



# Comparative study of the taphonomic history of Holocene gastropods and ostracods of the high basin of the Salado river, Buenos Aires, Argentina

Maria Florencia Pisano<sup>a,\*</sup>, Gabriela Catalina Cusminsky<sup>b</sup>, Enrique Eduardo Y Fucks<sup>c</sup>

<sup>a</sup> Centro de Estudios Integrales de la Dinámica Exógena, Argentina (CEIDE), Universidad Nacional de La Plata, Argentina (UNLP), Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina (CONICET), 64 Street, N 3, 1900, La Plata, Buenos Aires, Argentina

<sup>b</sup> Instituto de Investigaciones en Biodiversidad y Medioambiente. Delegación de Geología y Petróleo, Centro Regional Universitario Bariloche, Universidad Nacional del Comahue (INIBIOMA, CONICET-UNCOMA), Quintral Street, N 1250, San Carlos de Bariloche, 8400, Río Negro, Argentina

<sup>c</sup> CEIDE-UNLP, 64 Street, N 3, 1900, La Plata, Buenos Aires, Argentina

## ARTICLE INFO

### Keywords:

Comparative taphonomy  
Gastropods  
Ostracods  
Holocene  
Argentina

## ABSTRACT

Gastropods and ostracods are widely used in Quaternary paleoenvironmental reconstructions but the taphonomic studies that should precede them are not as common. In this paper we compare the taphonomic information obtained from assemblages recovered in Holocene fluvial sequences of the Salado River basin (Buenos Aires, Argentina) and analyze the changes or similarities between species, localities and stratigraphic units. Using taphonomic grades, gastropod shells were cataloged based on three attributes: fragmentation, discoloration and dissolution. For ostracods, discoloration and dissolution together with the population structure (adults-juveniles A/J, valves-carapace V/C and male-female ratios) were analyzed. For gastropods, *Heleobia parchappii*, *Biomphalaria peregrina* and *Succinea meridionalis* showed similar preservation patterns, and *Miradiscops brasiliensis* showed least evidence of alteration. In ostracods, these patterns varied among species. For V/C ratio, 7% of assemblages were formed only by valves, 82% were dominated by valves and 11% were dominated by carapaces. Fragmentation and population structure allowed autochthonous and allochthonous associations to be distinguished. Gastropod assemblages with low levels of fragmentation were recovered mainly from the uppermost levels of the stratigraphic profiles. For ostracods, the A/J ratio showed that 52% of the assemblages were dominated by adults with most ontogenetic stages represented and 29% retained their original population structure suggesting they would be autochthonous associations, whereas 19% of the assemblages were dominated by juvenile valves therefore assuming allochthonous associations. Our results indicate that taphonomic analysis is an effective tool that allows identifying autochthonous assemblages, which are the most reliable for robust paleoenvironmental reconstructions.

## 1. Introduction

Multi-proxy studies are ideal for carrying out paleoenvironmental and paleoclimatic reconstructions (e.g. Sayer et al., 1999; Adams et al., 2002; Palacios-Fest et al., 2006, 2016, 2021; Birks et al., 2010; Hassan et al., 2014; Laprida et al., 2006; Borrromei et al., 2018; Coviaga et al., 2017); however, the taphonomic analyses on which they should be based are mostly limited to individual taxa. Comparative taphonomic studies provide information on the preservational history of different groups accumulated in the same sequence (e.g. Brett and Baird, 1986; Adams et al., 2002; Hassan et al., 2014; Palacios-Fest et al., 2021), and how these biases can differentially affect the individuals involved and therefore the subsequent interpretations.

Taphonomic studies allow interpreting the degree in which the fossil assemblages reflect the community and the original environment (e.g. Cohen, 1989; Palacios-Fest et al., 1994; Park et al., 2003; Rodrigues et al., 2009; Ferrero, 2009; Hassan et al., 2014; Prieto et al., 2014; Pisano et al., 2015; Bullard et al., 2017). The analysis of fluvial sequences has several difficulties, such as the transport and the mixing of materials, which are common in water courses. Therefore, as long as the depositional characteristics of the environment are understood a priori, through taphonomic analyzes, it is possible to extract from the individuals and associations information to know with greater certainty the dynamics and characteristics of the environments they inhabited (e.g. Adams et al., 2002; Tomassini and Montalvo, 2013; Erthal et al., 2015; Martello et al., 2017; Pisano et al., 2018; Ilarri et al., 2019; Palacios-Fest

\* Corresponding author.

E-mail addresses: [f.pisano@fcnym.unlp.edu.ar](mailto:f.pisano@fcnym.unlp.edu.ar), [floripisano23@gmail.com](mailto:floripisano23@gmail.com) (M.F. Pisano).

<https://doi.org/10.1016/j.jsames.2022.103806>

Received 17 July 2021; Received in revised form 25 March 2022; Accepted 8 April 2022

Available online 12 April 2022

0895-9811/© 2022 Elsevier Ltd. All rights reserved.

et al., 2021).

Ostracods and gastropods are very abundant invertebrates in Quaternary freshwater environments. They share a series of characteristics, such as exoskeletons made of calcium carbonate and high sensitivity to changes in the aquatic environments they inhabit, e.g., temperature, pH, alkalinity, salinity and fluctuations in water levels (Adams et al., 2002; Dillon, 2004; Mezquita et al., 2005; Ruiz et al., 2013). However, they differ in other characteristics; for example, gastropods are bigger than ostracods, gastropods are univalves whereas ostracods have two valves. In addition, gastropod shells grow continuously throughout their lives, while ostracods grow by molting (8 stages), which means that a single individual can generate up to 16 potentially preservable sets of skeletal elements.

From an environmental point of view, taphonomic studies of marine invertebrates have been more frequent than those performed on freshwater associations and, the analysis of assemblages recovered in limnic environments has been prioritized over those of lotic environments (i.e. Kotzian and Simões, 2006; Martello et al., 2006; Kusnerik et al., 2020). The analysis of Quaternary fluvial sequences in the upper basin of Salado River, allows analyzing for the first time gastropod and ostracod assemblages from a taphonomic point of view in the area. With this general objective, the following specific goals were proposed for this study: (1) to characterize the general state of preservation of the recovered gastropod and ostracod species, based on taphonomic attributes; (2) to recognize and differentiate autochthonous and allochthonous assemblages via taphonomic analysis; (3) to evaluate whether the state of preservation of the groups is due to the particular characteristics of each locality or stratigraphic unit where the organisms were found; and (4) to compare and complement the taphonomic information obtained from both groups to decide which analysis are the most reliable to perform palaeoenvironmental reconstructions.

## 2. Study area

### 2.1. General characteristics

The Salado River basin is located in northeastern Buenos Aires Province, in the Pampa Deprimida (Depressed Pampa) region (Fig. 1A). The Salado River watershed, with an area nearly 170,000 km<sup>2</sup>, is the main watershed of this region. Its headwaters are located in an area of shallow lakes and wetlands in the province of Santa Fe and it flows east into the Samborombón Bay. The Salado River extends for about 650 km and receives, mainly from its right bank, the contribution of numerous

tributary courses and artificial channels (Pommarés et al., 2021).

The studied localities (Fig. 1B) are in the upper basin, where the Salado River is braided, with several active channels, internal bars and a wide and well-defined flood plain. This braided design contrasts with the sinuous pattern of much of the middle and lower basin. Unlike what happens in the middle sectors, in the study area the river has almost no ravines; therefore, the fluvial units could only be observed by manual drilling in the floodplain areas adjacent to the main course.

### 2.2. Stratigraphic scheme

Following the stratigraphic scheme proposed by Fucks et al. (2015), we recognized three lithostratigraphic units of the fluvial Luján Formation, the La Chumbiada, Gorch and Puente Las Gaviotas Members, and a soil that is developed in the top of these sequence. In previous works, numerous radiocarbon dates obtained from gastropod shells, organic matter and vertebrate collagenic allowed to obtain a chronological scheme between Late Pleistocene-Holocene for this succession (see Fucks et al., 2011; 2015; Mari et al., 2013; Scanferla et al., 2013; Pommarés et al., 2021).

The La Chumbiada Member is the lowest unit composed of sandy silt to silty sandy with brown to pinkish gray color, about 40 and 80 cm thick, deposited in channels and floodplains (Pommarés et al., 2021). The total thickness could not be determined, due to drilling limitations resulting from the sediments' hardness or the water table. This unit is poorly constrained temporarily due to the lack of datable material; some of the chronological ages taken from the literature are between 14,040 ± 50 and 12,100 ± 100 <sup>14</sup>C years BP (Scanferla et al., 2013; Fucks et al., 2015), which encompass the Late Pleistocene.

The Gorch Member consists of light gray to white sandy muddy to muddy sandy sediments, about 10–60 cm thick that increasing in thickness towards the west. Aggregates of fine sand, as well as other poorly sorted ones sediments with abundant carbonate cement, are common. They were interpreted as deposited in channels and floodplains, during the Early to Middle Holocene with maximum and minimum ages of 11,690 ± 110–5130 ± 100 <sup>14</sup>C years B. P. (Fucks et al., 2015; Pommarés et al., 2021). Two new AMS ages on *H. parchappii* specimens have been obtained for this unit, 10,539 ± 36 years BP (D-AMS 025862) in Vientos del Mar and 9911 ± 36 years BP (D-AMS 034847) in Ruta 30.

The Puente Las Gaviotas Member is composed of gray to light gray sandy silt to mud-clay silt sediments, about 10 and 75 cm thick that increase in thickness towards the west. Vegetal remains and

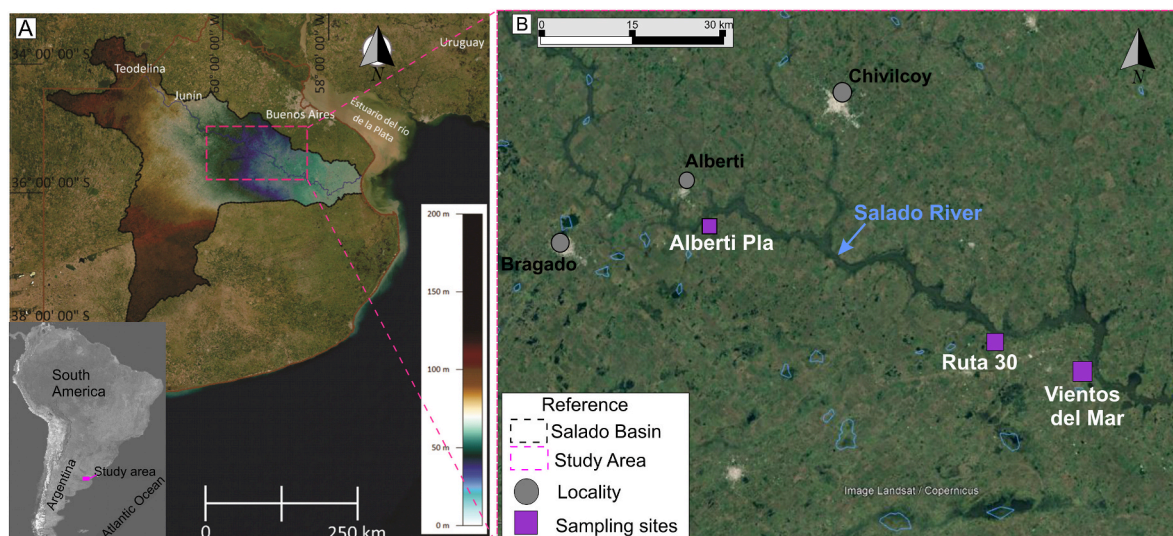


Fig. 1. Study area and Salado Basin (A) and location of sampling sites (B). Source: Google Earth, DigitalGlobe.

carbonaceous concretions are found in the very coarse sand fraction, while in the coarse and medium sands there are found seeds, vegetal remains and valves and shells of gastropods and ostracods. This unit is interpreted as channel and floodplain environments, was deposited during the Late Holocene, and its age ranges between  $3002 \pm 40$  and  $680 \pm 60$   $^{14}\text{C}$  years B.P. (Fucks et al., 2015). Finally, a soil is developed on the top of all sedimentary successions. It is dark gray to black, with abundant content of decomposing organic matter, roots, lots of seeds, and saline efflorescence on the surface. Its thickness, which increases towards the east, varies between 20 and 72 cm.

### 3. Material and methods

#### 3.1. Materials, sampling and processing

Three localities were selected for this study, from west to east: Alberti Pla (AP,  $35^\circ 4'9.60''\text{S}/60^\circ 14'32.70''\text{W}$ ), Ruta 30 (R30,  $35^\circ 13'20.80''\text{S}/59^\circ 43'4.00''\text{W}$ ) and Vientos de Mar (VM,  $35^\circ 16'6.10''\text{S}/59^\circ 32'54.20''\text{W}$ ) (Fig. 1B). An Edelman manual auger (Eijkelkamp) of 7 cm of diameter was used at each locality to extract samples at depth of approximately 5 or 6 cm. Therefore, the AP profile comprises 32 samples that were extracted along ~200 cm; the R30 profile comprises 31 samples that were extracted along ~160 cm, and the VM profile comprises 35 samples extracted along ~210 cm.

In the laboratory, each sample was divided in two and each subsample processed separately for gastropods and ostracods independently. Samples were washed under running water through two types of sieves, 500  $\mu\text{m}$  aperture to recover mainly gastropods and 63  $\mu\text{m}$  to mainly ostracods assemblages. Samples were weighted before and after washing, dried at room temperature and all valves, carapaces and shells were recovered using a stereoscopic microscope. The type of sediment and the stratigraphic unit to which it belonged were recorded for each sample.

#### 3.2. Methodology

##### 3.2.1. Faunal analyses

In order to select the species to be used in the subsequent taphonomic analyses, it was first necessary to identify the most abundant species in the profiles. With this objective, the absolute abundance data of recovered specimens (shells, carapaces or valves) were calculated for a fixed weight of sediment of 5 g for ostracods and 100 g for gastropods (Bernasconi et al., 2019; Calvo Marcilese et al., 2019; Parras et al., 2020) using a stereoscopic microscope. These abundances were graphically represented along stratigraphic profiles, and cluster plots were created from the Constrained Clustering Analysis, and a broken stick model was used to determine the number of significant groups or sectors in the cluster analysis (Birks, 2010); these groups made it possible to define sectors used to describe the results. Following Adams et al. (2002), the results for gastropods and ostracods are presented at the species and community levels, taking all the individuals that form a sample as an approximation of the paleocommunity.

