS and extends to bathyal depths (Boltovskoy et al., 1980). In the North Patagonian Subprovince, the fauna is mixed with taxa from the Brazilian Current and includes small foraminifers with little or no ornamentation (Boltovskoy, 1976; Boltovskoy et al., 1980). Both the North and South Patagonian subprovinces are distinguished by species of *Elphidium*; in the former *E. discoidale* predominates, while in the South Patagonian Subprovince it is replaced by *E. macellum* Fichtel & Moll (Boltovskoy, 1976). Finally, the Malvinas Subprovince is characterized especially by three species, *Angulogerina angulosa angulosa* (Williamson), *Cassidulina crassa* d´Orbigny, *Cassidulinoides parkerianus* (Brady) as well as *Ehrenbergina pupa* (d´Orbigny) and larger specimens of *Buccella peruviana* f. *campsi* among others (Boltoskoy et al., 1980). In this

[1] Delegación de Geología y Petróleo, INIBIOMA-CONICET, Universidad Nacional del Comahue, Quintral 1250, 8400 San Carlos de Bariloche, Argentina
[2] Universidad Nacional del Comahue, Quintral 1250, 8400 San Carlos de Bariloche, Río Negro, Argentina
* Correspondence author. E-mail: emibernasconi@yahoo.com.ar

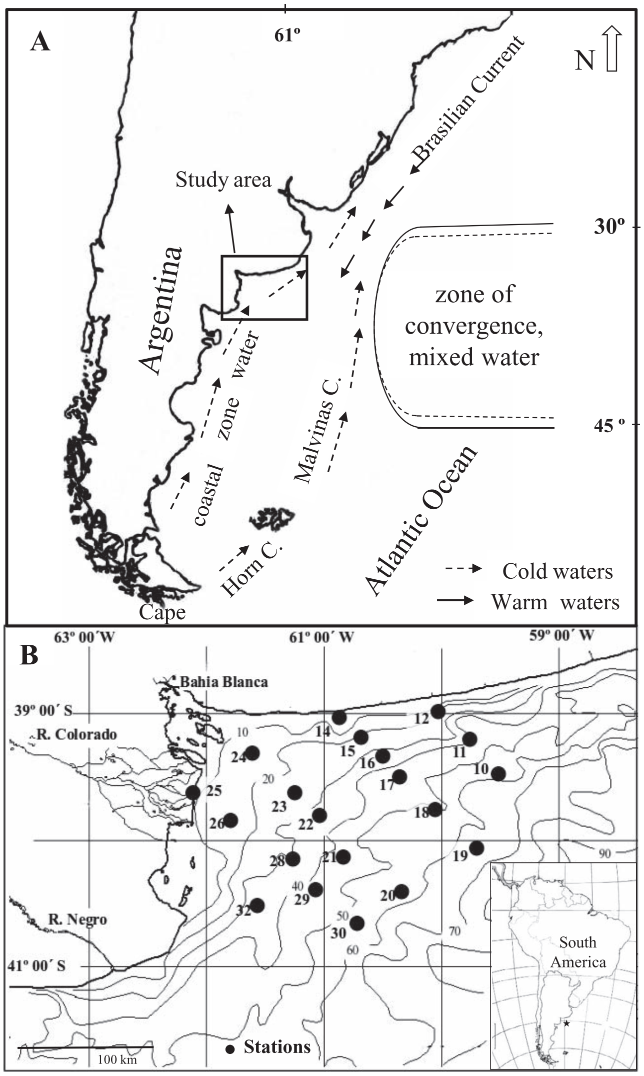


FIGURE 1. **A** Map showing location of the study area and main currents in South America. **B** Location of samples and isobaths (m) of the area.

context, the study area is included in the North Patagonian Subprovince.

The study area includes the coastal zone of the southwest Buenos Aires Province identified as El Rincón, on the continental shelf out to 70 m depth (Fig. 1A). This sector is influenced by the coastal waters of the Argentine inner shelf and the Patagonian Coastal Current), which are located between the continent and the Malvinas Current (also called the Falklands Current) of subantarctic origin. The southern boundary is approximately 52–53ºS and the northern boundary is the beginning of the zone of influence of La Plata River, which may be influenced by the warm waters of the Brazilian Current up to 40–42ºS (Boltovskoy et al., 1980; Boltovskoy, 1981). The surface waters are highly influenced by tides and wind action, which generate currents flowing predominantly northward (Guerrero, 1998).

Based on the distribution of salinity, the El Rincón zone is characterized by coastal water with lower salinity (S < 33.4) due to the fluvial contributions from the River Colorado, the River Negro and nearby wetlands (Martos & Píccolo, 1988). The outer domain extends from depths of 40–50 m to 100 m (approximate shelf edge). This sector was described as Middle Shelf Water (salinity: 33.4–33.7), comprising the northward-flowing Patagonian Current (Guerrero & Piola, 1997), and is affected by waters with origin in the San Matias Gulf with salinities of 33.7–34.2 (Martos et al., 2004). The coastal water is separated from the water of the continental shelf by the coastal front, which is created by the interaction of the different water masses (Lucas et al., 2005).

Topographically, the sector slopes gently downward from NW to SE (Gelós & Chaar, 1988) to depths somewhat greater than 70 m (Cortelezzi & Mouzo, 1979; Gelós et al., 1988). A variety of irregularities at the bottom range from soft undulations to rough topographical features (Mouzo et al., 1974; Mouzo, 1982). Holocene and recent sediments contributed by the Negro and Colorado rivers have been reworked by waves and currents and affected by coastal processes and littoral dynamics (Gelós & Spagnuolo, 1992; Ponce et al., 2011). Shelf sediments are predominantly sandy with homogeneous composition, immature mineralogy, and well-sorted texture.

## MATERIALS AND METHODS

### SAMPLE COLLECTION AND ANALYSES

Sediment samples were obtained on board the oceanographic ship Puerto Deseado (MINDEF-CONICET) during an oceanographic campaign from 1–20 October 2010. A Shipek surface-sediment sampler was used to collect samples at 20 stations with depths of 11–70 m (Fig. 1B). Table 1 presents the coordinates and depths, as well as temperature and salinity of the bottom water, at the sampling sites.

For grain-size analyses, bulk subsamples were sieved to separate gravel (>2 mm), sand (<2 mm), and mud (<63 μm; Bernasconi & Cusminsky, 2005, 2015). For foraminiferal assemblage analyses, subsamples were washed over a 63-μm sieve, then air-dried. All foraminiferal tests (i.e., representing the total assemblages) were extracted from 10 g of dry sediment (Table 1).

Systematic analysis of the genera was based on the work of Loeblich & Tappan (1992), and Sen Gupta (1999), whereas species analysis was based on the works of Boltovskoy et al. (1980), Bernasconi (2006), Ferrero (2006), Calvo Marcilese (2011), Laprida et al. (2011), and Bernasconi & Cusminsky (2015) among others. Representative specimens were photographed with a scanning electron microscope (Philips SEM 515) and stored at the repository of Universidad Nacional del Comahue, Río Negro province, Argentina, under numbers UNC-PMIC 115–130. Quantitative values such as total abundance, species richness (S), and Shannon Wiener (H) were determined to document diversity according to Buzas & Gibson (1969).

The genera of foraminifers also were classified according to lifestyle, microhabitat, tolerance for poorly oxygenated conditions, and feeding strategies. Lifestyle categories identified were free-living in the sediment, adhered to or closely associated with the substrate, and a combination of both across their life cycle (Murray, 1991). Microhabitat included epifaunal taxa, that is, those living in the top

TABLE 1. Location, depth, temperature and salinity of bottom water, sediment texture and total abundance per 10 g sediment for each station.

| Station | Latitude S | Longitude W | Depth (m) | Temperature (ºC) | Salinity (psu) | Gravel % | Sand % | Clay % | Total A/10 g |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 39° 33′ 36″ | 59° 16′ 43″ | 58.0 | 10.5 | 33.8 | 0.1 | 95.2 | 4.7 | 36 |
| 11 | 39° 18′ 42″ | 59° 27′ 34″ | 50.4 | 10.6 | 33.9 | 10.9 | 82.8 | 6.3 | 274 |
| 12 | 39° 04′ 00″ | 59° 38′ 3″ | 34.3 | 10.8 | 34.1 | 17.7 | 81.5 | 0.9 | 15 |
| 14 | 39° 00′ 58″ | 60° 44′ 46″ | 11.0 | 13.0 | 33.8 | 0.1 | 94.9 | 5.0 | 37 |
| 15 | 39° 16′ 26″ | 60° 29′ 24″ | 26.5 | 11.3 | 34.1 | 4.8 | 93.8 | 1.4 | 86 |
| 16 | 39° 27′ 37″ | 60° 16′ 09″ | 38.4 | 11.0 | 34.1 | 11.3 | 88.7 | 0.0 | 222 |
| 17 | 39° 37′ 52″ | 60° 03′ 10″ | 48.6 | 10.3 | 34.0 | 0.8 | 92.6 | 6.6 | 269 |
| 18 | 39° 52′ 19″ | 59° 47′ 22″ | 57.2 | 10.4 | 33.9 | 1.7 | 92.7 | 5.6 | 166 |
| 19 | 40° 05′ 11″ | 59° 30′ 57″ | 68.5 | 9.6 | 33.8 | 0.0 | 94.4 | 5.6 | 63 |
| 20 | 40° 24′ 30″ | 60° 15′ 37″ | 58.4 | 10.1 | 34.0 | 1.8 | 86.2 | 12.0 | 102 |
| 21 | 40° 10′ 16″ | 60° 34′ 03″ | 46.4 | 10.7 | 34.0 | 3.9 | 92.6 | 3.5 | 205 |
| 22 | 39° 57′ 06″ | 60° 49′ 48″ | 37.7 | 10.6 | 33.7 | 0.7 | 96.3 | 3.0 | 77 |
| 23 | 39° 38′ 53″ | 61° 02′ 07″ | 24.8 | 11.3 | 33.7 | 7.6 | 90.3 | 2.2 | 254 |
| 24 | 39° 23′ 43″ | 61° 15′ 13″ | 16.3 | 12.0 | 33.2 | 0.0 | 96.4 | 3.6 | 91 |
| 25 | 39° 33′ 38″ | 61° 59′ 30″ | 12.9 | 12.4 | 32.2 | 0.1 | 92.9 | 7.1 | 7 |
| 26 | 39° 47′ 53″ | 61° 38′ 43″ | 20.0 | 11.5 | 33.1 | 0.1 | 93.3 | 6.6 | 25 |
| 28 | 40° 07′ 26″ | 61° 13′ 21″ | 38.0 | 10.5 | 33.5 | 0.0 | 95.0 | 4.9 | 6 |
| 29 | 40° 19′ 59″ | 60° 58′ 42″ | 44.5 | 10.4 | 33.9 | 6.0 | 91.6 | 2.5 | 12 |
| 30 | 40° 36′ 46″ | 60° 37′ 58″ | 55.7 | 10.0 | 33.9 | 0.2 | 96.1 | 3.6 | 41 |
| 32 | 40° 31′ 57″ | 61° 25′ 14″ | 36.7 | 10.7 | 33.8 | 2.5 | 94.9 | 2.6 | 15 |

centimeter of sediment or on sediment; algae or hard substrata dwellers; and infaunal taxa that can live several centimeters beneath the sediment–water interface. Tolerance of low dissolved oxygen concentrations at the seafloor was determined using morphotypic characteristics of foraminifers, including test size, wall thickness, and morphology (Kaiho, 1994, 1999; Alperín et al., 2011). The feeding strategies considered were detritivores, herbivores, suspension feeder and those using herbivore–detritivore and suspension feeder–detritivore combinations (Murray, 1991). Ecological parameter interpretations for each taxon (Table 2) were made following the classifications of Murray (1991), Duleba et al. (1999), Bernasconi (2006), and Ferrero (2006).

