PROMETHEUS PRESS/PALAEONTOLOGICAL NETWORK FOUNDATION (TERUEL)

Journal of Taphonomy

2017 *Available online at www.journaltaphonoy.com*

VOLUME 15 (ISSUE 1-3)

# The Effects of Bioturbation by Earthworms. Preliminary Results of an Actualistic Taphonomy Experiment

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*Journal of Taphonomy 15 (1-3) (2017), 11-27.*

*Manuscript received 5 May 2017, revised manuscript accepted 29 June 2017.*

The Salado River Depression was inhabited during the Late Holocene (2400-400 $^{14}$C YBP) by pottery-maker societies with a hunting-gathering-fishing lifeway. The archaeological remains are deposited in the A horizon of the modern soil, which constitutes a “biomantle” as pedogenetic formation processes predominate. These include an intense biological activity produced by the action of roots and edaphic fauna that promote displacements of objects and their sinking to different depths. Hence the archaeological sites of this microregion are shallow. In order to broaden the knowledge about the action of earthworms in these sites, an actualistic taphonomy experiment was designed. The goal was to observe the activity of these invertebrates and to evaluate their possible incidence as a disturbing agent on small bones deposited on a soil. The aim of this paper is to introduce the methodological design of this experimentation and present the preliminary results. For this purpose, two containers with sediment containing humus and earthworms were placed in the open air. Some selected bones of *Dasypus hybridus* and *Gallus gallus* were deposited in each container. The activity of earthworms was observed along one year with a weekly record and was detected as deep as 16 cm. Other features associated –such as burrows– were documented, especially in autumn and winter. No modifications were identified on bone cortical surfaces, though vertical movement of some elements through the sediment is highlighted.

***Keywords:*** EXPERIMENTAL TAPHONOMY, FORMATION PROCESSES, BIOTURBATION, BIOMANTLE, SALADO RIVER DEPRESSION.

## Introduction

Towards the end of the last century, Marean (1995) emphasized the exponential increase of taphonomic studies within the zooarchaeological framework. This tendency was also shown in the southern Neotropics, where taphonomic observations multiplied during the last decades (Cruz, 2011). Therefore, actualistic taphonomy (both naturalistic and experimental) contributed to the construction of a worldwide theoretical *corpus* from which interpretations of the history of bone assemblages will be more successful (Lyman, 2008).



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As emphasised by Fernández-Jalvo & Andrews (2016), actualistic studies that include the monitoring of animal remains over different periods and throughout different types of landscape and/or climate are of great importance. Nevertheless, the experimentations that specialise in large mammals prevail whereas the long-term observations with small vertebrates imply greater difficulties. These authors also consider the need to continue exploring the modifications generated by insects and the dispersal of bone elements caused by earthworms through laboratory experiments, being the work of Armour-Chelu and Andrews (1994) a good precedent.

Also, as Canti (2003) stands out, archaeologists must understand the consequences of earthworm activity as an integral component of the earth surface processes that affect site interpretation. In this sense, the analysis presented here aims to continue with one of these lines of research that has not been fully developed yet.

In order to broaden the knowledge about the action of earthworms, an actualistic taphonomy experiment was set. Here, the methodological design of this experimentation is introduced and the results obtained so far are presented. This study was motivated by the *in situ* observations during fieldwork in the archaeological sites of the Salado River Depression of earthworms and some of their associated features: casts, cairns, cocoons and burrows. Therefore, the information derived from this study –framed in the actualistic experimental taphonomy (*sensu* Marean, 1995)– can serve as a tool to generate material expectations about the consequences of the activity of earthworms in soils containing archaeological material. Specifically, these expectations refer to the displacement of remains (considering type of material, size and shape), the depth of these movements and the seasonality of earthworm activity, among others.

## Background

### *The study area*

The Salado River Depression covers the area crossed by the lower course of the river, which runs through part of the province of Buenos Aires (Argentina) (Figure 1). It is located in the Pampa Ecoregion (see Brown *et al.*, 2006), characterised by a relatively flat relief with a gentle slope towards the Atlantic Ocean.

The climate is temperate and humid, summer is warm and the driest season is winter. Precipitation does not have a stable regime and there are usually interannual drought and flood cycles (Quirós, 2005). Within the Humid Pampa subregion, annual precipitation increases in an east-west direction, with the highest precipitation in the northeast –more than 900 mm– and the lowest in the southwest –less than 500 mm (Burgos & Vidal, 1951; González, 2005; Quirós, 2005). The average temperature for the area under analysis during the registered period will be provided with more detail in the "Results" section.