##### 3.2.2. Taphonomic characterization of gastropods

Taphonomic analysis was performed for each of three attributes: fragmentation, discoloration and dissolution. Fragmentation is the percentage of complete shells preserved, discoloration according to the colors or finish of the shells and dissolution considering the degradation of the external surface of the shell, manifested by micro-perforations or pits and even holes in extreme cases.

These taphonomic attributes were described using taphonomic grades, which are arbitrary hierarchies of measurements defined in advance of the analysis (Kowalewski and Flessa, 1995; Kowalewski et al., 1995) following the criteria described in Table 1 and illustrated in Fig. 2.

For each attribute, the Total Taphonomic Grade (TTG) was

**Table 1**

Description of taphonomic grades used for characterization in gastropods.

	Grade 0	Grade 1	Grade 2
Fragmentation	More than 80% of the shells preserved	Between 80 and 30% of the shells preserved	Less than 30% of the shells preserved
Discoloration	Translucent and shiny shells	White shells with matte finish	Yellowish, brownish or black shells
Dissolution	Without alteration or a chalky surface over less than 10% of the shell	Between 10 and 50% of the shell with a chalky surface and small pits	More than 50% of the shells with chalky surface and large pits or holes

calculated using the formula  $((N_0 \times 0) + (N_1 \times 1) + (N_2 \times 2)) / \text{total N}$  (Brandt, 1986; Brown et al., 2005) where  $N_0$ ,  $N_1$  and  $N_2$  are the number of individuals present in each taphonomic grade. Low TTG values are expected to be found in samples with well-preserved biological remains. Taphonomic characterization and quantification of the shells were undertaken using a stereoscopic microscope by a single operator in order to maintain consistency of the classification criteria (Rothfus, 2004). Taphonomic analysis was performed only on samples with more than 50 specimens per sample; in the case of those with a high abundance of individuals, 150 were randomly selected.

##### 3.2.3. Taphonomic characterization of ostracods

Taphonomic attributes (Fig. 3) and population structure were considered in this study.

For taphonomic characterization, three taphonomic grades were defined for the attributes of discoloration and dissolution, which are described in Table 2 and illustrated in Fig. 3. Fragmentation was not considered in the taphonomic analysis of ostracods. Although some authors have considered this attribute as a taphonomic parameter for microfossils (Laprida and Bertels-Psotka, 2003; Bernasconi et al., 2019). De Decker (1988, 2002) believes that the fragmentation of individuals may arise during sampling or the subsequent processing of the samples.

As for gastropods, taphonomic analysis was performed only for those samples with more than 50 specimens, and in the case of those samples with a high abundance of individuals, 150 were randomly selected. The TTG was calculated according to the formula described above and classification and quantification of the taphonomic grades were made by a single operator.

For population characteristics, following the guidelines of Whatley (1983, 1988), Wakefield (1995) and Boomer et al. (2003), the adult-juvenile (A/J) and valves-carapaces (V/C) ratios, were considered, as well as the male-female ratio in species which exhibit sexual dimorphism. For the A/J ratio, the length and height of the specimens were measured. These values were plotted as a graph that was made to define groups, for each locality and each species, assignable to the different ontogenetic stages (Danielopol et al., 2008; Coviaga et al., 2015; Ramos et al., 2019). The reconstruction of the population structure was carried out only for species with more than 50 individuals in at least one sample, to ensure the presence of the largest number of ontogenetic stages. From the A/J ratio, the structure of the assemblages was qualitatively classified (Coimbra et al., 2006) as excellent when it preserved the original proportions (1:8–1:7), very good when the proportions were 1:6–1:3, adult-dominated (<1:8) or juvenile-dominated (>1:3).

##### 3.2.4. Characterization of the associations

Taphonomic attributes and population characteristics were used to identify and differentiate autochthonous or parautochthonous assemblages that are a more reliable basis for paleoenvironmental reconstructions than allochthonous assemblages. For example, for gastropods the level of fragmentation has been considered, by many

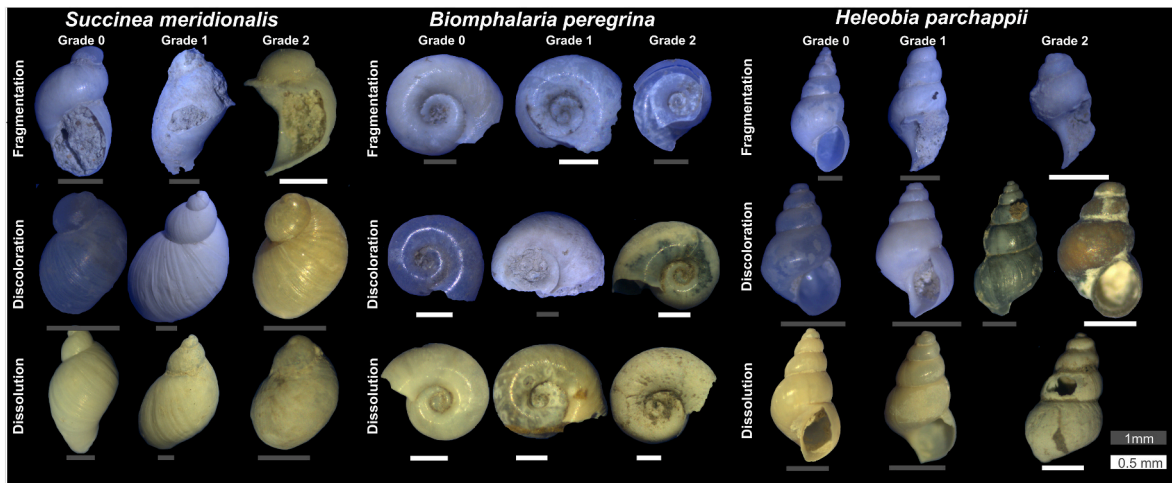


Fig. 2. Reference specimens of *Succinea meridionalis*, *Biomphalaria peregrina* and *Heleobia parchappii* showing different degrees of fragmentation, discoloration and dissolution. Scale: gray bar = 1 mm and white bar = 0.5 mm.

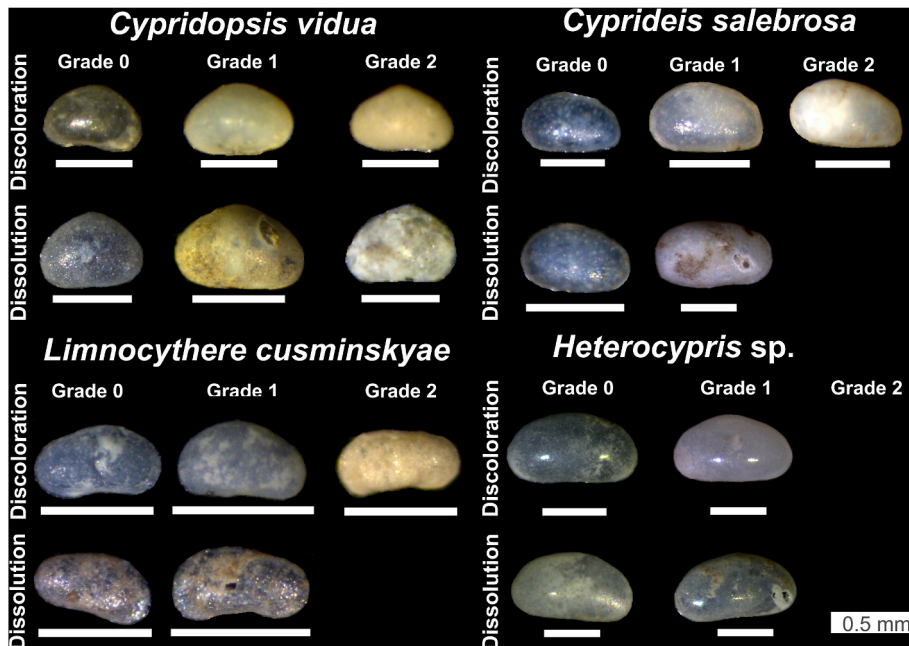


Fig. 3. Reference specimens of *Cypridopsis vidua*, *Cyprideis salebrosa*, *Limnocythere cusminskyae* and *Heterocypris* sp. showing different degrees of discoloration and dissolution. Scale bar = 0.5 mm.

**Table 2**  
Description of taphonomic grades used for characterization in ostracods.

	Grade 0	Grade 1	Grade 2
Discoloration	Translucent valves and carapace	Milky white valves or carapaces	White valves or carapaces
Dissolution	Without pits or microperforations (dissolution marks)	Marks occupied less than 50% of the valve or carapace	Marks present over more than 50% of the valve or carapace

authors, as a good indicator of the degree and energy of transport of the assemblages (i.e. [Kidwell and Bosence, 1991](#); [Parsons-Hubbard, 2005](#); [Hauser et al., 2008](#)), but for ostracods this is better determined by the relationships A/J and V/C (i.e. [Palacios-Fest et al., 1994](#); [Wakefield, 1995](#); [Arias, 1999](#); [Boomer et al., 2003](#); [Coimbra et al., 2006](#)).

### 3.3. Statistical analysis

To evaluate whether the profiles of preservation of the species vary in the same locality, we compared the TTG values of each taphonomic attribute using the Kruskal-Wallis test. In those cases where the differences were significant, we performed pair-wise comparisons using a Wilcoxon rank sum test. P-values obtained were adjusted by the Bonferroni method.

To assess whether the state of preservation of the assemblages (samples) was due to particular characteristics of the studied location or to their age, we carried out a Multivariate Analysis of Variance with Permutation (PERMANOVA; [Anderson et al., 2008](#)). Two factors were selected: locality with three levels of analysis: AP, R30 and VM; and stratigraphic unit also with three stratigraphic levels: Gorch Mb., Puente Las Gaviotas Mb., and soil. The samples from the La Chumbiada Mb. were excluded from the taphonomic analysis because most of them had very few (less than 10) or no specimens. PERMANOVA analysis was

performed with 999 permutations and Manhattan distance, followed by pairwise comparison tests, to assess the contribution of localities or stratigraphic units to differences in taphonomic modifications.

All analyses and diagrams were performed with the rioja (Juggins, 2012) and vegan statistical packages (Oksanen et al., 2011) of the program R version 3.0.1. (R CORE TEAM, 2013).

## 4. Results

### 4.1. Gastropods: abundance and preservation

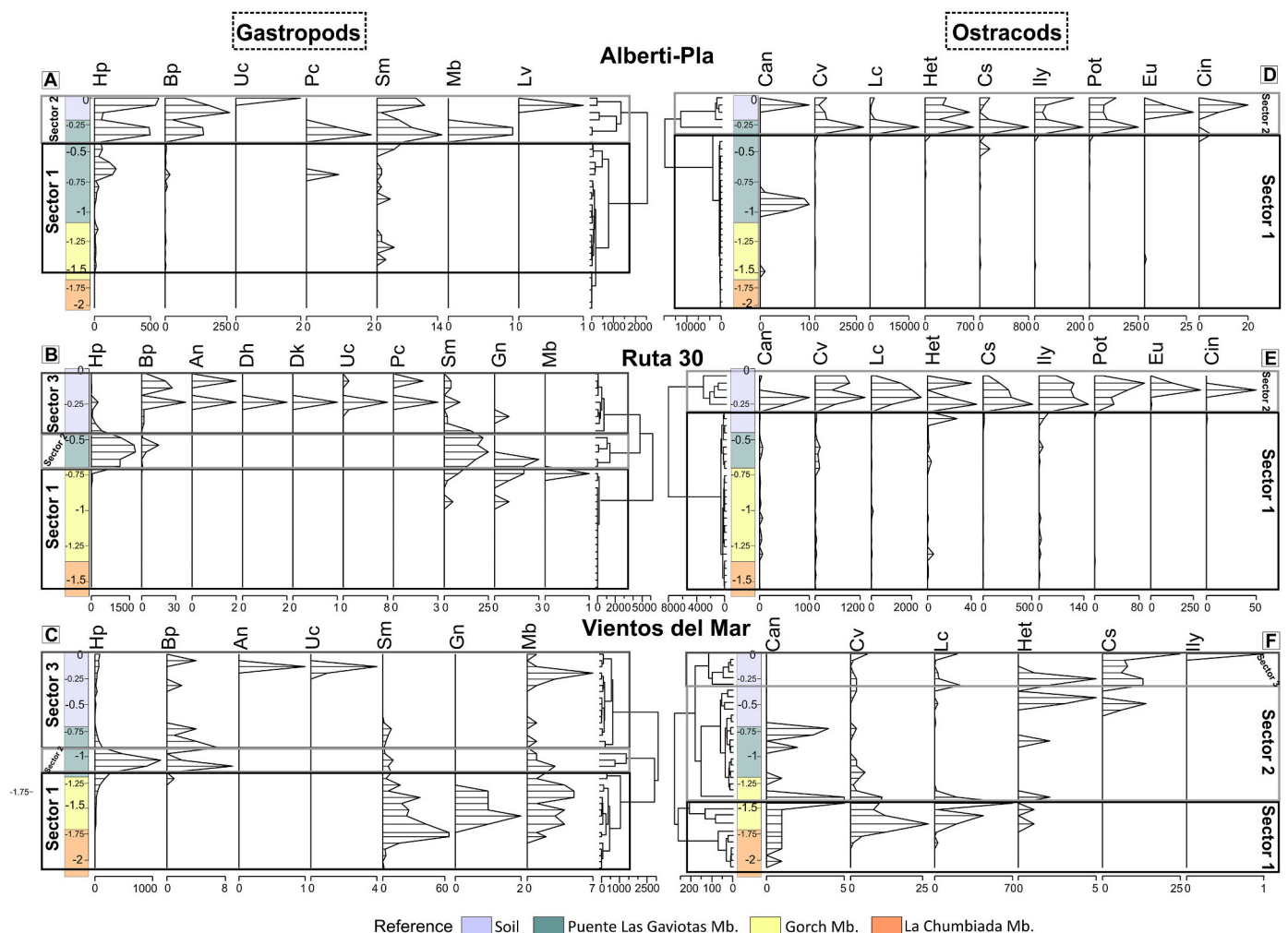
In the Alberti Pla profile, specimens assignable to seven gastropod species were recovered (in order of abundance): *Heleobia parchappii* (d'Orbigny, 1835) (75.86%), *Biomphalaria peregrina* (d'Orbigny, 1835) (22.13%), *Succinea meridionalis* d'Orbigny, 1846 (1.79%), *Uncancylus concentricus* (d'Orbigny, 1835) (0.05%), *Miradiscops brasiliensis* (Thiele, 1927) (0.05%), *Lymnaea viator* d'Orbigny, 1835 (0.02%) and *Pomacea canaliculata* (Lamarck, 1822) (0.1%). Two sectors were recognized in the profile (Fig. 4A, Supplementary material 1.A). In sector 1 (from -150 to -36 cm) the assemblages of Gorch Mb and a large part of Puente Las Gaviotas Mb. were composed of only the three main species with low abundance: *H. parchappii* was recorded in all samples, while *B. peregrina* and *S. meridionalis* appear discontinuously. In the samples recovered from the uppermost 36 cm of the profile (sector 2, Puente Las Gaviotas

Mb. and soil), the highest abundance of individuals and diversity of species were recorded.