Taphonomic analysis was performed to evaluate the degree of preservation of each foraminiferal test, based on the color and degradation of the test. Four preservational groups were determined based on Brandt (1989) and Laprida & Bertels-Psotka (2003). Group A included broken or fragmented specimens in which a precise taxonomic identification was difficult (very low taphonomic grade). Group B included stained tests (moderate taphonomic grade). Group C included abraded and likely reworked specimens (intermediate taphonomic grade). Group D were specimens with no major alterations in which most individuals showed no more than 1 or 2 chambers broken (high taphonomic grade).

### Statistical Analysis

Statistical analyses addressed two major goals. The first was to characterize the sites according to environmental factors measured in the field, including temperature, depth, salinity, and type of sediment. The second goal was to describe the variability of benthic foraminiferal associations, including differences in their habitats, by multivariate ordination using Canoco 5.0 software (Ter Braak & Smilauer, 1998).

To determine the most appropriate ordination method, a Detrended Correspondence Analysis (DCA) was applied. This method determines the gradient length, which measures the beta diversity in community composition along individual-independent gradients (ordination axes). If the length of the environmental gradient is >4.0 standard deviations (SD), it is advisable to use a unimodal ordination model as a Canonical Correspondence Analysis (CCA; Mello e Sousa et al., 2006). If the length is <3.0 SD, a linear method, such as Principal Component Analysis, is considered to be a better choice (Leps & Smilauer, 2003; Teodoro et al., 2010; Milker et al., 2011).

## RESULTS

### Foraminiferal Assemblages

Foraminiferal assemblages were dominated by hyaline specimens, reaching 100% in 50% of the samples. Porcelanaceous (<43%) and agglutinated (<9%) specimens were present in smaller proportions. A total of 44 species corresponding to 20 genera were identified, two of them with open nomenclature. Total abundances (Total A) ranged from 6–274 specimens/10 g of sediment, and number of species (S) were 2–21. Diversity H range was 0.4–2.4 (Fig. 2).

The orders represented in the association included: Rotaliida (78%), Miliolida (12%), Buliminida (10%), and Lagenida (0.06%). *Buccella peruviana* was the most abundant species (up to 66% and only missing from one sample), followed by *Elphidium* aff. *poeyanum* (3.4–26.1%), *Bulimina* cf. *pseudoaffinis* (1.6–20%), *Cibicides dispars* (1.8–15%), *C. aknerianus* (1.5–11.9%) and *Quinqueloculina patagonica* (2.0–14.0%). Images of these taxa are shown in Figure 3, and their relative abundances are shown in Figure 4.

Free-living was the most common lifestyle, reaching up to 100% in assemblages at stations 10 and 19 (Fig. 5A). The

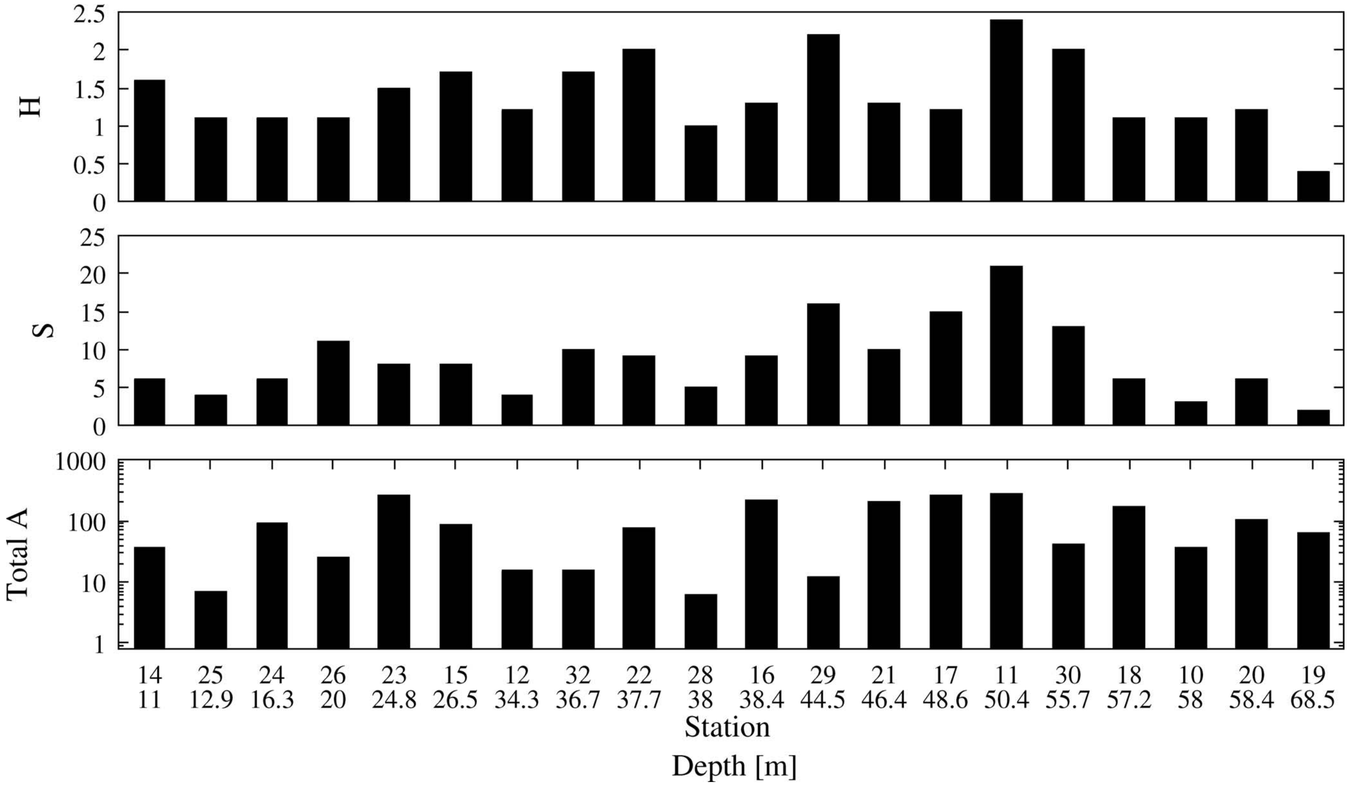


FIGURE 2. Plot of total abundance (Total A) in $\log_{10}$ and diversity parameters: species number (S) and Shannon-Wiener (H).

sessile lifestyle was less common, though it reached 71% at station 12. Some individuals exhibited a combination of both free and adhered lifestyles, most notably at Station 15. Regarding microhabitat, epifaunal specimens predominated over infaunal ones in all stations except Station 10 (Fig. 5B). Taxa indicating well-oxygenated waters were most abundant at all stations except 10 and 22; both types were found in samples from all stations (Fig. 5C). Regarding trophic strategy, detritivores were the most abundant, with 100% in stations 10 and 19. Herbivores dominated at Station 12 (71%), one of the most inshore sites (Fig. 5D). Morphologies indicating combined strategies were present in samples from most of the stations.

From taphonomic analysis, well preserved specimens (Group D), which exhibited high taphonomic grade, were most common in all the samples. Group C specimens (intermediate taphonomic grade), were mostly found in samples from the western part of the study area and were represented mainly by *Buccella peruviana*, *Quinqueloculina patagonica*, and *Cibicides aknerianus*. A few Group B specimens (i.e., with brown coloration) were found at stations 26 and 30, and included individuals of *Buccella peruviana*, *Cibicides aknerianus*, and *Quinqueloculina patagonica*. Group A specimens, which were generally unidentifiable to species, were most common at inshore stations 12 and 25 (Fig. 6).

## Statistical Analysis

Since the environmental parameters examined showed limited variability (Table 1) and the DCA indicated a gradient length of only 0.5 SD, a linear method (PCA) was used to characterize the sites in relation to environmental parameters. The first two PCA axes explained 75% of total variance (Table 3A). On axis 1, the samples were distributed along salinity (positive) and temperature (negative) gradients, whereas on axis 2, the samples were distributed by sediment texture with % gravel showing the strongest (negative) influence (Table 3B). The PCA indicated four zones (Fig. 7A). Zone I stations are clustered in the upper right quadrant and correlate with depth (40–70 m), slightly higher salinity (33.8–34), and lower temperatures (9.6–10.7ºC). Zone II stations (22, 28, 32) were from depths of 30–40 m that were intermediate in temperature (10.5ºC) and had minimal gravel. Zone III occurred at 20–40 m depth where sediments were characterized by some gravel content (5–18%). Zone IV included the inshore sites (<20 m) nearest the Colorado River delta, associated with higher temperature (11.5–13ºC), salinity as low as 32.2, and essentially no gravel.