During the late Holocene, human societies inhabited this microregion between 2400 and 400 $^{14}$C YBP. Archaeological contexts showed a varied repertoire of technological and subsistence remains. Based on the use of resources, settlement pattern and technology, these people have been defined as *hunter-gatherer-fishers and potters* (González, 2005).

So far, thirty-seven archaeological sites have been identified (González, 2005;

Escosteguy *et al.*, 2015; Frère, 2015). All of them are open-air sites repeatedly occupied by groups of hunter-gatherer-fishers with low mobility and an intensive use of local resources. These sites are located on high mounds in open-air, temperate environments on the lower course of the Salado River and its adjacent lakes and ponds (Frére *et al.*, 2016). The recovered archaeofaunal remains belong to animals of different species and varying sizes that were hunted in the area. Two species of *Cervidae* (*Blastocerus dichotomus* and *Ozotoceros bezoarticus*) were among the big game, while the record of small and middle sized vertebrates include mainly rodents, fish and, to a lesser extent, birds and armadillos (Salemme *et al.,* 2012; Escosteguy *et al.*, 2015).

*Site formation processes in the Salado River Microregion*

The archaeological record, though buried, is not static since the sediment containing the remains is constantly in motion due to a variety of postdepositional processes that archaeologists must recognize before making any inference about the human behaviours that produced the observed pattern (Wood & Johnson, 1978; Schiffer, 1987; Waters, 1992).

The combination of fluvial and aeolian processes in the microregion has resulted in the formation of dunes and loessic sediments composed of sand, silt and clays (Dangavs *et al.*, 1983; González de Bonaveri & Zárate, 1993-1994). The characteristic alternation of dry and wet periods in the Humid Pampa subregion caused the formation of cracks. These conditions have produced soils with a dynamic characterized by the recurrent incorporation, transformation and translocation of organic and clastic material in the profiles; thus altering the original space-time relationships and reorganizing the materials. Therefore, the small fragments (including the archaeological ones) were incorporated into the A horizon and later recovered several centimeters deep (González de Bonaveri & Zárate, 1993-1994; Zárate *et al.*, 2000-2002). In addition, the intense biological activity produced by the action of roots and edaphic fauna is an active process observed in these profiles (Zárate *et al.*, 2000-2002; González, 2005). This small fauna, especially the invertebrates, can induce important modifications in the archaeological record, burying and/or displacing material remains (Balek, 2002).

The continuous bioturbation, in addition to the physical processes previously explained, created a distinctive zone in the A horizon of the modern soil –approximately the first thirty centimetres– referred to as “biomantle” by Johnson (1990). Due to this pedogenetic dynamics, the sites of the study area show a low stratigraphic resolution; thus, they cannot be considered stratigraphic or sealed as defined by Butzer (1982). However, it is not appropriate to call them “surface sites” because the material is not exposed to subaerial conditions (Frère *et al.*, 2016). Therefore, those sites in which material is located a few centimetres deep are known as “shallow archaeological sites” (Zárate *et al.*, 2000-2002).

Earthworms are important bioturbation agents, since they continuously mix and displace particles, including artefacts, while burrowing. Because of their activity, larger objects are displaced downward and smaller ones upward (Balek, 2002). This can largely modify the context by displacing and burying these materials and creating a subsurface accumulation zone (a “stone line” or “artefact line”) that can be mistaken for a cultural feature (Canti, 2003; Favier Dubois, 2008, 2009). This has been observed in La Guillerma archaeological locality, where earthworm activity is evident as burrows are clearly visible through soil profiles (González de Bonaveri & Zárate, 1993-1994); being this a distinctive biofabric feature in worm-worked biomantles (Peacock & Fant, 2002). Besides, many earthworms and cocoons (earthworm eggs) appeared during excavations; and casts and cairns were spotted the day after cleaning up the work area.

*Biology and ethology of earthworms and previous observations*

Earthworms are invertebrates that, following Mischis (2000), belong to the phylum Annelida, class Oligochaeta, order Haplotaxida and suborder Lumbricina. They encompass several families with varied distributions and origins. Among these, five have been recognized in Buenos Aires province: two of them, Megascolecidae and Lumbricidae, are non-native but widely distributed in Argentina and have displaced most of the native species. Today, the genre *Microscolex* (Acanthodrilidae family) is the only autochthonous that remains in Buenos Aires province (Mischis, 2007). The allochthonous species may have been introduced into the province by colonizers around 1700 AD and were unintentionally dispersed to the rest of the country, mainly through the action of horticulturalists, floriculturists and fishers (Momo & Falco, 2003; Falco *et al.*, 2007). So far, the knowledge of earthworm species and their ethology in Argentina is incomplete; so it is probable that new taxa may be revealed by future analyses (Mischis, 2007).