Of the 32 samples in the Alberti Pla profile, four were devoid of fossils and for the subsequent taphonomic analysis only 12 samples were considered, all of them from the upper 90 cm, since in the remaining 16, the number of individuals recovered was insufficient for taphonomic characterization.

Regarding preservation (Fig. 5A), the specimens of *S. meridionalis* had the highest fragmentation values and low dissolution. For *H. parchappii*, TTG values showed an increase with depth in the three taphonomic attributes. For *B. peregrina* the highest TTG values for fragmentation were found in sector 2, while for dissolution there are records of low values throughout the entire profile, without any obvious trend.

Profile Ruta 30 displayed the highest abundance (8160 specimens) and diversity of gastropods, with 10 species: *H. parchappii* (96.33%), *S. meridionalis* (1.86%), *B. peregrina* (1.45%), *U. concentricus* (0.1%), *Gastrocopta nodosaria* (d'Orbigny, 1835) (0.1%), *P. canaliculata* (0.06%), *Antillorbis nordestensis* (Lucena, 1954) (0.05%), *Drepanotrema heloicum* (d'Orbigny, 1835) (0.03%), *D. kermatoides* (d'Orbigny, 1835) (0.01%) and *M. brasiliensis* (0.01%). Three sectors were identified in Ruta 30 profile (Fig. 4B, Supplementary material 1.B). In sector 1 (from -150 to -70 cm) samples of La Chumbiada and Gorch Members were characterized by absence or a very low density of specimens (maximum 37). In



**Fig. 4.** Stratigraphic profiles indicating the absolute abundance of gastropods (A, B, C) and ostracods species (D, E, F) in the localities studied. Abbreviations for gastropods: **Hp:** *H. parchappii*, **Bp:** *B. peregrina*, **An:** *A. nordestensis*, **Dh:** *D. heloicum*, **Dk:** *D. kermatoides*, **Uc:** *U. concentricus*, **Pc:** *P. canaliculata*, **Sm:** *S. meridionalis*, **Gn:** *G. nodosaria*, **Mb:** *M. brasiliensis* and **Lv:** *L. viator*. Abbreviations for Ostracods: **Can:** *Candonopsis* sp., **Cv:** *C. vidua*, **Lc:** *L. cusminskyae*, **Het:** *Heterocypris* sp., **Cs:** *C. salebrosa*, **Ily:** *Ilyocypris* sp., **Pot:** *Potamocypris* sp., **Eu:** *Eucypris* sp. and **Cin:** *Ch. incisa*.

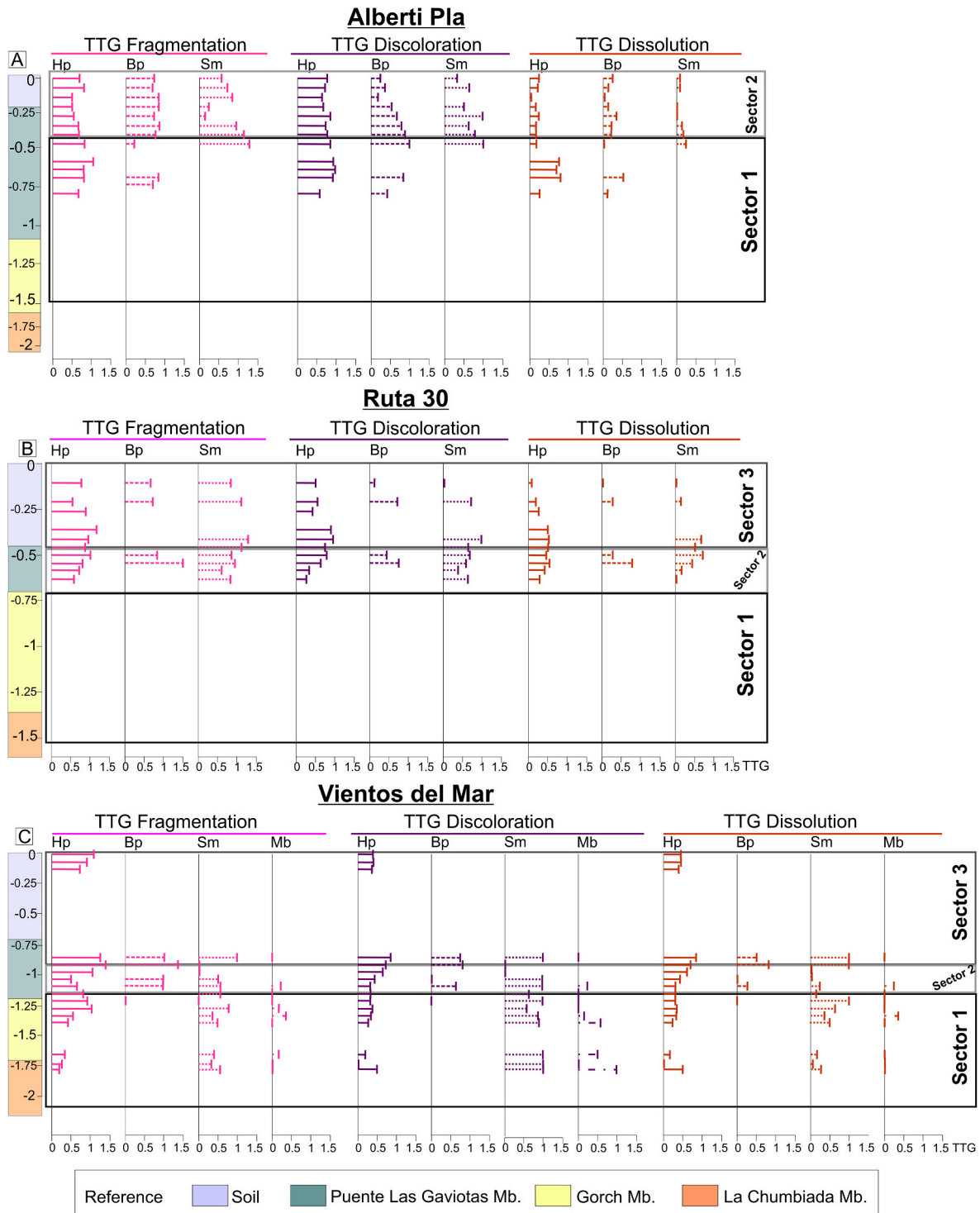


Fig. 5. Variations in TTG values for the most abundant species of gastropods in terms of fragmentation, discoloration, and dissolution in the localities of Alberti Pla (A), Ruta 30 (B) and Vientos del Mar (C). Abbreviations: Hp: *H. parchappii*, Bp: *B. peregrina*, Sm: *S. meridionalis*, Mb: *M. brasiliensis*, TTG: total taphonomic grade.

sector 2 (from -70 to -45 cm) samples of Puente Las Gaviotas Mb. had the highest abundance of *H. parchappii* and *S. meridionalis*. Sector 3, the upper 45 cm, includes the samples of the soil where the highest diversity of species was recorded.

The taphonomic analysis was performed in 10 of the 31 samples obtained from sectors 2 and 3 of Ruta 30 profile (Fig. 5B), because four were devoid of specimens and 17 did not have the minimum number of specimens. The samples with the greatest deterioration (the highest TTG values) come from the transition zone between sectors 2 and 3.

Fragmentation was the process that most affected the specimens from this locality; discoloration was more frequent on the specimens of *H. parchappii* and *S. meridionalis*, while dissolution affected most *B. peregrina* and *S. meridionalis*.

Finally, in Vientos del Mar, seven species were recorded: *H. parchappii* (89.27%), *S. meridionalis* (8.43%), *M. brasiliensis* (1.21%), *B. peregrina* (0.8%), *G. nodosaria* (0.16%), *U. concentricus* (0.11%) and *A. nordestensis* (0.02). In this profile a clear difference was observed in the composition of the assemblages, allowing the identification of three

sectors (Fig. 4C, Supplementary material 1.C). In sector 1 (from -212 to -114 cm) the assemblages of La Chumbiada and Gorch Members were dominated by *S. meridionalis* together with *H. parchappii* and *M. brasiliensis* and yielded the only specimens of *G. nodosaria*. In sector 2 (up to -90 cm) where some samples of Puente Las Gaviotas Mb. were included, *H. parchappii* reached its maximum abundance and *B. peregrina* was recorded; *S. meridionalis* and *M. brasiliensis* completed the assemblage. In the last section (from -90 cm to the top) upper samples of Puente Las Gaviotas Mb. and the soil were characterized by assemblages with a high diversity of species but very low abundance of individuals.

From the 35 samples, 16 were analyzed taphonomically, mainly from sectors 1 and 2 and with few samples from sector 3 of the Vientos del Mar profile. One sample was sterile and 18 did not reach the necessary number for analysis. The specimens of *M. brasiliensis* had the lowest fragmentation and dissolution values in the profile. For *H. parchappii* and *B. peregrina* the highest TTG values for fragmentation were obtained, while discoloration and dissolution affected mainly *S. meridionalis* specimens (Fig. 5C).

4.2. Ostracods: abundance and preservation

The ostracod assemblages of Alberti Pla yielded of nine species (in abundance order): *Limnocythere cusminskyae* Ramon Mercau et al., 2014 (70.71%), *Cypridopsis vidua* (Müller, 1776) (15.64%), *Heterocypris* sp. Claus, 1893 (6.35%), *Cyprideis salebrosa* Van den Bold, 1963 (3.72%), *Potamocypris* sp. Brady, 1870 (1.87%), *Ilyocypris* sp. Brady and Norman, 1889 (1.47%), *Eucypris* sp. Vavra, 1891 (0.12%), *Chlamydotheca incisa* (Claus, 1893) (0.09%) and *Candonopsis* sp. Vavra, 1891 (0.03%). Two sectors were recognized in this profile (Fig. 4D, Supplementary material 1.D). In sector 1 (from the base to -30 cm, including samples of La Chumbiada, Gorch and some of Puente Las Gaviotas Members) the assemblages recorded all the species mentioned above, except for *Ch. incisa*, in low abundance. In sector 2 (upper 30 cm) the samples of Puente Las Gaviotas Mb and the soil showed the highest abundance of individuals and diversity, as well as the few specimens of *Ch. incisa* were identified.

The structure of the assemblages of sector 1 showed a large proportion of samples devoid of ostracods or with a low number of individuals that prevented their characterization. However, in the samples in which the population structure could be reconstructed (Fig. 6) not all ontogenetic stages were found, as juvenile forms of the first stages were underrepresented. So, these assemblages were dominated by adult or large juvenile forms. This sector was dominated by assemblages composed exclusively or mainly by valves (Supplementary material 2). In a few assemblages the V/C ratio was 2 or 1. Regarding the sex ratio, females were dominant for both *L. cusminskyae* and *C. salebrosa*. The exceptions in which males predominated correspond to samples with a low abundance of individuals.

In sector 2, the population structure of the different species could be analyzed in all samples; representatives of almost all ontogenetic stages were recovered (Fig. 6). The A/J ratio (Fig. 7A) showed that for *L. cusminskyae* the assemblages were dominated by adults, whereas juveniles dominated for *C. salebrosa*. Only in the case of *C. vidua* and *Heterocypris* sp. did assemblages preserve the normal proportions of the original structure (1:6-1:3). Assemblages were mostly dominated by valves. For *L. cusminskyae* and *C. salebrosa* the sex ratio could be quantified and in both species females were dominant.

Regarding the preservation along the profile (Fig. 8A), 10 samples could be analyzed to a taphonomic approach. In color changes, the highest values were for *Heterocypris* sp. and *C. salebrosa*, while most specimens of *C. vidua* and *L. cusminskyae* retained their original color. Dissolution in valves or carapace was very low; in general TTG values were not higher than 0.25.