The DCA applied to the species resulted in a gradient length of 4.2 SD. So, to analyze the relationship between species and the environment, the unimodal ordination method CCA was applied. From this analysis, all axes were significant ($P = 0.006$). The first two axes accumulated 25% of the variance (Table 4a; Fig. 7B). In axis 1, three species (*Bulimina gibba*, *Bulimina* cf. *pseudoaffinis*, and *Epistominella exigua*) were arranged along the gradient corresponding to depth and clay. Along axis 2, another group of species, *Quinqueloculina patagonica*, *Q. frigida*, *Pyrgo ringens*, *Discorbis peruvianus*, *Cassidulina laevigata*,

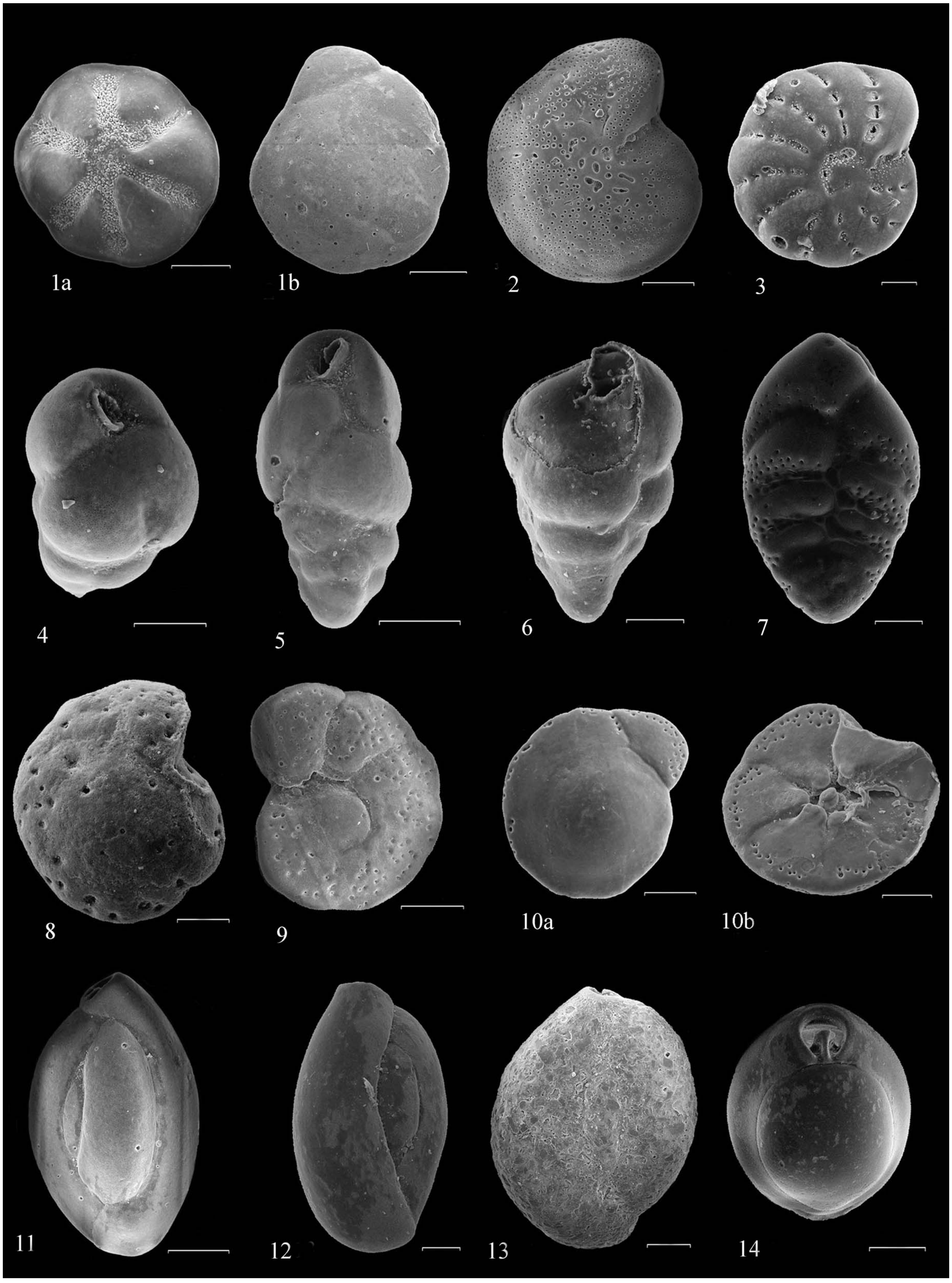


FIGURE 3. Common taxa identified. **1** *Buccella peruviana* (d´Orbigny): **a** umbilical side; UCN–PMIC–115; **b** spiral side; UCN–PMIC–116. **2** *Elphidium* aff. *poeyanum* (d´Orbigny), UCN–PMIC–117. **3** *Elphidium* aff. *clavatum* Cushman, UCN–PMIC–118. **4** *Bulimina* cf. *pseudoaffinis* Kleinfell, edge view; UCN–PMIC–119. **5** *Bulimina patagonica* d´Orbigny; UCN–PMIC–120. **6** *Bulimina gibba* Fornasini; UCN–PMIC–121. **7** *Bolivina ordinaria* (Phleger & Parker); UCN–PMIC–122. **8** *Cibicides dispars* (d´Orbigny), umbilical side; UCN–PMIC–123. **9** *Cibicides aknerianus* (d´Orbigny), spiral side, UCN–PMIC–124. **10** *Discorbis williamsoni* (Chapman & Parr), **a** spiral side; UCN–PMIC–125; **b** umbilical side; UCN–PMIC–126. **11** *Quinqueloculina patagonica* d´Orbigny; UCN–PMIC–127. **12** *Quinqueloculina seminulum* (Linné); UCN–PMIC–128. **13** *Quinqueloculina frigida* Parker; UCN–PMIC–129. **14** *Pyrgo ringens* Lamarck, UCN–PMIC–130. Scale: 20 µm (7); 50 µm (3, 4, 8, 10a, 10b, 12); 100 µm (1a, 1b, 2, 5, 6, 9, 11, 13, 14).

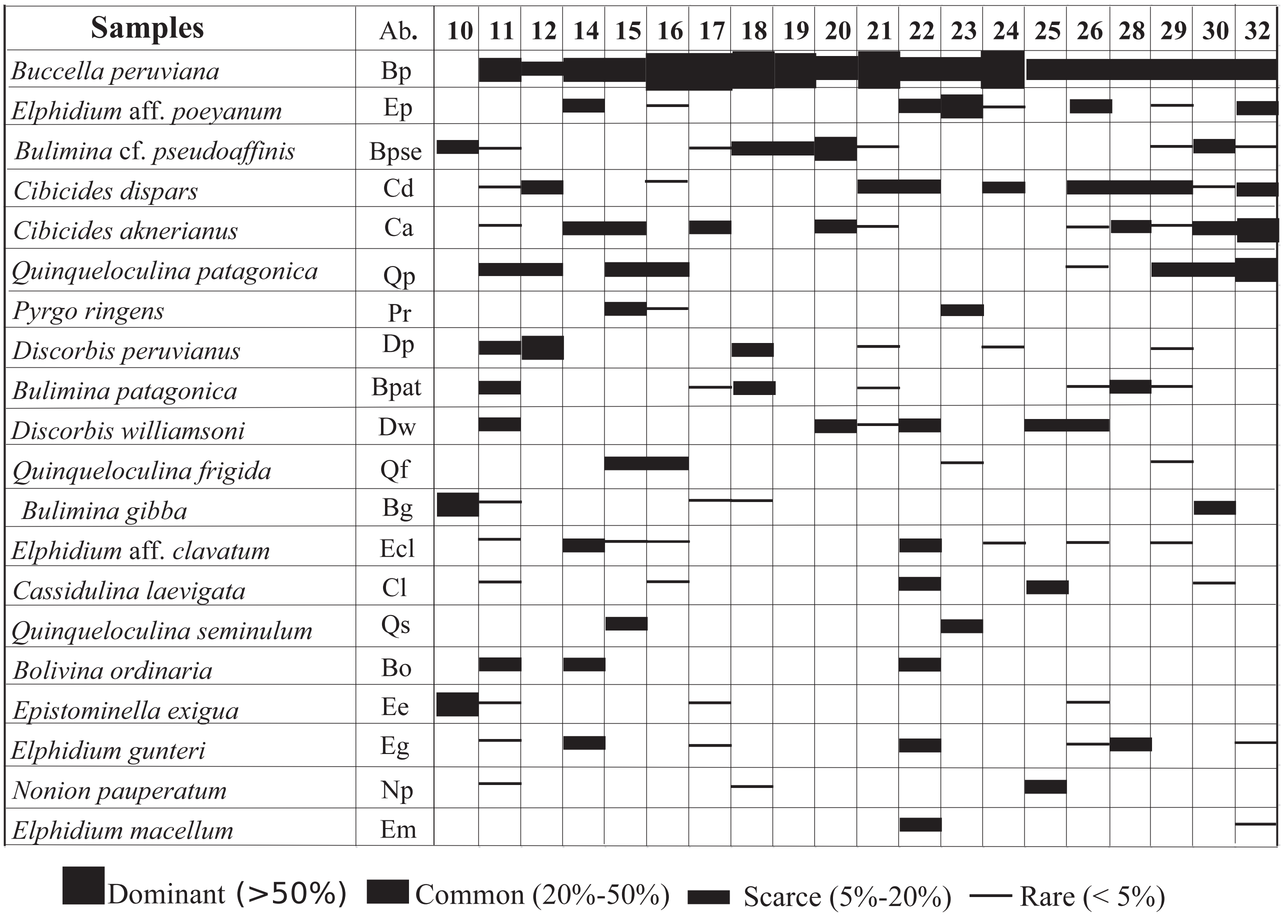


FIGURE 4. Relative abundances of the species of foraminifers found with 5% of abundance in at least one station.

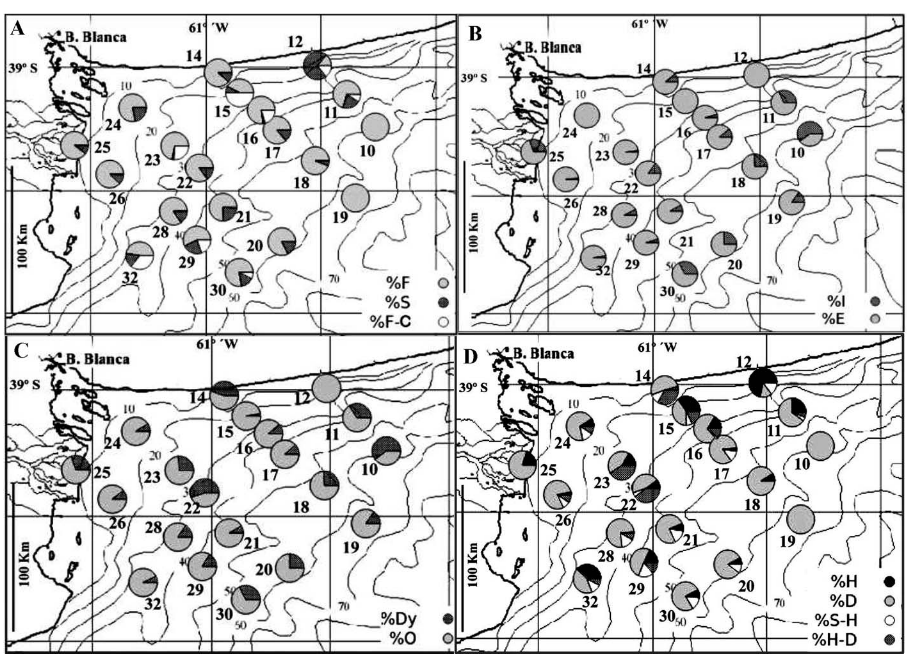


FIGURE 5. **A** Proportions of specimens with lifestyles categorized as free (F), sessile (S), or free–sessile (F–C) combination at each station. **B** Proportions of specimens with microhabitat categorized as epifaunal (E) or infaunal (I) for each station. **C** Proportions of specimens with oxygen requirements categorized as oxic (O) and dysoxic (Dy) at each station. **D** Proportions of specimens with trophic strategies categorized as detritivorous (D), herbivorous (H), combined herbivorous-detritivorous (H–D), and combined suspension-feeding-herbivorous (S–H) for each station.

Table 2. Ecological parameters assigned to each species. L (lifestyle): free-living (F), sessile (S), and free–Clinging (F–C); M (microhabitat): epifaunal (E), infaunal (I); Ts (trophic strategy): detritivorous (D), herbivorous (H), and combinations of herbivorous–detritivorous (H–D) and suspension feeding–herbivorous (S–H); Ot (oxygenation tolerance): oxic (O), dysoxic (Dy).

| Species | L | M | Ts | Ot |
|---|---|---|---|---|
| *Ammonia parkinsoniana* (d´Orbigny) | F | I | H–D | O |
| *Bolivina compacta* Sidebottom | F | I | D | Dy |
| *Bolivina ordinaria* (Phleger & Parker) | F | I | D | Dy |
| *Bolivina pseudoplicata* Heron–Allen & Earland | F | I | D | Dy |
| *Bolivina variabilis* d´Orbigny | F | I | D | Dy |
| *Bucella peruviana* (d´Orbigny) | F | E | D | O |
| *Bulimina* cf. *pseudoaffis* Kleinpell | F | I | D | Dy |
| *Bulimina gibba* Fornasini | F | I | D | Dy |
| *Bulimina marginata* d´Orbigny | F | I | D | Dy |
| *Bulimina patagonica* d´Orbigny | F | I | D | Dy |
| *Buliminella elegantísima* (d´Orbigny) | F | I | D | Dy |
| *Cassidulina carinata* Silvestri | F | I | D | Dy |
| *Cassidulina laevigata* d´Orbigny | F | I | D | Dy |
| *Cibicides aknerianus* (d´Orbigny) | S | E | S–H | O |
| *Cibicides dispars* (d´Orbigny) | S | E | S–H | O |
| *Cibicides fletcheri* Galloway & Wissler | S | E | S–H | O |
| *Cibicides* sp. | S | E | S–H | O |
| *Cibicides variabilis* (d´Orbigny) | S | E | S–H | O |
| *Discorbis bertheloti* (d´Orbigny) | S | E | H | O |
| *Discorbis peruvianus* (d´Orbigny) | S | E | H | O |
| *Discorbis valvatus* (Boltovskoy) | S | E | H | O |
| *Discorbis williamsoni* (Chapman & Parr) | S | E | H | O |
| *Elphidium* aff. *clavatum* Cushman | F | E | H–D | O |
| *Elphidium* aff. *poeyanum* (d´Orbigny) | F | E | H–D | O |
| *Elphidium alvarezianum* (d´Orbigny) | F | E | H–D | O |
| *Elphidium articulatum* (d´Orbigny) | F | E | H–D | O |
| *Elphidium gunteri* Cole | F | E | H–D | O |
| *Elphidium macellum* Fitchell & Moll | F | E | H–D | O |
| *Epistominella exigua* (Brady) | F | E | D | O |
| *Funserkoina shreibersiana* (Czjzek) | F | I | D | Dy |
| *Globocassidulina subglobosa* Brady | F | I | D | O |
| *Guttulina problema* (d´Orbigny) | F | E | D | O |
| *Lenticulina laevigata* (d´Orbigny) | F | E | D | Dy |
| *Lenticulina limbosa* (Reuss) | F | E | D | Dy |
| *Miliolinella subrotunda* (Montagu) | F–C | E | H | O |
| *Nonion pauperatum* (Balkwill & Wright) | F | I | H | Dy |
| *Nonion* sp. | F | I | H | Dy |
| *Pyrgo nasuta* Cushman | F–C | E | H–D | O |
| *Pyrgo ringens* Lamarck | F–C | E | H–D | O |
| *Quinqueloculina* frigida Parker | F–C | E | H | O |
| *Quinqueloculina lamarckiana* d´Orbigny | F–C | E | H | O |
| *Quinqueloculina patagonica* (d´Orbigny) | F–C | E | H | O |
| *Quinqueloculina seminulum* (Linné) | F–C | E | H | O |
| *Triloculina baldai* Bermudez & Seiglie | F–C | E | H–D | O |

and *Nonion pauperatum*, correlated with higher percentages of gravel (Table 4b). A third loose association composed of *Elphidium* aff. *poeyanum*, *E.* aff. *clavatum*, *E. gunteri*, *E. macellum*, *Buccella peruviana*, *Bulimina patagonica*, *Bolivina ordinaria*, *Cibicides aknerianus*, *C. dispars*, *Q. seminulum*, and *Discorbis williamsoni* showed non-specific distributions.

## DISCUSSION

### Foraminiferal Assemblages

This study analyzed the foraminiferal fauna from recent sediments in the SE of Buenos Aires Province, a sector of the Argentinean Continental Shelf out to a depth of 70 m. Sediments are mainly sandy with presence of small quantities of gravel and mud in some stations (Gelós & Spagnuolo, 1992; Alperín et al., 2008). All foraminiferal taxa recorded were benthic, consistent with an inner-shelf environment (Boltovskoy, 1976, 1979; Caramés & Malumián, 2000).

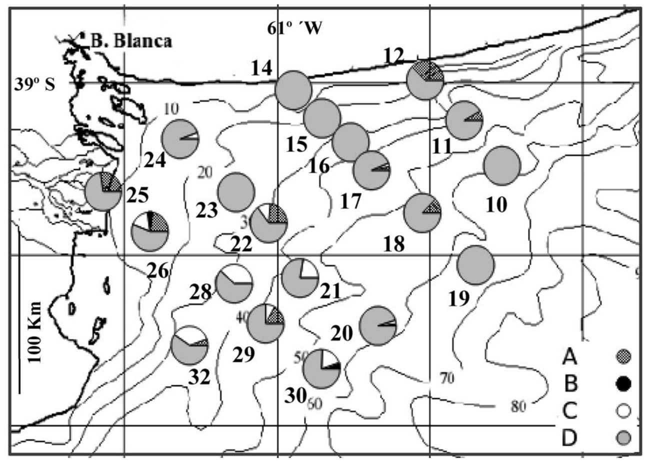


Figure 6. Proportions of specimens from taphonomic analysis categorized according to one of four preservation groups for each station: A is most degraded, B is discolored, C is abraded and reworked, D is minimally or not damaged.

The foraminiferal assemblage was dominated by *Buccella peruviana*, with smaller proportions of the genera *Elphidium*, *Quinqueloculina*, *Bulimina*, and *Cibicides*. *Buccella peruviana* f. *campsi* was described by Boltovskoy (1976) as widely distributed in the Argentine Zoogeographic Province and common in inner-shelf environments, typical of the Malvinas Current (Falklands Current). Recently, Calvo Marcilese & Langer (2012) determined that *B. peruviana* f. *campsi* is a juvenile stage of *B. peruviana*, unifying synonymy of this species. It has been recorded in Holocene and modern sediment from marginal environments, such as lagoons and estuaries (Boltovskoy, 1957; Wright, 1968; Ferrero, 2006, 2009; Cusminsky et al., 2006, 2009; Calvo Marcilese, 2011;

Table 3. **A** Eigenvalues and percentage of explained variance for each principal component, based upon environmental parameters assessed. **B** Correlation coefficients of the variables in axes 1 and 2 from PCA.

**A**

| PC | Eigenvalues | % Variance | Cumulative Variance (%) |
|---|---|---|---|
| 1 | 2.59 | **43.3** | 43.3 |
| 2 | 1.89 | **31.6** | **74.9** |
| 3 | 1.07 | 17.9 | 92.8 |
| 4 | 0.37 | 6.2 | 99.9 |
| 5 | 0.60 | 1.0 | 100.0 |

**B**

| Variables | Axis 1 | Axis 2 |
|---|---|---|
| Depth | 0.48 | 0.44 |
| Temperature | – 0.49 | – 0.37 |
| Salinity | **0.50** | – 0.01 |
| Sand | – 0.36 | 0.38 |
| Gravel | 0.36 | **– 0.58** |
| Clay | – 0.08 | 0.44 |