Profile Ruta 30 yielded the same nine species as Alberti Pla: *L. cusminskyae* (51.07%), *C. vidua* (29.08%), *C. salebrosa* (9.16%), *Ilyocypris* sp. (3.78%), *Eucypris* sp. (3.03%), *Potamocypris* sp. (1.64%), *Candonopsis* sp. (1.14%), *Heterocypris* sp. (0.75%) and *Ch. incisa* (0.35%). Two sectors were identified in the profile (Fig. 4E, Supplementary material 1.E). Sector 1 extends from the base to -25 cm including all the samples of La Chumbiada, Gorch and Puente Las Gaviotas Members and some of the soil, and sector 2 from -25 cm to the top of the profile, which includes the most superficial samples of the soil. The difference

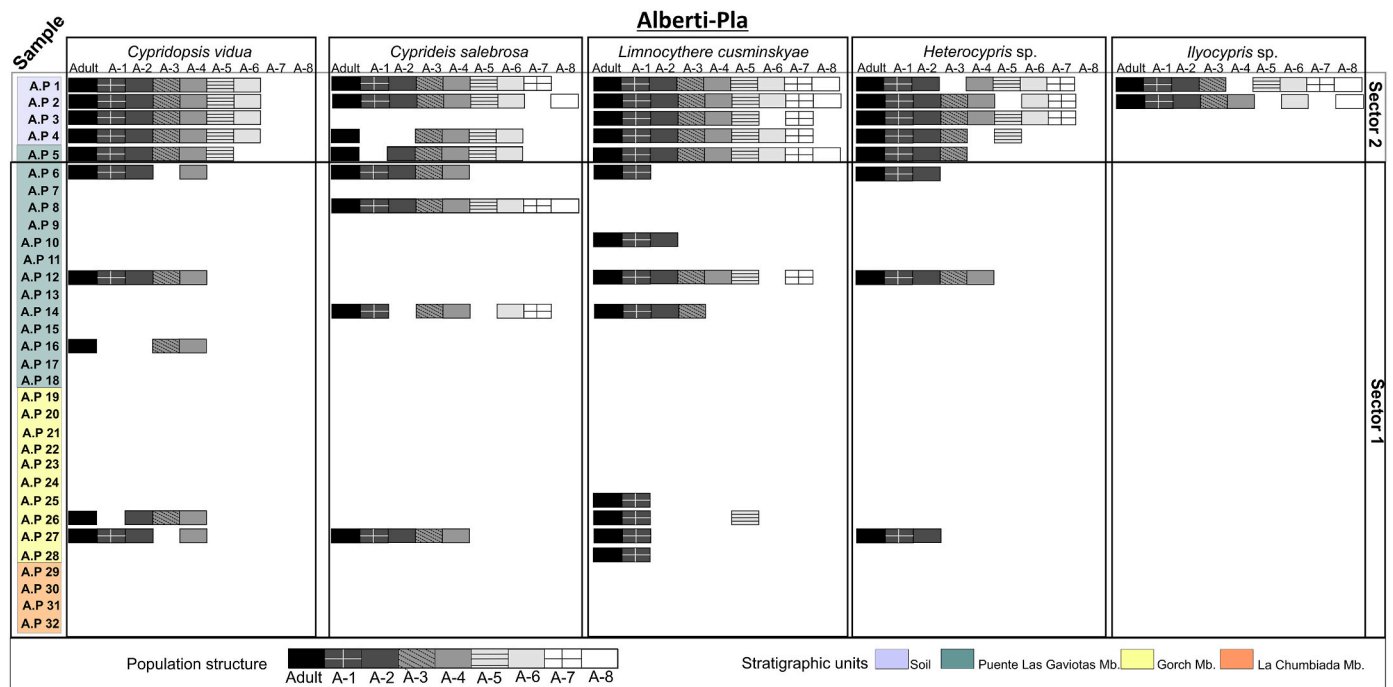
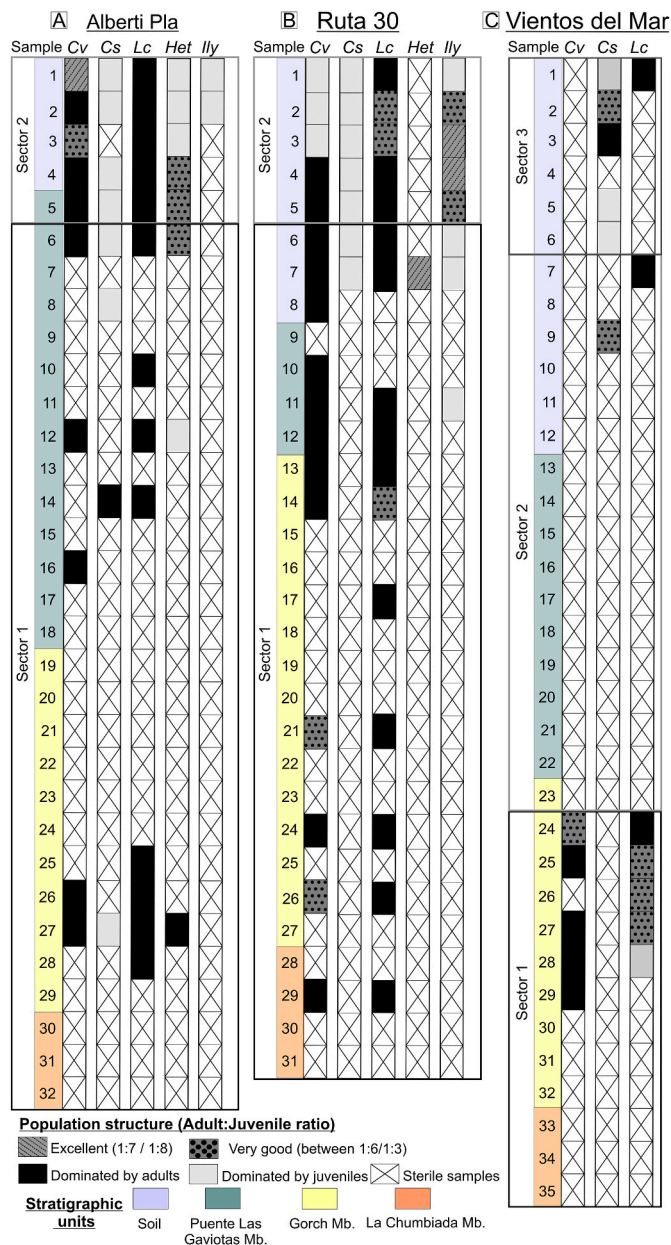


Fig. 6. Ostracod population structure for Alberti Pla locality showing the different ontogenetic stages present in the ostracod species. Note: if a symbol box is present under ontogenetic stage, that means that this stage was present in the analyzed sample, in contrast if no symbol is present no representatives of that growth stage were present.



**Fig. 7.** The population structure for the most abundant ostracod species along profiles in the localities Alberti Pla (A), Ruta 30 (B) and Vientos del Mar (C). Abbreviations: Cv: *C. vidua*, Lc: *L. cusminskyae*, Cs: *C. salebrosa*, Het: *Heterocypris* sp. and Ily: *Ilyocypris* sp.

between them is a growth in diversity in the assemblages from the upper sector. In addition, a notable increase in abundance occurs. For example, *L. cusminskyae* went from 16 individuals in sector 1 to 1000 in sector 2, *C. vidua* from 29 to 540, and *C. salebrosa* abundance from 10 specimens in sector 1 to 510 in sector 2.

Regarding the population structure (Fig. 7B, Fig. 9), although for *C. vidua* and *L. cusminskyae* almost all ontogenetic stages have been recovered, mainly in sector 2. In the case of *C. vidua* a higher proportion of juvenile specimens was recorded in the upper 15 cm, while in the rest adults are more abundant. For *L. cusminskyae* also adults are dominant, and in some assemblages the proportions of the original structure was very good, (A/J ratio between 1:6–1:3). For *C. salebrosa* the assemblages were dominated by juveniles. For *Ilyocypris* sp. the A/J ratios showed an excellent (1:8–1:7) to very good (1:6–1:3) representation population structure in sector 2, while sector 1 was dominated by juveniles.

As for the V/C ratio, although the valves dominated the assemblages of this profile (Supplementary material 3), for *C. vidua* carapace appear more than valves or in the same proportion, in the interval between –80 and –40 cm, and these assemblages correspond mainly to adult specimens. In *C. salebrosa* and *L. cusminskyae* females were more abundant than males, and in a large number of assemblages of *C. salebrosa*, no male specimens of *C. salebrosa* were recovered.

Alterations of color and dissolution were almost absent in the upper samples (sector 2). However, in sector 1, maximum TTG were recorded for discoloration (Fig. 8B) in specimens of *C. vidua* and *L. cusminskyae* in samples between –100 and –50 cm deep. Dissolution in these samples showed TTG near 1 for *Ilyocypris* sp., whereas the maximum TTG values for *C. salebrosa* and *L. cusminskyae* were 0.5.

Species richness was lower in the Vientos del Mar profile which had the least number of specimens, only 481 specimens were recovered (Fig. 4F, Supplementary material 1.F). The six species recorded were: *L. cusminskyae* (45.74%), *C. vidua* (24.53%), *C. salebrosa* (19.13%), *Candonopsis* sp. (5.82%), *Heterocypris* sp. (4.57%) and *Ilyocypris* sp. (0.21%). Three sectors were recognized in this profile. Sector 1 (from –212 to –141 cm) include samples of La Chumbiada and some of Gorch Members. Sector 2 (from –141 to –30 cm) comprehend samples of Gorch and Puente las Gaviotas Members and some of the soil, and sector 3 from –30 to the top of the profile which includes the upper samples of the soil. Sectors 1 and 3 yielded the highest number of specimens.

Population structure (Fig. 7C; Fig. 10) could be reconstructed in sector 1 only for *C. vidua* and *L. cusminskyae*. Most stages were preserved in the assemblages of *L. cusminskyae*, reflecting a very good structure (A/J ratio 1:6–1:3) regarding proportion of adults (mostly females) and juveniles, with a dominance of valves. For *C. vidua*, the structure was very incomplete and with mostly adult specimens.

In sector 2 the population structure could not be reconstructed due to the low number of specimens, but we found assemblages dominated or formed exclusively by valves.

In sector 3 the structure could only be reconstructed for *C. salebrosa* which was dominated by juveniles of different stages, and to a lesser extent for *L. cusminskyae* formed mainly by adult females. Males dominated in samples with a low number of individuals. Concerning the V/C ratio (Supplementary material 4), in the assemblages of *C. vidua* and *Heterocypris* sp. valves and carapace were recovered in equal proportion or carapace dominated, opposite to what was observed in the remaining species.

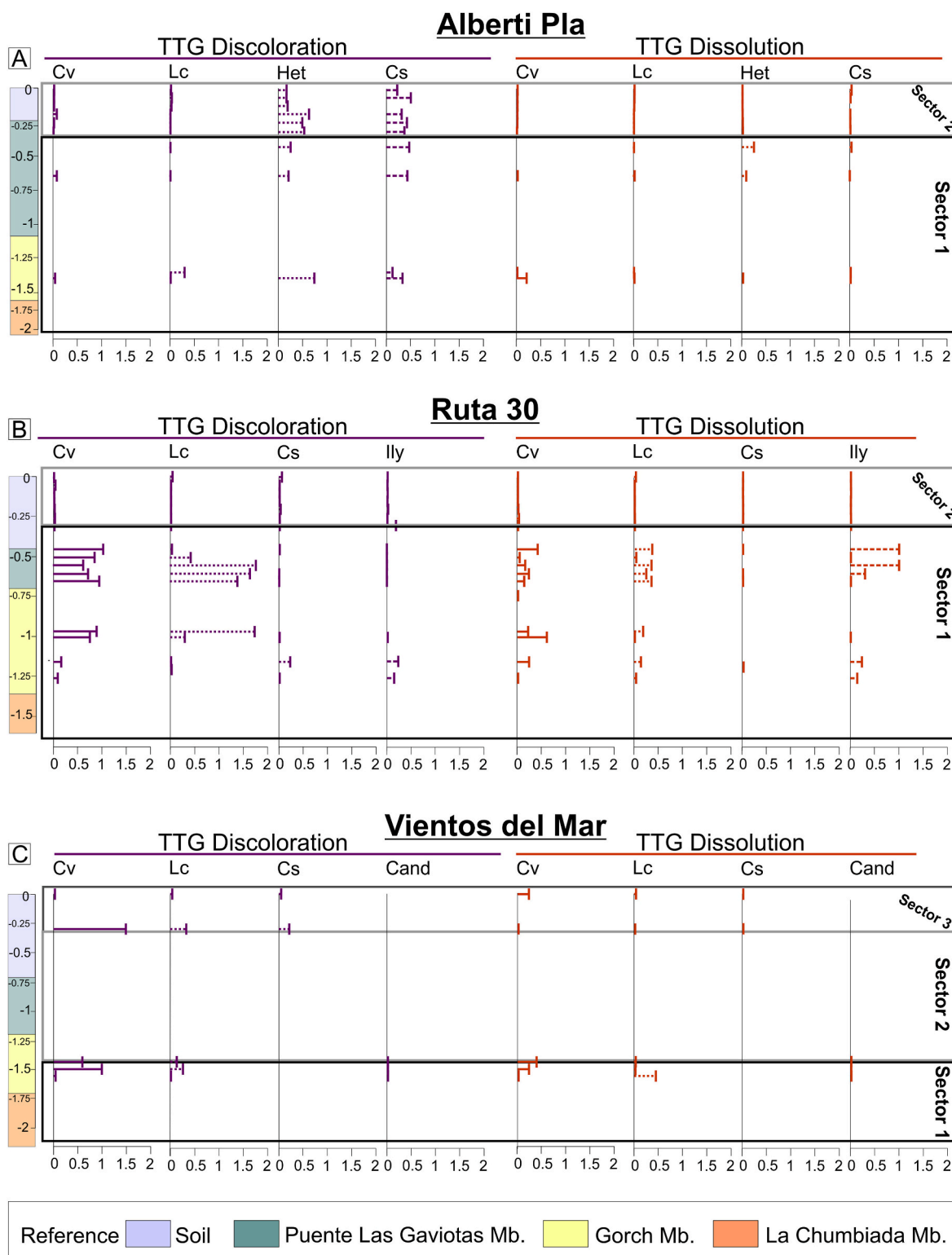
Only five samples from sector 1 and 3 could be analyzed from the taphonomic approach (Fig. 8C). The few associations analyzed showed greater evidence of discoloration, and the highest TTG values, for discoloration and dissolution, were obtained in *C. vidua* and *L. cusminskyae*.

#### 4.3. Spatio-temporal changes in preservation

The analysis of taphonomic attributes in gastropods shows that *M. brasiliensis* was the single species with significant differences in its preservation, and the specimens recovered showed the lowest values of TTG, although it could only be quantified in Vientos del Mar (Table 3). The remaining species showed similar preservation profiles to each other. Consequently, since the shells of *H. parchappii*, *B. peregrina* and *S. meridionalis* showed no interspecific variation within any locality, the specimens of one sample could be analyzed as a set.