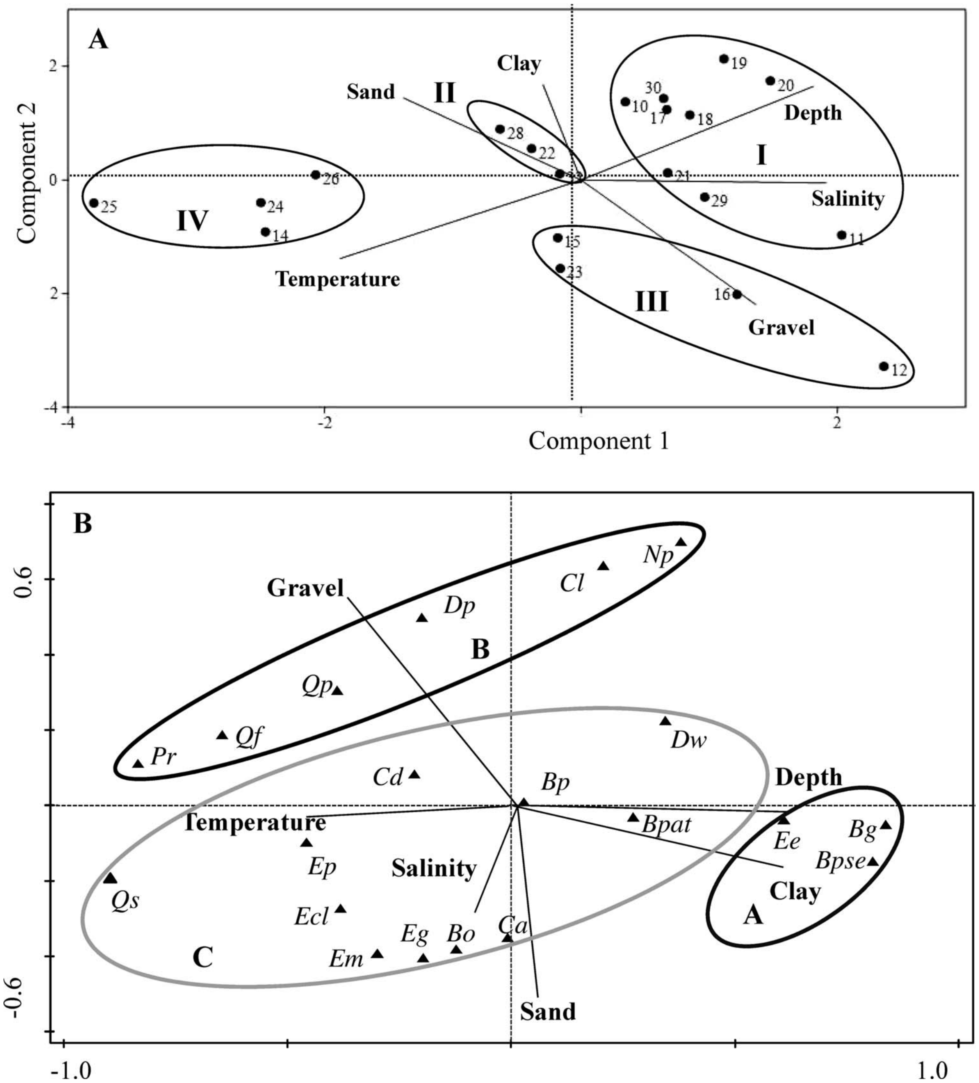


FIGURE 7. **A** PCA-diagram indicating four zones (I, II, III, and IV), the samples associated with each zone, and the environmental parameters characterizing those zones. **B** CCA-diagram showing the three foraminiferal assemblages (A, B, and C), the taxa that make up each assemblage (see Table 2 for abbreviations), and the environmental parameters associated with each assemblage.

Calvo Marcilese et al., 2013; Márquez & Ferrero, 2011; Márquez et al., 2016). It has also been found near the study area at depths ranging from 40 to 70 m (Boltovskoy et al., 1980; Alperín et al., 2008, 2011) in recent shelf sediments and in Holocene sequences (Bernasconi, 2006; Laprida et al., 2007, 2011; Bernasconi & Cusminsky, 2007, 2015). We found *Buccella peruviana* at depths between 11 and 70 m, consistent with the findings of the aforementioned studies.

*Elphidium*, a free-living, epifaunal genus, also was well-represented in our samples. Murray (1991) characterized this genus as living on sandy substrata of the inner shelf at depths of 0–50 m. As a diverse genus, *Elphidium* is represented by different species at different latitudes (Boltovskoy, 1966). The most abundant species we found were *Elphidium* aff. *poeyanum*, *E.* aff. *clavatum*, *E. gunteri*, and *E. macellum*, consistent with findings of Calvo Marcilesse (2011) and Calvo Marcilese et al. (2013) in sediments from Bahía Blanca estuary. Boltovskoy et al. (1980) recorded *Elphidium* aff. *poeyanum* in hyposaline waters, estuaries, and lagoons. The species has also been found in modern and Holocene estuarine environments (Cusminsky et al., 2006, 2009; Laprida et al., 2007, 2011; Márquez & Ferrero, 2011; Calvo Marcilese et al., 2013; Marquéz et al., 2016; Márquez, 2017), shallow inner-shelf environments (Alperín et al., 2008, 2011) and Holocene sequences (Bernasconi & Cusminsky, 2007). Moreover, we found *E. macellum* in sample 32, located farther south, where *E.* aff. *poeyanum* was absent, possibly reflecting the gradual passage from the North Patagonian Subprovince to the South Patagonian Subprovince, as described by Boltovskoy (1976) and Boltovskoy et al. (1980).

Miliolids included several *Quinqueloculina* species, which have been cited by Murray (1991) as epifaunal species, either free-living or attached to the substrate in marine to hypersaline shelf environments. Boltoskoy (1966) and Boltovskoy et al. (1980) reported both *Quinqueloculina patagonica* and *Q. seminulum* distributed along the Argentine Shelf. We recorded these species to depths of 50 m in agreement with

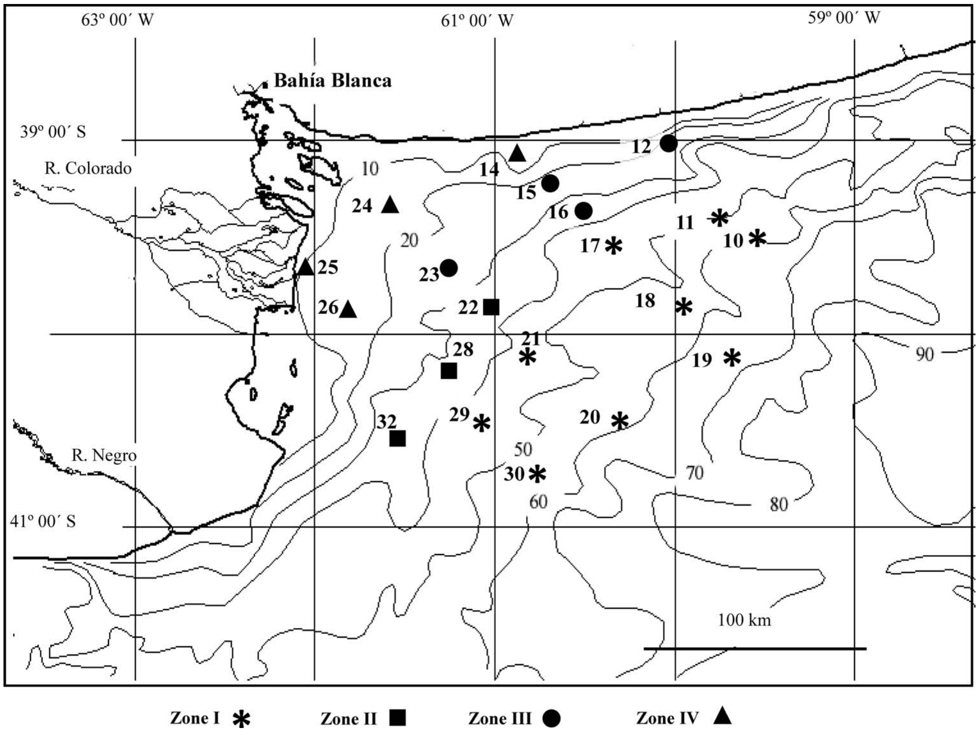


FIGURE 8. Map showing the distribution of samples characteristic of zones I, II, III, and IV, as identified in Figure 7A.

Boltovskoy & Totah (1985) and Alperín et al. (2008, 2011), who mentioned them at depths of 40–55 m in recent sediments.

The three most common genera, *Buccella*, *Elphidium*, and *Quinqueloculina*, found in most of our samples, in general reflect an inner-shelf environment (Boltovskoy, 1966). The assemblage was recognized in recent sediments by Cusminsky et al. (2006), Alperín et al. (2008, 2011), and Laprida et al. (2011) as belonging to the coastal area of Buenos Aires Province. This species assemblage has been recorded in Holocene sediments from the Bahía Blanca estuary (Gómez et al., 2005; Cusminsky et al., 2009; Calvo Marcilese et al., 2013), the zone of the Río de La Plata estuary (Laprida & Bertels Psotka, 2003; Laprida et al., 2007), and the inner shelf (Bernasconi & Cusminsky, 2007, 2015; Márquez et al., 2016).

The genus *Bulimina* was found between 40 and 150 m depth in sediments from inner shelf and San Matias Gulf (Bernasconi & Cusmininsky, 2005; Alperín et al., 2008). An assemblage of *Bulimina* species was observed at some of our sites and included *Bulimina* cf. *pseudoaffinis*, *B. patagonica*, and *B. gibba*. These are free-living, infaunal detritivores, typical of inner shelf to bathyal environments in association with silty to fine sandy sediments (Boltovskoy et al., 1980; Murray, 1991, 2006; Villanueva-Guimerans, 2000).

The genus *Bolivina*, represented by the species *Bolivina ordinaria*, was less commonly encountered in our samples. *Bolivina* was described by Murray (1991) as an infaunal genus living in inner-shelf to deep environments in clayey sediments. Other researchers (Boltovskoy et al., 1991; Sen Gupta & Machain-Castillo, 1993; Bernhard et al., 1997; Hayward et al., 2002; Smart, 2002; Bernasconi, 2006; Alperín et al., 2008) concluded that some *Bolivina*, *Bulimina*, and other biserial species are adapted to living in zones with minimal oxygen levels (Kaiho, 1999). Bernasconi & Cusminsky (2009) and Bernasconi et al. (2009) interpreted different oxygen levels in Holocene sequences from Nuevo Gulf, which correlated with paleoclimatic events.

*Cibicides*, described by Murray (1991) as epifaunal, is eurythermal and has been found at depths of 0 to >2000 m. It may be an indicator of the strength of bottom currents (Kaiho, 1994, 1999; Figueroa et al., 2005; Bernasconi & Cusminsky, 2007, 2015; Schönfeld et al., 2011) and low sedimentation rates (Hromic, 2006; Murray, 2006). The species *C. dispars* and *C. aknerianus* were among the

TABLE 4. **A** Eigenvalues and percentage of explained variance accumulated in the axes. **B** Correlation coefficients of the explanatory variables in axes 1 and 2.

| **A** | | |
|---|---|---|
| Axis | Eigenvalues | Cumulative Variance % |
| 1 | 0.37 | 17.6 |
| 2 | 0.16 | **25.0** |
| 3 | 0.15 | 33.0 |
| 4 | 0.08 | 35.9 |
| **B** | | |
| Variables | Axis 1 | Axis 2 |
| Depth | **0.67** | – 0.02 |
| Temperature | – 0.41 | – 0.02 |
| Salinity | – 0.10 | 0.36 |
| Sand | 0.05 | – 0.54 |
| Gravel | – 0.40 | **0.60** |
| Clay | **0.67** | – 0.21 |

most frequently recorded in our study. Boltovskoy (1966), Bernasconi & Cusminsky (2007), Alperín et al. (2008), Gordillo et al. (2010, 2013) and Hromic & Montiel (2011) speculated that, when alive, *Cibicides* individuals are firmly attached to the substrate where they "graze" and thereby may be able to withstand substantial water movement.