PERMANOVA results suggest that the preservational state, calculated TTG, of the gastropod samples varied according to the stratigraphic units (0.001) which explained 32% of the taphonomic variability of the assemblages, but no variations between localities were found. Therefore, with respect to the stratigraphic units, the highest TTG values for fragmentation and dissolution were recorded in samples from the Puente Las Gaviotas Mb., while the lower TTG were obtained in the oldest samples that belong to the Gorch Mb. and that differed significantly from those of the younger levels (Table 4, Fig. 11). For





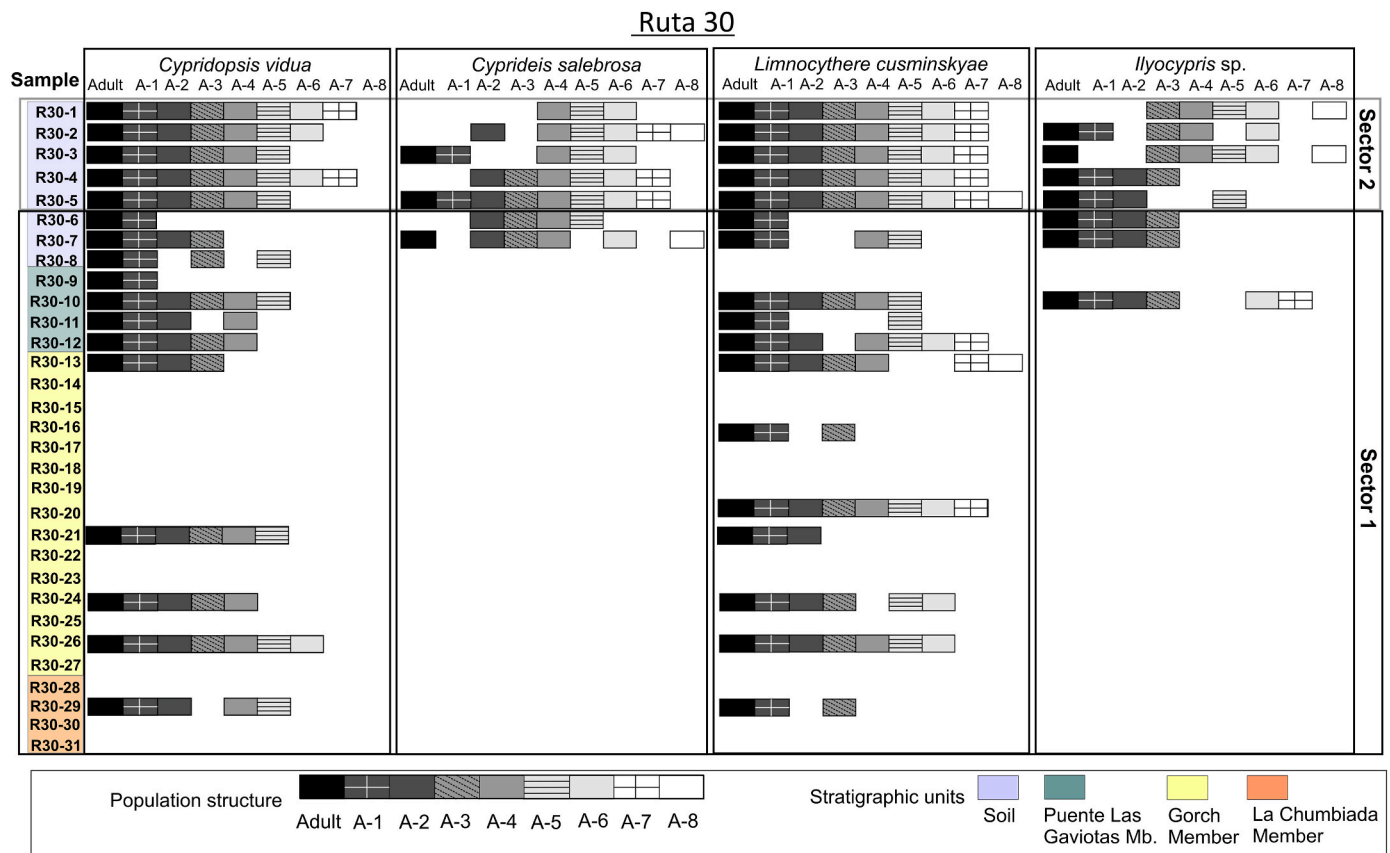
**Fig. 8.** Variations in TTG values for the most abundant ostracod species along profiles for the localities Alberti Pla (A), Ruta 30 (B) and Vientos del Mar (C). Abbreviations: **Can:** *Candonopsis* sp., **Cv:** *C. vidua*, **Lc:** *L. cusminskyae*, **Het:** *Heterocypris* sp., **Cs:** *C. salebrosa*, **Ily:** *Ilyocypris* sp.

discoloration, the highest TTG were recorded in samples from Puente Las Gaviotas and Gorch Members. Specifically, a larger number of the specimens recovered from the Gorch Mb. are whitish because they are full of the surrounding sediment that gives it that characteristic color, and this can raise the TTG values.

For ostracods, discoloration was selective, with differences among species in AP and Ruta 30 localities. In AP, *L. cusminskyae* recorded the

least evidence of change in color, and its preservation was significantly different from *C. salebrosa* and *Heterocypris* sp. In R30 the highest values for discoloration were obtained to *C. vidua*, and were significantly different from those registered for *C. salebrosa* and *Ilyocypris* sp. Dissolution did not show variations between the species.

The analysis of the behavior of the taphonomic attributes in the different units (discoloration  $p = 0.007$ , dissolution  $p = 0.009$ ) revealed



**Fig. 9.** Ostracod population structure for Ruta 30 locality showing the different ontogenetic stages present in the ostracod species. Note: if a symbol box is present under ontogenetic stage, that means that this stage was present in the analyzed sample, in contrast if no symbol is present no representatives of that growth stage were present.

that color changes were more intense (higher TTG values) than evidence of dissolution. Significant differences were found when comparing the assemblages recovered from the Gorch Mb. with those from the soil. These differences regarding color, as with gastropods, occur because the specimens, present in the Gorch Mb., are usually whitish and filled with the surrounding sediment.

Among localities, the assemblages showed no differences in color ( $p = 0.82$ ), unlike dissolution ( $p = 0.004$ ), which was different between Alberti Pla and Ruta 30 (Fig. 11).

The V/C ratio showed that valves were dominant in 82% of the assemblages and in 7% they were the only elements recovered. Carapaces were dominant only in 11% of the samples which, mostly, were recovered from the transitional zone between the Gorch and Puente Las Gaviotas Members in the Ruta 30 locality. Except for this distinctive feature, the V/C ratio did not show discrepancies either among localities or stratigraphic units.

## 5. Discussion

The taphonomic information provided by the study assemblages of gastropods and ostracods from the Holocene fluvial sequences of the Salado River basin is reported here, especially the changes or similarities among species, localities and stratigraphic units. Few works jointly analyzed the taphonomic history of different groups of microfossils (e.g. Martin et al., 1996; Palacios-Fest et al., 2006; Hassan et al., 2014) and when it comes to ostracods and gastropods, these are particularly scarce (Adams et al., 2002; Palacios-Fest, 2017; Palacios-Fest and Holliday, 2017; Palacios-Fest et al., 2021). Therefore, this work is an important contribution to understand what kind of taphonomic information can be obtained by evaluating both groups together in the same Holocene

sequences.

### 5.1. Assemblage characteristics

Regarding the composition of the gastropod assemblages, the species found in this work are similar to those found elsewhere in Holocene sediments of the Salado River basin (Pisano and Fucks, 2016) and in other sectors of the Pampean region (Tietze and De Francesco, 2010; De Francesco et al., 2013; Steffan et al., 2014).

However, the assemblages analyzed in this work present some particular characteristics compared to the lower Salado Basin (Pisano and Fucks, 2016), such as the first report of specimens of *G. nodosaria* and the greater abundance of *S. meridionalis* and *M. brasiliensis*. According to the environmental preferences of the diverse species, two groups can be recognized. *Heleobia parchappii*, *B. peregrina*, *U. concentricus*, *L. viator* and *P. canaliculata* inhabit freshwater bodies, lotic and mainly lentic with high vegetation; whereas *S. meridionalis*, *M. brasiliensis* and *G. nodosaria* have terrestrial or amphibious habits and live in humid areas near water bodies (Castellanos and Fernández, 1976; Castellanos and Landini, 1981; Rumi, 1991; Tietze and De Francesco, 2010, 2012).

The species of the ostracod assemblages collected in this study were already mentioned for the Pampean region, both in modern and Late Quaternary sediments. In the first case, *C. salebrosa*, *L. cusminskyae* (referred as *L. aff. L. stapplini*) and *C. vidua*, as well as species of the genera *Ilyocypris* and *Heterocypris* were found in shallow lakes or oligotrophic permanent streams (Laprida, 2006). Species of the genera *Candonopsis* and *Chlamydotheca* were cited in temporary hypo-to oligohaline environments (Laprida, 2006). In Pleistocene-Holocene sequences of the Province of Buenos Aires, *L. cusminskyae* and *C. salebrosa*

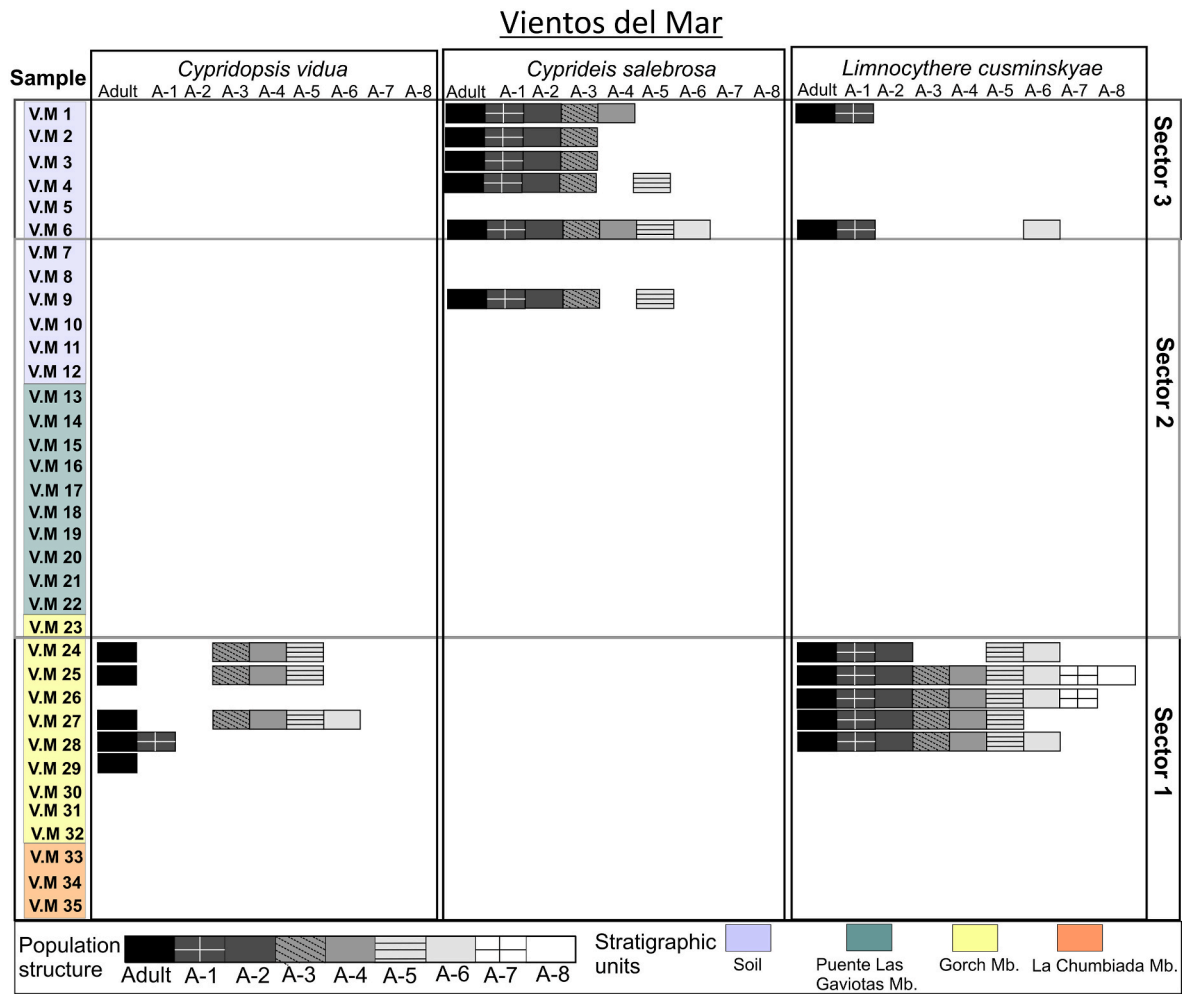


Fig. 10. Ostracod population structure for Vientos del Mar locality showing the different ontogenetic stages present in the ostracod species. Note: if a symbol box is present under ontogenetic stage, that means that this stage was present in the analyzed sample, in contrast if no symbol is present no representatives of that growth stage were present.

Table 3

Summary of the results of the Kruskal Wallis tests among the TTG calculated for the attributes by species between the different localities. When the differences were significant (\*), a pairwise comparison using Wilcoxon rank sum tests was performed, p-value adjustment method was Bonferroni. **Abbreviations:** AP = Alberti Pla, R30 = Ruta 30, VM= Vientos del Mar, Hp: *H. parchappii*, Sm: *S. meridionalis*, Mb: *M. brasiliensis*, Cv: *C. vidua*, Lc: *L. cusminskyae*, Het: *Heterocypris* sp., Cs: *C. salebrosa*, Ily: *Ilyocypris* sp.

	Locality	TTG Fragmentation P-value	TTG Dissolution P-value	TTG Discoloration P-value
Gastropods	AP	0.93	0.10	0.22
	R30	0.47	0.80	0.48
	VM	0.0003*	0.005*	0.005*
		Mb-Hp: 0.0007 Mb-Sm: 0.03	Mb-Hp: 0.0039 Mb-Sm: 0.0140	Mb-Hp: 0.009 Mb-Sm: 0.05
Ostracods	AP		0.97	0.0002* Lc-Cs: 0.005 Lc-Het: 0.007
	R30		0.056	0.002* Cv-Cs: 0.001 Cv-Ily: 0.015
	VM		0.14	0.10

Table 4

Summary of the results of the Kruskal Wallis tests among the calculated TTG for the attributes between the different stratigraphic units and localities. When the differences were significant (\*), a pairwise comparison using Wilcoxon rank sum tests was performed, p-value adjustment method was Bonferroni. **Abbreviations:** G = Gorch Mb., PLG= Puente Las Gaviotas Mb., S= Soil, AP = Alberti Pla, R30 = Ruta 30, VM= Vientos del Mar.

		TTG Fragmentation P-value	TTG Dissolution P-value	TTG Discoloration P-value
Gastropods	Between stratigraphic units	0.0008* G-PLG: 0.002 G-S: 0.007	0.011* PLG-G: 0.09 PLG-S: 0.03	0.000006* S-G: 0.014 S-PLG: 0.00004
	Between localities	0.51	0.32	0.08
Ostracods	Between stratigraphic units		0.009* G-S: 0.009	0.007* G-S: 0.006
	Between localities		0.004* AP-R30: 0.05	0.82

have been found in salty environments of oligo-mesohaline waters (Ferrero, 2009; Márquez et al., 2016) and *L. cusminskyae*, *C. vidua* and species of *Heterocypris* or *Chlamydotheca* in alkaline waters or temporary

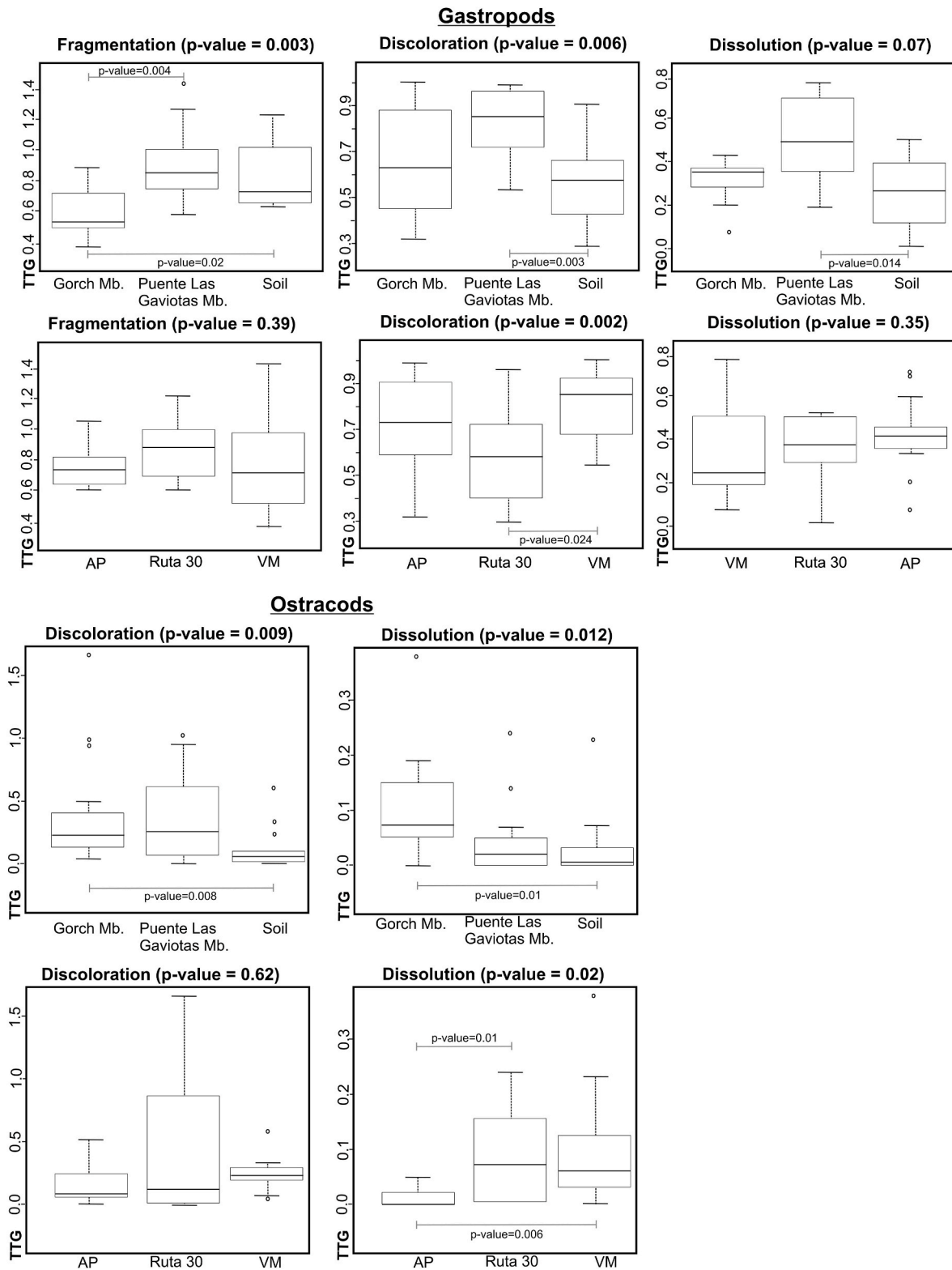


Fig. 11. Difference between TTG calculated for the attributes between the different stratigraphic units and localities. When the differences were significant, posteriori comparisons using Wilcoxon rank sum tests were calculated. The p-value adjustment method was Bonferroni as indicated by bars and the p-value.

shallow lakes from the Middle-Late Holocene (Laprida et al., 2014). Thus, the analysis of the abundance of the species in the associations, allowed selecting those suitable for subsequent taphonomic characterization by their representativeness in the sequences.

### 5.2. Assemblage preservations

The most abundant gastropod species, *H. parchappii*, *B. peregrina* and *S. meridionalis*, showed trends in preservation patterns similar to each other, mainly at the Alberti Pla and Ruta 30 localities. However, at Vientos del Mar, *M. brasiliensis* showed the least evidence of taphonomic

alteration when compared to the others species, allowing us to infer that the associations of *M. brasiliensis* would be a good environmental indicator in those levels where this species appears. Furthermore and particularly for *H. parchappii*, some congruencies are observed when comparing our findings from the high Salado River basin with the results previously obtained for assemblages of this species from the lower basin (Pisano et al., 2018). On the one hand, coloration changes were more frequent than alterations by dissolution and, in addition, the ranges in TTG values obtained for dissolution and discoloration were similar in both sectors, showing homogeneity for the region.

Erthal et al. (2011) noted that intrinsic characteristics, such as shell thickness, influence the preservation of remains by favoring the preservation of organisms with thick shells (such as *Heleobia*, among others) to the detriment of organisms with thin shells (e.g. *Biomphalaria*). According to the authors, in freshwater environments, the shells thickness could compromise the compositional fidelity of fossil associations when compared to dead or living associations. In the same sense, Tietze and De Francesco (2017) observed preservation differences in favor of *H. parchappii* when compared to *U. concentricus*, a thin shell species. In our results, no preservation changes were recorded between species, which could indicate that there is no preservation bias associated with shell thickness. Therefore, if taphonomic processes did not differentially affect the main species, it could be assumed that changes in diversity, abundance and dominance (of *H. parchappii*, *S. meridionalis* and *B. peregrina*) could be attributed mainly to extrinsic factors.

In the case of ostracods, dissolution did not differentially affect the species analyzed, but differences were observed when evaluating discoloration. In the Alberti Pla locality, the species affected were *L. cusminskyae*, *C. salebrosa* and *Hetocypris* sp., while in Ruta 30 they were *C. vidua*, *C. salebrosa* and *Illyocypris* sp. Regarding the analysis of this attribute, Palacios-Fest et al. (1994, 2021) proposed a scale of valves and carapace color alteration directly linked to changes in the oxygen concentration of the environment. Thus, the authors associate the dark remains (light to dark gray) to disoxic environments, the presence of light to dark orange stains to oxidizing environments, and the clear or white shells would be linked to well oxygenated environments. In this regard, it is important to note that, although our results showed intra-specific changes, all the samples analyzed consisted of translucent or white shells, with no dark or orange specimens. This result coincides with those found by Palacios-Fest et al. (2021) in freshwater environments, indicating clear and well oxygenated water environments, information that could be extrapolated in the reconstruction of the paleoenvironments developed in the Salado River Basin.

### 5.3. Changes in preservation over time

The preservation of the fossil remains in the different stratigraphic units of the profiles shows differences among them, both for gastropods and ostracods.

The taphonomically active zone (TAZ) is the sector in the stratigraphic sequence where taphonomic processes act more intensely (i.e. Davies et al., 1989; Sadler, 1993; Olszewski, 2004; Ritter and Erthal, 2011). The residence time of the fossils in this zone will determine that they can be modified, destroyed or even eliminated from the record. Generally, this zone is near the water-sediment interface, but Cristini and De Francesco (2017) reported that it may develop even below this interface.

The TAZ is a dynamic zone that changes over time and the processes that occur in it also, according to the deposition environments (Powell et al., 2011; Erthal et al., 2015). In freshwater environments where waters are usually undersaturated with respect to calcium carbonate, dissolution and color changes commonly occur (e.g. Brett and Baird, 1986; Nielsen et al., 2008; Powell et al., 2011; Erthal et al., 2011, 2015). Dissolution alters preservation of valves (Dwyer et al., 2002) and is more intense in freshwater fluvial than in marine environments (Erthal et al., 2015); it can be intensified by different processes that make the

carbonate remains more susceptible and fragile. For example, bacterial action can affect ostracod valves as soon as the organism dies, attacking the chitinous covering. In environments with a high percentage of organic matter, the waters can be slightly acidic and favor dissolution, which usually begins in the areas of pores where the ostracod valve is thinner (De Decker, 2002). Knowing that the dissolution is more active in the TAZ, this factor should be taken into account when analyzing the population structure of the ostracods that are in, or have crossed, this zone where the juvenile specimens, especially of the first stages more susceptible to dissolution, or those with thinner shells may be more affected and underrepresented (Kidwell and Bosence, 1991).

Our results indicate changes in the different stratigraphic units (Fig. 11). The gastropod specimens recovered from the Gorch Mb. (5130 ± 100–11,690 ± 110 <sup>14</sup>C years B.P.) showed less taphonomic alteration than those recovered from the Puente Las Gaviotas Mb. The low evidence of alteration in the specimens from the Gorch Mb., compared with others of minor age, could be explained by the low residence time in the TAZ at the moment of their accumulation (Olszewski, 2004). This may be due to the high sedimentation rates and/or the lack of rework that occurred after the accumulation of the assemblages, this is also consistent with the low fragmentation values obtained for the associations of this unit (Fig. 11). However, the few ostracod assemblages from Gorch Mb yielded slightly higher TTG values for dissolution.

Conversely, the gastropod specimens found in the Puente Las Gaviotas Mb. (3002 ± 40 and 680 ± 60 <sup>14</sup>C years B.P.) have the greater evidence of fragmentation, discoloration and dissolution, some of them would even be still undergoing denudation processes that alter their original color and could be subjected to more intense dissolution processes. Some of the causes that could explain this greater degree of modification could be a longer time of permanence of these associations in the TAZ, which would increase mainly the dissolution and discoloration and/or a greater degree of transport associated with the high values of TTG obtained for the fragmentation.

Finally, the remains found in the soil levels, near the surface, are recent accumulations that show little post-mortem modification. Discoloration and dissolution taphonomic attributes indicated the least evidence of alteration (the lowest TTG values) for assemblages of both groups in the soil.

It is important to note that the TTG values obtained for ostracods, both for discoloration and dissolution, are always lower than those obtained for gastropods found in the same stratigraphic unit. These differences could be due to a different time averaging or to a mixture of non-coetaneous populations; that is, the ostracod and gastropod associations recovered from the same level may not have accumulated at the same time; a more specific chronological control could help to resolve this question. In addition, the performance of laboratory taphonomic studies that evaluate, for example, the decay rates of ostracod and gastropod shells would allow us to analyze the rate at which dissolution affects the carbonatic fossils in these environments.

### 5.4. Ostracods as indicators of autochthonous and allochthonous associations

The A/J ratio and the identification of different ontogenetic stages in ostracods assemblages proved to be the best indicators to differentiate the thanatocoenosis of high and low energy that correspond to autochthonous or paraautochthonous assemblages from the taphocoenosis linked to allochthonous assemblages, as proposed by other authors (i.e. Whatley, 1988; Palacios-Fest et al., 1994, 2021; Wakefield, 1995; Arias, 1999; De Decker, 2002; Boomer et al., 2003; Coimbra et al., 2006; Palacios-Fest and Holliday, 2017). Those associations with adults and juveniles together are considered to be a thanatocoenosis, which are goods representative of the living communities from which they originated, with little or no transportation. Those associations with carapace and complete ranges of ontogenetic stages suggest low energy environments, where the transport capacity of the agent is lower and

preserves the molts of the smallest individuals, while in those with high energy, the valves and adult specimens prevail. On the contrary, taphocoenoses are allochthonous associations dominated by juvenile individuals, easily transported because of their small size and because they are much lighter. It is worth noting that certain anatomical characteristics of the shells (type of hinge, overlap of the valves), way of life and reproductive habits due to stability or environmental stress, can modify the adult-juvenile, valves-carapaces and male-female ratios in the analysis of population structure. Likewise, the presence of articulated carapaces have been interpreted as an indicator of unfavorable events, such as changes in the chemistry of the environment (anoxia, hypersalinity) or increases in temperature that can cause unexpected mortality, mainly in juvenile specimens. On the other hand, the presence of adult individuals may suggest a rapid burial that prevents the disarticulation of the valves (Whatley, 1988; Palacios-Fest et al., 1994; Wakefield, 1995; Arias, 1999; De Decker, 2002; Boomer et al., 2003).