From an ecological point of view, the most frequent lifestyle was free-living, although there was also a smaller proportion of exclusively sessile individuals and others that combined both strategies (Fig. 5A); this was similar to conditions reported by Alperín et al. (2008). We observed high percentages of epifaunal species adapted to well-oxygenated conditions (Fig. 5B). The most frequent diet among the individuals found in this study was detritivore, mainly due to the abundance of *Buccella peruviana* (Fig. 5D). Another strategy was herbivore, including *Discorbis peruvianus* and *D. williamsoni*, which are epifaunal and attached to firm substrata by their reticulopodia. Many of the species we found use combined strategies. Some, such as *Cibicides*, are suspension feeders and herbivores and feed on small organisms and detritus suspended in the water column (Goldstein, 2002). Others are herbivores and detritivores, such as *Elphidium*, which are free-living and can feed on detritus in the sediment or on marine algae, as reported by Náñez & Malumián (2008).

In quantitative analyses, Shannon-Wiener (H) values >3 generally indicate normal marine conditions, while lower values indicate more unstable environments (Buzas & Gibson, 1969). We recorded H values of only 0.4–2.4, a likely consequence of several factors, including the very low numbers of foraminiferal specimens found in the samples. Sediments from deltaic and estuary deposits are transported by the littoral drift of semi-permanent currents along the coastline (Gelós et al, 1988). The dynamics of a coastal system are typically driven by tides and winds, and their effects depend on the depth (Martos et al., 2004). Relatively strong winds in the region generate waves and currents that move sediments. Siliciclastic sediments tend to be much harder than carbonate shells, so that the small shells of dead foraminifers are readily broken and transported. Previous studies near the area also reported low diversities (Cusminsky et al., 2006; Alperín et al., 2008; Calvo Marcilese, 2011; Márquez, 2016).

## Taphonomy

Taphonomic processes recognized in this study in part reflected the bathymetric gradient of the study zone. Samples with poorly preserved (grade A) or broken (grade C) shells were found either offshore in the southwest part of the study area or at the shallow Station 12. According to Laprida et al. (2011), taphonomic processes are determined by water depth and depend mainly on water energy and dynamics, with high potential in (paleo) environmental determinations. We found that abraded specimens, especially of *Buccella peruviana* (mainly in stations 28 and 32) indicate some degree of reworking. The presence of broken specimens, particularly in stations 12 (Zone II), 25 and 26 (Zone IV), corresponding to stations closer to the coast, suggests damage associated with mechanical damage (Yanko et al., 2002; Laprida et al., 2007). Brown coloring was found in some specimens of *Buccella peruviana* and *Cibicides aknerianus*, mainly in stations 26 (Zone IV) and 30 (Zone I), possibly indicating the influence of terrestrial contaminants, such as oils, phenolic compounds, and heavy metals (e.g., Yanko et al., 2002) associated with the presence of ports and activities of the fishing industry (Perrota et al., 1996; Perrota, 2000; Calvo Marcilese & Langer, 2012).

Gelós & Spagnuolo (1992) noted that the distribution of sediments in the study area is the result of transgressive Holocene erosion. They recognized two sources of sediments: 1) relicts reworked by marine dynamics acting on the bottom and remodeling the pre-existing morphology and 2) Holocene and recent sediments contributed by the Negro and Colorado rivers that are affected by coastal processes and coastal dynamics. Our sampling found that the sediment was quite homogeneous, mainly sandy with small quantities of clay and gravel in some sectors, as reported by Alperín et al. (2008, 2011). These small variations may be associated with topographic features and may be significant indicators of variations in local environmental conditions (Mouzo et al., 1974; Gelós & Spagnuolo, 1992).

## Zonation Related to Environmental Settings

We evaluated the interaction among environmental factors and which variables affected each station. Salinity, depth, and sediment texture had the greatest influence, with four zones recognized in the study area (Figs. 7A–B, 8).

Zone I included the deepest stations with slightly higher salinities and consistently lower temperatures. The waters belong to the Mid-Shelf Water or Patagonian Current zone, located along the central shelf from its origins to 40–38ºS (Guerrero & Piola, 1997). Diversity and abundance were variable, but low overall. Assemblage A, comprised of *Bulimina gibba*, *Bulimina* cf. *pseudoaffinis*, and *Epistominella exigua*, was associated with this zone. This assemblage has been reported in fine sediments from shelf to bathyal depths (Murray, 1991; Bernasconi & Cusminsky, 2005; Alperín et al., 2008). The presence of *Epistominella exigua* may indicate the influence of the Malvinas Current (Falklands Current; Boltovskoy & Totah, 1985). The association between *Buccella peruviana* and *Epistominella exigua*, as found in this zone, has been recognized previously by other researchers who suggest a transition zone between the Patagonian Current and the Malvinas Current (Boltovksoy & Totah, 1985). An increase in the abundance of *E. exigua* compared to *B. peruviana* has been interpreted as a depth trend (Ferrero, 2006). This association was recognized by Alperín et al. (2008), who reported *E. exigua* as inhabiting cold, well-oxygenated waters. Alperín et al. (2011) studied morphogroups, describing this zone as a transition area between the outer and inner shelf, with the influence of the Malvinas Current (Falklands Current), and mentioning salinity and temperature as the main factors in the distribution of water masses. Thus, the presence of *E. exigua*, along with characteristics of the water, such as high salinity and low temperature, may indicate the influence of the Malvinas Current near the 70-m isobath and the influence of the Patagonian Current on the stations at shallower depths.

Zone II stations (30–40 m depth) were characterized by sandy sediments and intermediate temperature and salinity. The greater number of reworked specimens found in these samples may be due to the typical tidal action and currents in this zone (Mouzo et al., 1974; Gelós et al., 1988), which flow NE, parallel to the coast (Gelós & Spaugnolo, 1992). Assemblage C taxa were common in this zone, including *Buccella peruviana*, *C. dispars*, *C. aknerianus*, *D. williamsoni*, *Bulimina patagonica*, *B. ordinaria*, *E.* aff. *poeyanum*, *E.* aff. *clavatum*, *E. macellum*, *E. gunteri*, and *Quinqueloculina* spp. The presence of *Cibicides* spp. indicates well-oxygenated, sandy sediments and relatively high-energy conditions, possibly reflecting the strength of the bottom currents (Kaiho, 1994, 1999; Figueroa et al., 2005; Schönfeld et al., 2011). This zone corresponds to the Inner Domain of Martos & Píccolo (1988) and is influenced by high salinity coastal water located in the central and southern zone of Buenos Aires Province (Guerrero & Piola, 1997; Alperín et al., 2011). This zone, which is external to El Rincón sector, may be affected by shelf waters that, through advection, move from the southern sector through the mid-depth shelf current (Guerrero, 1998) and is affected by the variable-salinity waters from the San Matias Gulf (Martos et al., 2004).

Zone III includes four samples from between the 20 and 40 m isobaths, characterized mainly by noticeable gravel. Salinity is higher than in Zone II, although not as high as the maximum values in Zone I. These waters correspond to the Inner Domain determined by Martos & Píccolo (1988) and highly saline Coastal Water located in the central and south zone of Buenos Aires Province (Guerrero & Piola, 1997). Alperín et al. (2011) associate this zone of highly saline coastal waters to the production of detritus generated by the Coastal Front, which occurs between the 40 and 50 m isobaths. Higher percentages of taphonomic group A (i.e., fragmented specimens) were recognized in Station 12 samples, associated with sandy sediments with the highest gravel content. These conditions reflect the high-energy environment (e.g., Mouzo et al., 1974; Gelós & Spagnuolo, 1992). We recorded here the highest number of *Quinqueloculina*, thus the combined free-living/clinging mode of life was predominant. *Quinqueloculina* has been cited as typical of shallow, inner-shelf environments (Boltovskoy, 1966; Brock, 1999). Assemblage (B), comprised of *Q. patagonica*, *Q. frigida*, *Pyrgo ringens*, *Discorbis peruvianus*, *Cassidulina laevigata*, and *Nonion pauperatum*, was found in this zone because these species were associated with detectable gravel content. Relative abundance in the Order Miliolida could be related to the resistance to damage of their shells (Usera & Blázquez, 1997; Alperín et al., 2011). Strong rhizopodial attachment to the substrate, as in *Discorbis*, *Pyrgo*, and *Quinqueloculina* spp., enables these genera to live in such conditions despite water movement (Goldstein, 2002).

Zone IV included the stations nearest the coast in El Rincón sector, at 10–20 m depths. The lowest salinities and highest temperatures were recorded at these sites. The El Rincón sector is characterized by marked vertical homogeneity, whereas horizontally it has a saline coastal front separating diluted waters from the Negro and Colorado rivers from shelf waters (Guerrero, 1998). This zone is also influenced by the waters from the San Matías Gulf that have variable salinity (33.4–33.7) and from the discharge of the Colorado River (<33.4; Martos et al., 2004). This sector corresponds to the Inner Domain of homogeneous coastal waters determined by Martos & Píccolo (1988) and to the low-salinity Coastal Water of Guerrero & Piola (1997). This zone is characterized by assemblage C that includes taxa that did not correlate significantly to environmental factors analyzed for this study.

## CONCLUSIONS

This paper contributes information on foraminifers in sand-dominated sediments on the inner continental shelf of the Buenos Aires Province. The sparse total (living plus dead) assemblages of benthic foraminifers (<27 specimens per gram of sediment) included 44 species belonging to 20 genera. The assemblage represented by *Buccella peruviana*, *Elphidium* aff. *Poeyanum*, and *Quinqueloculina* spp. reflects the inner- to middle-shelf environments sampled (<70 m depth).

Salinity, depth, and gravel content had the greatest influence on foraminiferal assemblages in the study area, distinguishing four environmental zones: Zone I with the deepest, coolest and most saline waters in the area, Zone II with sandy sediments and intermediate depths, Zone III with sediments with notable presence of gravel, and Zone IV in the shallowest, lowest-salinity waters influenced by adjacent deltas. Those zones and their associated assemblages indicate the influence of different water masses: 1) Malvinas Current (Falklands Current) at the southern limit of the inner-shelf environment, 2) Patagonian Coastal Current and High-Salinity Coastal Water in the inner-shelf environment, and 3) low-salinity Coastal Water in the littoral environment at El Rincón.