Based upon the population characteristics of the ostracods, different types of associations have been reconstructed in this study:

- 1) Associations dominated by adult individuals ( $A/J < 1:8$ ): these were recorded mainly for *L. cusminskyae* and *C. vidua*, which are the most abundant species in the studied samples. These associations would be thanatocoenoses, i.e., autochthonous or paraautochthonous assemblages, and on the basis of presence/absence of the different ontogenetic stages whether they are of high or low energy can be defined. For example, low energy thanatocoenoses with a good record of all or most ontogenetic stages are mainly recorded in the upper levels of localities AP and R30. Whereas high energy thanatocoenoses with an incomplete record of ontogenetic stages, mainly with adult or advanced juvenile forms, are distributed along the profiles and mainly in the lower samples from all localities. Although these high-energy thanatocoenoses indicate some degree of flow transport or biological activity, they are still good for reconstructing environmental features.
- 2) Associations in which population structure were excellent ( $A/J 1:8$  to  $1:7$ ) or very good ( $1:6$  to  $1:3$ ): although less abundant, they are another example of low energy thanatocoenoses and would be representative of the environments in which they are found. For example this condition was recorded in samples from the basal levels of *C. vidua* and *L. cusminskyae* of R30 and VM, and in some upper samples of *Ilyocypris* sp. and *Heterocypris* sp. of R30.
- 3) Associations dominated by juveniles ( $A/J > 1:3$ ): these are mostly represented by *C. salebrosa*. These associations are considered taphocoenoses, specimens have been transported and hence are not good for environmental reconstructions because the species may be out of their natural context.
- 4) Finally, special cases are those associations in which carapace was dominant or the only preserved element. These are the least numerous associations and were mostly characterized by adult individuals of *C. vidua*. These levels would represent mass mortality events, probably due to the desiccation of the water bodies, which implies unfavorable conditions for the association, or a rapid burial of the individuals.

## 6. Conclusions

This work is one of first, where the taphonomic state of ostracods and gastropods assemblages are analyzed together in a fluvial environment.

In gastropods, the states of preservation of *Heleobia parhappii*, *Succinea meridionalis* and *Biomphalaria peregrina* (the most abundant species) were similar. The specimens of *Miradiscops brasiliensis* suffered the least damage (low TTG values), probably because they represent assemblages with little transport. In any case, this species' low abundance would not allow regional inferences to be made, but would help in the interpretation of local situations.

For the ostracods, the analysis of population structure through the

record of the different ontogenetic stages and the C/V ratio was the best indicator in the differentiation of high and low energy thanatocoenoses and taphocoenosis. In ostracods, the states of preservation vary between species, but the evidences of dissolution and discoloration obtained in this group is lower than for the gastropods recovered from the same levels. So, subsequent analyses are necessary to elucidate whether these particularities are due to the time averaging, or the ecological requirements of the species, or maybe intrinsic characteristic that influence the effect of the processes.

This analysis suggests that the study of fragmentation and population structure in gastropods and ostracods, respectively, allows differentiating autochthonous from allochthonous assemblages. On the other hand, to analyze color changes and dissolution contributes to location of the Taphonomic Active Zone in the profiles, and therefore to recognition of which are the associations with more propensity to undergo modifications in terms of their composition and structure, either due to the disappearance or underrepresentation of the least calcified species, the smallest or the juvenile specimens.

Although some questions remain open, we consider that to perform taphonomic and population structure analyzes are important for the future paleoenvironmental reconstructions based on these groups, which are the most abundant in the Holocene fluvial sequences of Buenos Aires Province of Argentina.

## CRedit authorship contribution statement

**Maria Florencia Pisano:** Formal analysis, Conceptualization, Funding acquisition, Investigation, Project administration, Visualization, Writing – original draft, Writing – review & editing, Methodology. **Gabriela Catalina Cusminsky:** Writing – review & editing, Conceptualization, Funding acquisition, Investigation, Writing – original draft. **Enrique Eduardo Y Fucks:** Writing – original draft, Investigation, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

This research was funded by the Agencia Nacional de Promoción Científica y Tecnológica, Argentina (BID PICT 2017-0491 and 2019-02408), the Universidad Nacional de La Plata (N 924) and the Universidad Nacional del Comahue (B04-237). We thank to Nicole Pommarés and Simon Fucks for their help in the field work and sampling; those people who allowed access to their farms to develop our fieldwork; and Silvia Ametrano, Marco Alvares and Adriana Blasi for lending us the microscopy equipment of the Mineralogy Division of the Museo de La Plata. We thank to Dr. Eduardo Macagno, Distinguished Professor of Biological Sciences from University of California San Diego, for advising us and correcting the English writing of this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jsames.2022.103806>.

## References

- Adams, K.R., Smith, S.J., Palacios-Fest, M.R., 2002. Pollen an microinvertebrates from modern earthen canals and other fluvial environments along the Middle Gila River, Central Arizona: implications for archaeological interpretation. *Gila River Indian Commun. Anthropol. Res. Pap.* 1, 1–76.
- Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth, UK, p. 218.

- Arias, C., 1999. Procesos de transporte en las asociaciones de Ostrácodos del Jurásico Inferior de la cordillera Ibérica, España. *Rev. Esp. Palaontol.* 14 (1), 1–11.
- Bernasconi, E., Cusminsky, G., Gordillo, S., 2019. Distribution of foraminifera from South Shetland islands (Antarctic): ecology and taphonomy. *Reg. Stud. Mar. Sci.* 29 <https://doi.org/10.1016/j.rsma.2019.100653>.
- Birks, H.J., 2010. Numerical methods for the analysis of diatom assemblage data. In: Smol, J.P., Stoermer, E.F. (Eds.), *The Diatoms: Applications for the Environmental and Earth Sciences*. Cambridge University Press, Cambridge, pp. 23–56.
- Birks, H.J.B., Heiri, O., Seppä, H., Björne, A.E., 2010. Strengths and weaknesses of quantitative climate reconstructions based on late-quaternary biological proxies. *Open Ecol. J.* 3, 68–11.
- Boomer, I., Horne, D.J., Slipper, L.J., 2003. The use of Ostracods in paleoenvironmental studies, or what can you do with an ostracod shells. *Paleontol. Soc. Pap.* 9, 153–180.
- Borromei, A.M., Candel, M.S., Musotto, L.L., Cusminsky, G.C., Martínez, M.A., Coviaga, C.A., Ponce, J.F., Coronato, A.M.J., 2018. Late Holocene wet/dry intervals from Fuegian steppe at Laguna Carmen, southern Argentina, based on a multiproxy record. *Paleogeogr. Palaeoclimatol. Palaeoecol.* 499, 56–71. <https://doi.org/10.1016/j.palaeo.2018.03.008>.
- Brandt, D.S., 1986. Taphonomic grades as a classification for fossiliferous assemblages and implications for paleoecology. *Palaios* 4, 303–309.
- Brett, C.E., Baird, G.C., 1986. Comparative taphonomy: a key to paleoenvironmental interpretation based on fossil preservation. *Palaios* 1, 207–227.
- Brown, M.M., Kowalewski, M., Neves, R., Cherry, D., Schreiber, M., 2005. Freshwater Mussel shells as environmental chronicles: geochemical and taphonomic signatures of mercury-related extirpations in the North Fork Holston River, Virginia. *Environ. Sci. Technol.* 39 (6), 1455–1462. <https://doi.org/10.1021/es048573p>.
- Bullard, E.M., Yanes, Y., Miller, A.I., 2017. Compositional variability of Pleistocene land snail assemblages preserved in a cinder cone volcano from Tenerife, Canary Islands. *Paleogeogr. Palaeoclimatol. Palaeoecol.* 417, 196–208. <https://doi.org/10.1016/j.palaeo.2017.02.001>.
- Calvo Marcielse, L., D'Ambrosio, D. S., Rojo, L. D., Cusminsky, G. C., 2019. New Micropaleontological Record (Foraminifera and Ostracoda) from the Late Glacial and Holocene in Salinas del Bebedero, Luis, Argentina: A Paleoenvironmental Interpretation. In: G. C. Cusminsky et al. (eds.), *Advances in South American Micropaleontology*, Springer Earth System Sciences 142–158.
- Castellanos, Z.A., Fernández, D., 1976. Mollusca, gasteropoda, Ampullariidae. In: *Fauna de agua dulce de la República Argentina*, Buenos Aires, vol. 15, pp. 5–33 (1).
- Castellanos, Z.A., Landini, N., 1981. La Familia Lymnaeidae en la República Argentina. In: *Fauna de agua dulce de la República Argentina*, Buenos Aires, vol. 15, pp. 55–82 (5).
- Cohen, A.S., 1989. The taphonomy of gastropod shells accumulations in large lakes: an example from Lake Tanganyika, Africa. *Paleobiology* 15 (1), 26–45.
- Coimbra, J.C., Badaraco Costa, K., Fauth, G., 2006. Paleoenvironmental significance of allochthonous vs. autochthonous late quaternary ostracodes from Imaruf lagoon and D'una river, southern Brazil. *Rev. Bras. Palaontol.* 9 (3), 295–302.
- Coviaga, C., Cusminsky, G., Bacallá, N., Pérez, P., 2015. Dynamics of ostracod populations from shallow lakes of Patagonia: life history. *J. Nat. Hist.* 49 (17–18), 1023–1045. <https://doi.org/10.1080/00222933.2014.981310>.
- Coviaga, C., Rizzo, A., Pérez, P., Daga, R., Poire, D., Cusminsky, G., Ribeiro Guevara, S., 2017. Reconstruction of the hydrological history of a shallow Patagonian steppe lake during the last 700 yr: using chemical, geological and biological proxies. *Quat. Res.* 87, 208–226. <https://doi.org/10.1017/qua.2016.19>.
- Cristini, P.A., De Francesco, C.G., 2017. Molluscan taphonomic patterns below the sediment-water interface in freshwater shallow lakes from the southeastern Pampa plain, Argentina. *Palaios* 32, 528–542. <https://doi.org/10.2110/palo.2016.081>.
- Danielopol, D.L., Baltan, A., Namioito, T., Geiger, W., Pichler, M., Reina, M., Roidmayr, G., 2008. Developmental trajectories in geographically separated populations of non-marine ostracods: morphometric applications for palaeoecological studies. *Senckenberg. Lethaea* 88 (1), 183–193.
- Davies, D.J., Powell, E.N., Stanton Jr., R.J., 1989. Taphonomic signature as a function of environmental process: shells and shell beds in a hurricane influenced inlet on the Texas coast. *Paleogeogr. Palaeoclimatol. Palaeoecol.* 27, 317–356.
- De Decker, P., 1988. An account of the techniques using ostracodes in paleolimnology in Australia. *Paleogeogr., Palaeoclimatol. Palaeoecol.* 62, 463–475.
- De Decker, P., 2002. Ostracod palaeoecology. In: *The Ostracoda: Applications in Quaternary Research Geophysical Monograph*, p. 131.
- De Francesco, C.G., Tietze, E., Cristini, A.P., 2013. Mollusk successions of Holocene shallow-lake deposits from the southeastern Pampa plain, Argentina. *Palaios* 28, 851–862. <https://doi.org/10.2110/palo.2013.100>.
- Dillon Jr., R.T., 2004. *The Ecology of Freshwater Molluscs*. Cambridge University Press, Cambridge, United Kingdom, p. 499.
- Dwyer, G., Cronin, T., Baker, P., 2002. Trace elements in marine ostracodes. In: *The Ostracoda: Applications in Quaternary Research Geophysical Monograph*, p. 131.
- Erthal, F., Kotzian, C.B., Simões, M.G., 2011. Fidelity of molluscan assemblages from the Touro Passo Formation (Pleistocene-Holocene), Southern Brazil: taphonomy as a tool for discovering natural baselines for freshwater communities. *Palaios* 26, 433–446. <https://doi.org/10.2110/palo.2010.p10-145r>.
- Erthal, F., Kotzian, C.B., Simões, M.G., 2015. Multistep taphonomic alterations in fluvial mollusk shells: a case study in the Touro Passo formation (Pleistocene-Holocene), southern Brazil. *Palaios* 30, 388–402. <https://doi.org/10.2110/palo.2013.104>.
- Ferrero, L., 2009. Foraminíferos y ostrácodos del Pleistoceno tardío (Mar Chiquita, provincia de Buenos Aires, Argentina). *Ameghiniana* 46 (4), 637–656.
- Fucks, E., Pisano, F., Carbonari, J., Huarte, R., 2011. Aspectos geomorfológicos del sector medio e inferior de la Pampa Deprimida, provincia de Buenos Aires. *Rev. Soc. Geol. Espana* 25 (1–2), 107–118.
- Fucks, E., Pisano, M.F., Huarte, R., Di Lello, C.V., Mari, F., Carbonari, J., 2015. Stratigraphy of the fluvial deposits of the Salado River basin, Buenos Aires province: lithology, chronology and paleoclimatology. *J. S. Am. Earth Sci.* 60, 129–139. <https://doi.org/10.1016/j.jsames.2015.03.007>.
- Hassan, G.S., Tietze, E., Cristini, P.A., De Francesco, C.G., 2014. Differential preservation of freshwater Diatoms and Mollusks in Late Holocene sediments: paleoenvironmental implications. *Palaios* 29, 612–623. <https://doi.org/10.2110/palo.2014.016>.
- Hauser, I., Oschmann, W., Gischler, E., 2008. Taphonomic signatures on modern caribbean bivalve shells as indicators of environmental conditions (Belize, Central America). *Palaios* 23. <https://doi.org/10.2110/palo.2007.p07-075r>, 586–60.
- Ilari, M.I., Souza, A.T., Amorim, L., Sousa, R., 2019. Decay and persistence of empty bivalve shells in a temperate riverine system. *Sci. Total Environ.* 683, 185–192. <https://doi.org/10.1016/j.scitotenv.2019.05.208> 0048-9697.
- Juggins, S., 2012. *Rioja: Analysis of Quaternary Science Data, R Package Version (0.8-4)*. Checked March 2020. <http://cran.r-project.org/package=rioja>.
- Kidwell, S.M., Bosench, D.W.J., 1991. Taphonomy and time averaging of marine shelly faunas. In: Allison y Briggs, P.A. D.E.G. (Ed.), *Taphonomy: Releasing the Data Locked in the Fossil Record*, Volume 9 of Topics in Geobiology. Plenum Press, New York, pp. 115–209.
- Kotzian, C.B., Simões, M.G., 2006. Taphonomy of recent freshwater molluscan death assemblages, Touro Passo stream, southern Brazil. *Rev. Bras. Palaontol.* 9 (2), 243–260. <https://doi.org/10.4072/rbp.2006.2.08>.
- Kowalewski, M., Flessa, K.W., 1995. Taponomía comparativa y composición faunística de cheniens de conchas del noreste de baja California, México. *Cienc. Mar.* 21 (2), 155–177.
- Kowalewski, M., Flessa, K.W., Hallman, D.P., 1995. Ternary taphograms: triangular diagrams applied to taphonomic analysis. *Palaios* 10, 478–483. <https://doi.org/10.2307/3515049>.
- Kusnerik, K.M., Means, G.H., Portell, R.W., Brenner, M., Hua, Q., Kannai, A., Means, R., Monroe, M.A., Kowalewski, M., 2020. Live, dead, and fossil mollusks in Florida freshwater springs and spring-fed rivers: taphonomic pathways and the formation of multisourced, time-averaged death assemblages. *Paleobiology* 1–23. <https://doi.org/10.1017/pab.2020.25>.
- Laprida, C., 2006. Ostrácodos recientes de la llanura pampeana, Buenos Aires, Argentina: ecología e implicancias paleolimnológicas. *Ameghiniana* 43 (1), 181–204.
- Laprida, C., Bertels-Psotka, A., 2003. Benthic foraminifers and paleoecology of a Holocene shelly concentration, Salado Basin, Argentina. *Geobios* 36 (5), 559–572. [https://doi.org/10.1016/S0016-6995\(03\)00061-5](https://doi.org/10.1016/S0016-6995(03)00061-5).
- Laprida, C., Díaz, A., Ratto, N., 2006. Ostracods (Crustacea) from thermal waters, southern Altiplano, Argentina. *Micropaleontology* 52 (2), 177–188.
- Laprida, C., Plastani, M.S., Irurzun, M.A., Gogorza, C.S., Navas, A., Valero Garces, B., Sinito, A.M., 2014. Mid-Late Holocene climate and trophic states in a shallow lake from the Southern Pampa Plain, Argentina. *J. Limnol.* 73 (2), 325–339 [dx.doi.org/10.4081/jlimnol.2014.830](https://doi.org/10.4081/jlimnol.2014.830).
- Mari, F., Fucks, E., Pisano, F., Huarte, R., Carbonari, J., 2013. Cronología radiocarbónica en paleoambientes del Pleistoceno tardío y Holoceno de la Pampa Deprimida, provincia de Buenos Aires. *Rev. Museo La Plata, Sec. Antropol.* 13 (87), 51–58.
- Márquez, M., Ferrero, L.D., Cusminsky, G.C., 2016. Holocene paleoenvironmental evolution of the Pampa coastal plain (Argentina) based on calcareous microfossils. *Rev. Bras. Palaontol.* 19, 25–40. <https://doi.org/10.4072/rbp.2016.1.03>.
- Martello, A.R., Kotzian, C.B., Simões, M.G., 2006. Quantitative fidelity of recent freshwater mollusk assemblages from the Touro Passo river, Rio Grande do Sul, Brazil. *Iheringia* 96 (4), 453–465.
- Martello, A.R., Kotzian, C.B., Simões, M.G., 2017. The role of topography, river size and riverbed grain size on the preservation of riverine mollusk shells. *J. Paleolimnol.* 59 (3), 309–327. <https://doi.org/10.1007/s10933-017-0010-z>.
- Martin, R.E., Wehmiller, J.F., Scott Harris, M., Liddell, W.D., 1996. Comparative taphonomy of bivalves and foraminifera from Holocene tidal flat sediments, Bahía la Choya, Sonora, Mexico (Northern Gulf of California): taphonomic grades and temporal resolution. *Paleobiology* 22 (1), 80–90.
- Mezquita, F., Roca, J.R., Reed, J.M., Wansard, G., 2005. Quantifying species environment relationships in non-marine Ostracoda for ecological and paleoecological studies: examples using Iberian data. *Paleogeogr., Palaeoclimatol. Palaeoecol.* 225, 93–117.
- Nielsen, J.K., Helama, S., Nielsen, J.K., 2008. Taphonomy of freshwater molluscs in carbonate-poor deposits: a case study of the river pearl mussel in northeastern Finnish Lapland. *Norw. J. Geol.* 88, 103–116.
- Olszewski, T.D., 2004. Modeling the influence of taphonomic destruction, reworking, and burial on time-averaging in fossil accumulations. *Palaios* 19, 39–50.
- Oksanen, J., Blanchet, G., Kindt, R., Legendre, P., Minchin, P.R., O'hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.R.H., Wagner, H., 2011. *Vegan: Community Ecology Package*. R Package Version 2.01. World Wide Web. Checked March 2020. <http://CRAN.R-project.org/package=vegan>.
- Palacios-Fest, M., 2017. Preliminary report: microinvertebrates and gyrogonites from lake Cahuilla, California. In: Moratotto, M., Mc Dougall, D.D. (Eds.), *Data Recovery at Prehistoric Site CA-RIV-6896/6897 (33-011573/33-011574)*.
- Palacios-Fest, M., Holliday, V., 2017. Paleoecology of a ciénaga at the mockingbird gap site, Chupadera Draw, New Mexico. *Quat. Res.* 1, 15. <https://doi.org/10.1017/qua.2017.82>.
- Palacios-Fest, M.R., Cohen, A.S., Anadón, P., 1994. Use of Ostracods as Paleoenvironmental tools in the interpretations of ancient lacustrine records. *Rev. Esp. Palaontol.* 9 (2), 145–164.
- Palacios-Fest, M.R., Cusminsky, G.C., McGlue, M.M., 2016. Late quaternary lacustrine ostracods (ostracoda, Crustacea) and charophytes (Charophyta, Charales) from the Puna plateau, Argentina. *J. Micropaleontology* 35 (1) <https://doi.org/10.1144/jmpaleo2015-012>, 2015 – 2012.

- Palacios-Fest, M.R., Duke, D., Young, D.C., Kirk, J.D., Oviatt, C.G., 2021. A paleo-lake and wetland paleoecology associated with human use of the distal old river bed delta at the pleistocene-holocene transition in the Bonneville basin, Utah, USA. *Quat. Res.* 1–19. <https://doi.org/10.1017/qua.2021.49>.
- Palacios-Fest, M.R., Homburg, J.A., Brevik, E.C., Orme, A.R., Davis, O.K., Shelley, S.D., 2006. Paleocología del Cuaternario Tardío en la Laguna de Ballona en el sur de California. *Cienc. Mar.* 32 (3), 485–504.
- Park, L.E., Cohen, A.S., Martens, K., Bralek, R., 2003. The impact of taphonomic processes on interpreting paleoecologic changes in large lake ecosystems: ostracodes in Lakes Tanganyika and Malawi. *J. Paleolimnol.* 30, 127–138.
- Parras, A., Guerstein, G., Pérez Panera, J.P., Griffin, M., Nández, C., Cusminsky, G., Quiroga, A., 2020. Integrated stratigraphy and paleontology of the early Miocene Monte León formation, Austral/Magallanes basin, southeastern Patagonia, Argentina palaeogeography, palaeoclimatology. *Palaeoecology* 556, 1–22. <https://doi.org/10.1016/j.palaeo.2020.109701>.
- Parsons-Hubbard, K., 2005. Molluscan taphofacies in recent carbonate reef/lagoon systems and their application to sub-fossil samples from reef cores. *Palaios* 20, 175–191. <https://doi.org/10.2210/palo.2003.p03-105>.
- Pisano, M.F., Fucks, E.E., 2016. Quaternary mollusc assemblages from the lower basin of Salado River, Buenos Aires Province: their use as paleoenvironmental indicators. *Quat. Int.* 391, 100–111. [doi.org/10.1016/j.quaint.2015.07.022](https://doi.org/10.1016/j.quaint.2015.07.022).
- Pisano, M.F., De Francesco, C.G., Fucks, E.E., 2015. Taphonomic signatures in concentrations of *Heleobia* Stimpson, 1865 from Holocene deposits of the Salado River basin, Buenos Aires, Argentina: their utility in paleoenvironment reconstructions. *Palaios* 30, 248–257. <https://doi.org/10.2110/palo.2014.034>.
- Pisano, M.F., Pommáres, N.N., Luengo, M.S., Fucks, E.E., 2018. Comparative taphonomy of mollusk assemblages in Quaternary freshwater sequences from the Salado River basin, Buenos Aires. *Ameghiniana* 55, 197–209. <https://doi.org/10.5710/AMGH.28.11.2017.3139>.
- Pommarés, N.N., Fucks, E.E., Pisano, M.F., Luengo, M.S., Ramos, N.A., Di Lello, C.V., 2021. Late pleistocene-holocene paleoenvironments in the middle basin of the Salado River, province of Buenos Aires, Argentina. *J. S. Am. Earth Sci.* 105. <https://doi.org/10.1016/j.jsames.2020.103001>.
- Powell, E.N., Staff, G.M., Callender, W.R., Ashton-Alcox, K.A., Brett, C.E., Parsons-Hubbard, K.M., Walker, S.E., Raymond, A., 2011. Taphonomic degradation of molluscan remains during thirteen years on the continental shelf and slope of the northwestern Gulf of Mexico. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 312, 209–232.
- Prieto, A.R., Romero, M.V., Vilanova, I., Bettis, E.A., Espinosa, M.A., Haj, A.E., Gómez y, L., Bruno, L.I., 2014. A multi-proxy study of Holocene environmental change recorded in alluvial deposits along the southern coast of the Pampa region, Argentina. *J. Quat. Sci.* 29 (4), 329–342.
- R CORE TEAM, 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Checked March 2020. <http://www.R-project.org/>.
- Ramos, N.A., Carignano, A.P., Cusminsky, G.C., Fucks, E., 2019. Calcareous microfossils (ostracoda and foraminifera) from the Holocene (MIS 1) at the Salado Basin (Arroyo san Miguel site, Pila, Buenos Aires province, Argentina). In: *Advances in South American Micropaleontology*. Springer, pp. 159–174.
- Ritter, M.N., Erthal, F., 2011. Zona tafonomicamente ativa em ambiente estuarino lagunar com base em moluscos da planície costeira do Rio Grande do Sul, Brasil. In: Carvalho, I.S., Srivastava, N.K., Strohschoen Jr., O., Lana, C.C., Orgs (Eds.), *Paleontologia, Cenários da Vida*, vol. 4. Interciência, pp. 355–365.
- Rodrigues, S.C., Simões, M.G., Pires-Domingues, R.A., 2009. Viés analítico em estudos tafonômicos com macroinvertebrados: implicações (paleo)ambientais e (paleo) ecológicas. *Geol. Usp. Série Científica* 9, 101–114.
- Rothfús, T.A., 2004. How many taphonomists spoil the data? Multiple operators in taphofacies studies. *Palaios* 19, 514–519. 0883-1351/04/0019-0514.
- Ruiz, F., Abad, M., Bodergat, A.M., Carbonel, P., Rodríguez Lázaro, J., González Regalado, M.L., García, E.X., Prend, J., 2013. Freshwater ostracods as environmental tracers. *Int. J. Environ. Sci. Technol.* 10, 1115–1128. <https://doi.org/10.1007/s13762-013-0249-5>.
- Rumi, A., 1991. La familia Planorbidae Rafinesque, 1815, en la República Argentina. In: En Ringuet, R. (Ed.), *Fauna de agua dulce de la Repúbli Argent.* 15 (8), 5–51.
- Sadler, P.M., 1993. Models of time-averaging as a maturation process: how soon do sedimentary sections escape reworking? In: Kidwell, S.M., Behrensmeier, A.K. (Eds.), *Taphonomic Approaches to Time Resolution in Fossil Assemblages. Short Courses in Paleontology No. 6*. Paleontological Society, Knoxville, pp. 188–209.
- Sayer, C., Roberts, N., Sadler, J., David, C., Wade, P.M., 1999. Biodiversity changes in a shallow lake ecosystem: a multi-proxy palaeolimnological analysis. *J. Biogeogr.* 26 (1), 97–114.
- Scanferla, A., Bonini, R., Pomi, L., Fucks, E., Molinari, A., 2013. New Late Pleistocene megafaunal assemblage with well-supported chronology from the Pampas of southern South America. *Quat. Int.* 307, 97–161.
- Steffan, P.G., Aguirre, M.L., Miquel, S.E., 2014. Malacofauna continental holocena (Región pampeana, Argentina). *Rev. Bras. de Paleontol.* 17 (2), 225–248. <https://doi.org/10.4072/rbp.2014.2.09>.
- Tietze, E., De Francesco, C.G., 2010. Environmental significance of freshwater mollusks in the Southern Pampas, Argentina: to what detail can local environments be inferred from mollusk composition? *Hydrobiologia* 641, 133–143. <https://doi.org/10.1007/s10750-009-0072-7>.
- Tietze, E., De Francesco, C.G., 2012. Compositional fidelity of subfossil Mollusk assemblages in streams and lakes of the southeastern Pampas, Argentina. *Palaios* 27, 401–413. <https://doi.org/10.2110/palo.2011.p11-124r>.
- Tietze, E., De Francesco, C.G., 2017. Compositional fidelity and taphonomy of Freshwater mollusks from three Pampean shallow lakes of Argentina. *Ameghiniana* 54, 208–223. <https://doi.org/10.5710/AMGH.18.10.2016.3022>.
- Tomassini, R.L., Montalvo, C.I., 2013. Taphonomic modes on fluvial deposits of the Monte Hermoso formation (early pliocene), Buenos Aires province, Argentina. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 369, 282–294. <https://doi.org/10.1016/j.palaeo.2012.10.035>.
- Wakefield, M.I., 1995. Ostracod biostratigraphy at lagoonal shorelines: examples from the great estuarine group, middle Jurassic, Scotland. *Proc. Geol. Assoc.* 106, 211–218.
- Whitley, R.C., 1983. The application of Ostracoda to palaeoenvironmental analysis. In: Maddocks, R.F. (Ed.), *Applications of Ostracoda*. University of Houston, pp. 51–77.
- Whitley, R., 1988. Population structure of ostracods: some general principles for the recognition of palaeoenvironments. In: De Deckker, P., Colin, J.P., Peypouquet, J.P. (Eds.), *Ostracoda in the Earth Sciences*. Elsevier, Amsterdam, pp. 245–256.