## ACKNOWLEDGMENTS

This research was supported by CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas) (Projects-PIP 112-201201-00021, the National Agency for the Promotion of Science and Technology: Project-PICT-2014-1271) and Universidad del Comahue (UNCo B195). Thanks are due to all members of the team working aboard the oceanographic survey ship ARA Puerto Deseado during the "Puerto Deseado 2010" campaign. The authors wish to thank P. Troyon (Centro Atómico Bariloche) for preparing SEM samples and G. Beamud for her advice in the statistical treatment of the data. Special thanks to P. Hallock, B. Wilson, A. Caramés, and W. Majewski, who helped to improve the original version of this manuscript.

## REFERENCES

Alperín, M., Bernasconi, E., and Cusminsky, G., 2008, Asociaciones de foraminíferos bentónicos actuales de la plataforma continental Argentina (39º–43ºS y 58º–65ºO) analizados con métodos estadísticos para datos composicionales: Ameghiniana, v. 45, p. 443–461.

Alperín, M., Cusminsky, G., and Bernasconi, E., 2011, Benthic foraminiferal morphogroup assemblages in recent sediments of the Argentine Continental Shelf (39º–43ºS and 58º–65ºW): Journal of Foraminiferal Research, v. 41, p. 155–166.

Bernasconi, E., 2006, Los foraminíferos del Holoceno de testigos de la plataforma continental Argentina (40º 30´–42º 48´LS y 59º 25´ – 64º 40´LO): Unpublished PhD thesis, Universidad Nacional del Comahue, 210 p.

Bernasconi, E., and Cusminsky, G., 2005, Distribución de *Nonionella auris* (d'Orbigny) (Foraminiferida) en el golfo San Matías, Provincia de Río Negro, Argentina: Ameghiniana, v. 42, p. 167–174.

Bernasconi, E., and Cusminsky, G., 2007, Foraminíferos bentónicos de un testigo holocénico de la plataforma continental Argentina (40º 30' S y 60º 59'05" O): Ameghiniana, v. 44, p. 271–278.

Bernasconi, E., and Cusminsky, G., 2009, Estudio paleoecológico de foraminíferos de testigos del Holoceno de Golfo Nuevo (Patagonia, Argentina): Geobios, v. 42, p. 435–450.

Bernasconi, E., and Cusminsky, G., 2015, Study of the distribution of *Elphidium* aff. *poeyanum* (d´Orbigny) and *Buccella peruviana* (d´Orbigny) from the Colorado basin (South America): Holocene paleoenvironmental inferences: The Holocene, v. 25, p. 810–819.

Bernasconi, E., Cusminsky, G., and Gómez, E., 2009, Foraminíferos bentónicos del holoceno del golfo Nuevo, Argentina: inferencias paleoclimáticas: Revista Española de Micropaleontología, v. 41, p. 21–34.

Bernhard, J., Sen Gupta, B., and Borne, P., 1997, Benthic foraminiferal proxy to estimate dysoxic bottom-water oxygen concentrations: Santa Barbara basin, U. S. Pacific continental margin: Journal of Foraminiferal Research, v. 27, p. 301–310.

Boltovskoy, E., 1954a, Foraminíferos del Golfo San Jorge: Revista Instituto Nacional de Investigaciones Naturales y Museo Argentino de Ciencias Naturales Bernardino Rivadavia, Ciencias Geológicas, v. 3, p. 79–228.

Boltovskoy, E., 1954b, Foraminíferos de la Bahía San Blas: Revista del Instituto Nacional de Investigaciones de Ciencias Naturales y Museo Argentino de Ciencias Naturales Bernardino Rivadavia, Ciencias Geológicas, v. 3, p. 247–300.

Boltovskoy, E., 1957, Foraminíferos del estuario del Río de La Plata y su zona de influencia: Revista del Instituto Nacional de Investigación de las Ciencias Naturales y Museo Argentino de Ciencias Naturales Bernardino Rivadavia, v. 6, p. 1–78.

Boltovskoy, E., 1962, Planktonic foraminifera as indicators of different water masses in the South Atlantic: Micropaleontology, v. 8, p. 403–408.

Boltovskoy, E., 1966, Los Foraminíferos Recientes (Biología, métodos de estudio, aplicaciones oceanográficas): Eudeba, Buenos Aires, 510 p.

Boltovskoy, E., 1976, Distribution of Recent Foraminifera of the South American Region: Foraminifera, v. 2, p. 171–236.

Boltovskoy, E., 1979, Paleoceanografia del Atlántico Sudoccidental desde el Mioceno, según estudios foramiferológicos: Ameghiniana, v. 16, p. 357–389.

Boltovskoy, E., 1981, Masas de agua en el Atlántico Sudoccidental, *in* Atlas de Zooplancton del Atlántico Sudoccidental: INIDEP, Mar del Plata, 839 p.

Boltovskoy, E., and Totah, V., 1985, Diversity, similarity and dominance in benthic foraminiferal fauna along one transect of the Argentine shelf: Revue de Micropaleontologie, v. 28, p. 23–31.

Boltovskoy, E., Giussani, G., Watanabe, S., and Wright, S., 1980, Atlas of Benthic Shelf Foraminifera of the Southwest Atlantic: Junk, The Hague, 174 p.

Boltovskoy, E., Scott, D., and Medioli, F., 1991, Morphologic variations of benthic foraminiferal tests in response to changes in ecological parameters: A review: Journal of Paleontology, v. 65, p. 175–185.

Boltovskoy, E., Boltovskoy, D., Correa, D. N., and Brandini, F., 1996, Planktic foraminifera from the southwestern Atlantic (30º–60ºS): Species specific patterns in the upper 50 m: Marine Micropaleontology, v. 28, p. 53–72.

Brandt, D., 1989, Taphonomic grades as a classification for fossiliferous assemblages and implications for paleoecology: Palaios, v. 4, p. 303–309.

Brock, G., 1999, Application of Foraminiferida in earth sciences: Geos, v. 39, p. 1–6.

Buzas, M. A., and Gibson, T. G., 1969, Species diversity: Benthonic Foraminifera in Western North Atlantic: Science, v. 163, p. 72–75.

Calvo Marcilese, L., 2011, Holoceno del área del estuario de Bahía Blanca, Argentina: PhD thesis, Universidad Nacional del Comahue, Bariloche, 255 p.

Calvo Marcilese, L., and Langer, M., 2012, Ontongenetic morphogenesis and biogeographic patterns: Resolving taxonomic incongruences within "species" of *Buccella* from South American coastal waters: Revista Brasilera de Paleontología, v. 15, p. 23–32.

Calvo Marcilese, L., Pérez Panera, J. P., Cusminsky, G., and Gómez, E. A., 2013, Micropaleontological record of Holocene estuarine stages in the Bahía Blanca estuary, Argentina: Journal of South American Earth Sciences, v. 45, p. 147–159.

Caramés, A., and Malumián, N., 2000, Foraminíferos bentónicos del Cenozoico del pozo Estrella x-1, Cuenca del Colorado, plataforma continental Argentina: Ameghiniana, v. 37, p. 387–419.

Cortelezzi, C. R., and Mouzo, F. H., 1979, Estudio sedimentológico de testigos del Margen Continental Argentino sobre un perfil a los 40º Lat. Sur: Sexto Congreso Geología Argentino, Buenos Aires: Abstracts, v. 11, p. 249–264.

Cushman, J. A., and Parker, F., 1931, Recent foraminifera from the Atlantic coast of South America: Proc. U. S. National Museum, v. 80, p. 1–24.

Cusminsky, G., Martínez, D., and Bernasconi, E., 2006, Foraminíferos y ostrácodos de sedimentos recientes del estuario de Bahía Blanca, Argentina: Revista Española de Micropaleontología, v. 38, p. 395–410.

Cusminsky, G., Bernasconi, E., and Calvo Marcilese, L., 2009, Holocene benthic foraminifera from Bahía Blanca estuary: a review and update of systematic and palaeoenvironmental aspects: The Holocene, v. 19, p. 1221–1231.

d'Orbigny, A., 1839, Voyage dans l'Amerique meridionale Foraminifers: v. 5, 86 p.

Duleba, W., Debenay, J. P., Eichler, B. B., and De Mahiques, M. M., 1999, Holocene environmental and water circulation, changes: Foraminifer morphogroups evidence in Flamengo Bay (SP, Brazil): Journal of Coastal Research, v. 15, p. 554–571.

Ferrero, L., 2006, Micropaleontología y Paleoecología del Cuaternario del sudeste de la provincia de Buenos Aires: PhD thesis, Universidad Nacional de Mar del Plata, Facultad de Ciencias Exactas and Naturales, La Plata, 373 p.

Ferrero, L., 2009, Foraminíferos y ostrácodos del Pleistoceno tardío (Mar Chiquita, provincia de Buenos Aires, Argentina): Ameghiniana, v. 46, p. 637–656.

Figueroa, S., Marchant, M., Giglio, C., and Ramírez, S. M., 2005, Foramineros bentonicos rotalinidos del centro sur de Chile (36º S y 44ºS): Gayana, v. 69, p. 329–363.

Gelós, M. E., and Chaar, E., 1988, Estudio sedimentológico-mineralógico de testigos de la plataforma continental Argentina entre los paralelos de 39º y 42º de latitud Sur. Segundas Jornadas Geológicas Bonaerenses, Bahía Blanca: Actas, p. 441–450.

Gelós, M. E., and Spagnuolo, J., 1992, Relación área de aporte-ambiente tectónico de las psamitas de la plataforma continental argentina entre los 39º y 43º de latitud sur y el golfo San Matías: Revista de la Asociación Geológica Argentina, v. 47, p. 141–146.

Gelós, M. E., Spagnuolo, J., and Schillizzi, R., 1988, Las unidades morfológicas de la costa norte del golfo San Matías y su evolución: Revista de la Asociación Geológica Argentina, v. 3, p. 315–327.

Goldstein, S., 2002, Foraminifera: A biological overview, *in* Sen Gupta, B. K. (ed.), Modern Foraminifera: Kluwer Academic Publishers, Dordrecht, The Netherlands, 371 p.

Gómez, E., Martínez, D., Borel, M., Guerstein, G. R., and Cusminsky, G., 2005, Submarine evidences of Holocene sea-level fluctuations in the Bahía Blanca Estuary, Argentina: Journal of South America Earth Sciences, v. 20, p. 139–155.

Gordillo, S., Cusminsky, G., Bernasconi, E., Ponce, F., Rabassa, J. O., and Pino, M., 2010, Pleistocene marine calcareous macro-and-microfossils of Navarino Island (Chile) as environmental proxies during the last interglacial in southern South America: Quaternary International, v. 221, p. 159–174.

Gordillo, S., Bernasconi, E., Cusminsky, G., Coronato, A., and Rabassa, J. O., 2013, Late Quaternary environmental changes in southernmost South America reflected in marine calcareous macro-and-microfossils: Quaternary International, v. 305, p. 149–162.

Guerrero, R., 1998, Oceanografía física del estuario del río de La Plata y el sistema costero de El Rincón. Instituto Nacional de Investigación y Desarrollo Pesquero–Inidep: Technical report, v. 21, p. 29–534.

Guerrero, R., and Piola, A. R., 1997, Masas de agua en la Plataforma Continental: En: El Mar Argentino y sus recursos pesqueros, Contribución Instituto Nacional de Investigación y Desarrollo Pesquero–Inidep: Technical report, 998, v. 1, p. 107–118.

Hayward, B., Neil, H., Carter, R., Grenfell, H., and Hayward, J., 2002, Factors influencing the distribution patterns of recent deep-

sea benthic foraminifera, east of New Zealand, Southwest Pacific Ocean: Marine Micropaleontology, v. 46, p. 139–176.
Heron-Allen, E., and Earland, A., 1932, Foraminifera: Part 1. The ice free area of the Falkland Island and adjacent seas: Discovery Republic, v. 4, p. 291–460.
Hromic, T., 2006, Distribución latitudinal de foraminíferos bentónicos (Protozoa: Foraminiferida) a nivel de subórdenes y familias, en canales y fiordos patagónicos chilenos: Investigaciones Marinas, v. 34, p. 71–81.
Hromic, T., and Montiel, A., 2011, Foraminíferos bentónicos de seno Gallegos y bahía Brookes (54.5°S – 69.5°S), Chile: patrones de distribución y diversidad: Anales del Instituto de la Patagonia, v. 39, p. 33–46.
Kahn, G., and Watanabe, S., 1980, Foraminíferos bentónicos como indicadores de la corriente de Malvinas: Revista Española de Micropaleontología, v. 12, p. 169–177.
Kaiho, K., 1994, Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean: Geology, v. 22, p. 719–722.
Kaiho, K., 1999, Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI): Marine Micropaleontology, v. 37, p. 67–76.
Laprida, C., and Bertels-Psotka, A., 2003, Benthic foraminifers and paleoecology of a Holocene shelly concentration, Salado Basin, Argentina: Geobios, v. 36, p. 559–572.
Laprida, C., García-Chapori, N., Violante, R., and Compagnucci, R., 2007, Mid-Holocene evolution and paleoenvironments of the shoreface-offshore transition, north-eastern Argentina: New evidence based on benthic microfauna: Marine Geology, v. 240, p. 43–56.
Laprida, C., Chandler, D., Mercau, J. R., Alvaro López, R., and Marcomini, S., 2011, Modern foraminifera from coastal settings in northern Argentina: Implications for the paleoenvironmental interpretation of Mid Holocene littoral deposits: Revista Mexicana de Ciencias Geológicas, v. 28, p. 45–64.
Leps, J., and Smilauer, P., 2003, Multivariate analysis of ecological data using Canoco: Cambridge University, Cambridge, England, 269 p.
Loeblich, A. R., and Tappan, H., 1992, Present status of foraminiferal classification, *in* Studies in Benthic Foraminifera, Takayanagi, Y., and Saito, T. (eds.), Proceedings of the Fourth International Symposium on Benthic Foraminifera: Sendai, 1990 (Benthos '90): Tokai University Press, Tokyo, Japan, p. 93–102.
Lucas, A. J., Guerrero, R., Mianzan, H., Acha, E. M., and Lasta, C., 2005, Coastal oceanographic regimens of the Northern Argentine Continental Shelf (34º–43º S): *Estuarine,* Coastal and Shelf Science, v. 65, p. 405–420.
Márquez, M., 2017, Ecología y paleoecología de foraminíferos en ambientes litorales del sudeste de la provincia de Buenos Aires (partidos de Mar Chiquita y Gral. Pueyrredón), Argentina. PhD thesis, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata, Mar del Plata, 257 p.
Márquez, M., and Ferrero, L., 2011, Paleoecología de foraminíferos de un testigo holoceno en la planicie costera de la laguna Mar Chiquita, Buenos Aires, Argentina: Ameghiniana, v. 48, p. 289–304.
Márquez, M., Ferrero, L., and Cusminsky, G., 2016, Holocene palaeoenvironmental evolution of the Pampa coastal plain (Argentina) based on calcareous microfossils: Revista Brasilera de Paleontología, v. 19, p. 25–40.
Martos, P., and Píccolo, M. C., 1988, Hydrography of the Argentine continental shelf between 38º and 42ºS: Continental Shelf Research, v. 8, p. 1043–1056.
Martos, P., Reta, R., and Guerrero, R. A., 2004, El ambiente físico de las costas marplatenses: su clima y sus aguas, *in* Boschi, E. E., and Cousseoau, M. B. (eds.), La vida entre mareas: vegetales y animales de las costas de Mar del Plata, Argentina, Instituto Nacional de Investigación y Desarrollo Pesquero-Inidep, Technical report, p. 29–42.
Mello e Sousa, H., Passos, R., Fukumoto, M., Almeida da Silveira, C., Lopes Figueira, C., Koutsoukos, A. M., Michaelovitch de Mahiques, A., and Rezende, E., 2006, Mid-lower bathyal benthic foraminifera of the Campos Basin, Southeastern Brazilian margin: Biotopes and controlling ecological factor: Marine Micropaleontology, v. 61, p. 40–57.
Milker, Y., Schmiedl, G., and Betzler, C., 2011, Paleobathymetric history of the Western Mediterranean Sea shelf during the latest glacial period and the Holocene: Quantitative reconstructions based on foraminiferal transfer functions: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 307, p. 324–338.
Mouzo, F., 1982, Geología Marítima y Fluvial, *in* Cuántica, S. A. (ed.), Historia Marítima Argentina: Cuántica Editora, Buenos Aires, v. 1, p. 47–117.
Mouzo, F., Garza, M., Izquierdo, J., and Zibecchi, R., 1974, Contribución al conocimiento del substrato en un sector de la plataforma continental Argentina entre Mar del Plata y Bahía Blanca (abstract): Tercera Reunión Argentina de Ecología–Simposio. Evolución de la Plataforma continental y Regiones Costeras Durante el Pleistoceno–Holoceno, La Plata, v. 12, p. 1–19.
Murray J. W., 1991, Ecology and Paleoecology of Benthic Foraminifera: Longman Scientific and Technical, Harlow, 397 p.
Murray, J. W., 2006, Ecology and Applications of Benthic Foraminifera: Cambridge University Press, Cambridge, 426 p.
Náñez, C., and Malumián, N., 2008, Foraminiferida, *in* Camacho, H. (ed.), Los Invertebrados Fósiles: Buenos Aires, Universidad Maimónides. Fundación de Historia Natural Félix de Azara, p. 65–100.
Perrota, G. R., 2000, Caballa (*Scomber joponicus*), *in* Pesquerías de Argentina, Inidep, Mar del Plata, v. 1997–1999, p. 217–225.
Perrota, G. R., Madirolas, A., Viñas, M., Akselman, R., Guerrero, R., Sánchez, R., López, F., Castro Machado, F., and Machi, G., 1996, La Caballa (*Scomber japonicus*) y las condiciones ambientales en el área bonaerense de El Rincón (39°- 40°30′ S). Instituto Nacional de Investigación y Desarrollo Pesquero–Inidep: Technical report, v. 26, 48 p.
Ponce, F., Rabassa, J., Coronato, A., and Borromei, A. M., 2011, Palaeogeographical evolution of the Atlantic coast of Pampa and Patagonia from the last glacial maximum to the Middle Holocene: Biological Journal of the Linnean, v. 103, p. 363–379.
Schönfeld, J., Dullo, W. C., Pfannkuche, O., Freiwald, A., Rüggeberg, A., Schmidt, S., and Weston, J., 2011, Recent benthic foraminiferal assemblages from cold-water coral mounds in the Porcupine Seabight: Facies, v. 57, p. 187–213.
Sen Gupta, B. K., 1999, Systematic of modern Foraminifera., *in* Sen Gupta, B. K. (ed.), Modern Foraminifera: Kluwer Academic Publishers, Dordrecht, The Netherlands, 371 p.
Sen Gupta, B. K. S., and Machain-Castillo, M. L., 1993, Benthic foraminifera in oxygen-poor habitats: Marine Micropaleontology, v. 20, p. 183–201.
Smart, C., 2002, Quaternary environmental micropaleontology, *in* Haslett, S. (ed.), Environmental Applications of Deep-Sea Benthic Foraminifera: Arnold Publishers, London, v. 3, p. 14–58.
Teodoro, A. C., Duleba, W., Gubitoso, S., Prada, S. M., Lamparelli, C. C., Bevilacqua, J. E., 2010, Analysis of foraminifera assemblages and sediment geochemical properties to characterize the environment near Araçá and Saco da Capela domestic sewage submarine outfalls of São Sebastião Channel, São Paulo State, Brazil: Marine Pollution Bulletin, v. 60, p. 536–553.
Ter Braak, C. J., and Smilauer, P., 1998, Canoco reference manual and user's guide to Canoco for windows: Software for canonical community ordination: Microcomputer Power, Ithaca, NY.
Usera, J., and Blázquez, A., 1997, Influencia del substrato en la distribución de los foraminíferos bentónicos de la plataforma continental interna entre Valencia y Alicante (España): Revista Española de Microplaeontología, v. 29, p. 85–104.
Villanueva-Guimerans, P., 2000, Bolivinidae y Buliminidae (Foraminíferos bentónicos) del margen septentrional del golfo de Cádiz (España): Revista Española de Micropaleontología, v. 32, p. 131–141.
Wright, R., 1968, Miliolidae (Foraminíferos) recientes del Río Quequén Grande. Revista del Museo Argentino de Ciencias Naturales: Hidrobiología, v. 2, p. 225–256.
Yanko, V., Arnold, A., and Parker, W. C., 2002, Effects of marine pollution on benthic foraminifera, *in* Sen Gupta, B. K. (ed.), Modern Foraminifera: Kluwer Academic Publishers, Dordrecht, The Netherlands, 371 p.

*Received 7 March 2017*
*Accepted 5 March 2018*