These tube-shaped and segmented worms are among the largest soil invertebrates. They live in the soil, eat almost all forms of organic matter as they burrow, breathe through their skin and are light sensitive through photoreceptors (Momo & Falco, 2003). Biologists group the species into three categories, following Bouché (1977 in Momo & Falco, 2003): the epigeic species live in the leaf litter layer; the anecic species are deep vertical burrowers and go to the surface to eat; and the endogeic species are horizontal burrowers, live in the subsurface and are geophagus. However, not all species can be ascribed to any of those categories as the classification system defines behaviour tendencies (Canti, 2003). No true anecic species have been identified in Argentina yet, but some have been classified into a mixed endo -anecic category (Momo & Falco, 2003).

Another distinction between surface and subsurface-casting species has been made. The former deposit their casts only on the soil surface, while the latter leave their casts underground in soil crevices (Stein, 1983; Yeates & Van der Meulen, 1995). For instance, Stein (1983) describes *Lumbricus terrestris* as casting only around its burrow openings, while *Aporrectodea trapezoides* casts below ground. Canti (2003) states that some species (like *Aporrectodea rosea, Allolobophora chlorotica* and *Eisenia andrei*) sometimes cast on the surface, so a specific behavioural distinction cannot be made. Nonetheless, this behavioural difference has notorious consequences. On the one hand, surface-casting earthworms bring up great quantities of sediment, burying materials that were originally on top and displacing some stratigraphic finds in the process; on the other, subsurface-casting implies mixing the soil matrix –going around finds– and prevents burial of objects (Stein, 1983; Canti, 2003).

By the end of nineteenth century, Darwin had already recognized the role of earthworm activity in pedogenetic processes, humus formation, burying of objects and structures through burrowing and casting, among others. He even performed a series of experiments that could be considered "actualistic" (Darwin, 1881). In this sense, though not using those terms, he wrote one of the first records on bioturbation and biomantle formation studies (Feller *et al.*, 2003; Johnson & Schaetzl, 2015).

Nowadays, several studies have proved that certain earthworm species indirectly displace small mammalian bones at considerable distances, both horizontally and vertically, causing them to mix with bones of other strata (Stein, 1983; Yeates & Van der Meulen, 1995; Canti, 2003, 2009; Favier Dubois, 2009). *L. terrestris*, an anecic European species, is the most thoroughly studied and is known to draw objects into the mouth of its burrow. During the colder months, they tend to reduce their activity and go deeper into the soil (Stein, 1983). In an experiment, similar in methodology and duration to the one presented here, Armour-Chelu & Andrews (1994) observed that earthworms may even break or abrade bones, and that other small objects are also likely to be moved in the same way.

## Materials and methods

In April 2016 two transparent containers of 36 litters of capacity and 34 cm of depth were placed in the open air in Ezeiza district, north-eastern area of Buenos Aires province (Figure 1). Five symmetrically arranged holes were drilled in the two larger sides of each container and three more holes in their bases; then, a 1 cm thick sand layer was placed at the bottom. This was done to ensure proper air circulation and water drainage, both necessary for the survival of the earthworms, following the suggestions made by the agronomists Pedro Rizzo and Nicolas Riera of the "Instituto Nacional de Tecnología Agropecuaria (INTA), Castelar Section". Then, the containers were filled with sediment extracted from a location close to the research area –containing humus (organic matter in decomposition process) and earthworms–, up to 5 cm from the top.

More earthworms were introduced and bone remains of an armadillo (*Dasypus hybridus*) and a bird (*Gallus gallus*) were placed on the surface of Container 1 and Container 2, respectively. Those species were chosen because the most abundant remains in the archaeological record of the area are of small and middle-sized animals. The armadillo was captured and eviscerated, while the bird was got at the butchery. Their carcasses were boiled, carefully butchered (in order not to fracture or leave marks on the bones) and served as a meal. After the consumption process, the following body portions were recovered and used for the experiment: head, scapular region, part of the ribcage, pelvic region, front and rear limbs and tail of *D. hybridus* (in Container 1; Figure 2C); and the thorax, parts of the spine, wing, leg and pelvic region (left side) of *G. gallus* (Figure 2D). The filling was completed with a vegetation layer. As earthworms are photosensitive, the containers were covered with dark nylon to prevent sunlight. This sequence is illustrated in Figure 2.

During the elapsed time of the experiment, the presence/absence of earthworms, their associated features (*e.g.,* burrows) and bone remains, either on the surface of the sediment or visible through the transparent sides, were weekly recorded. When no activity was observed or dead specimens were detected, new ones were added.

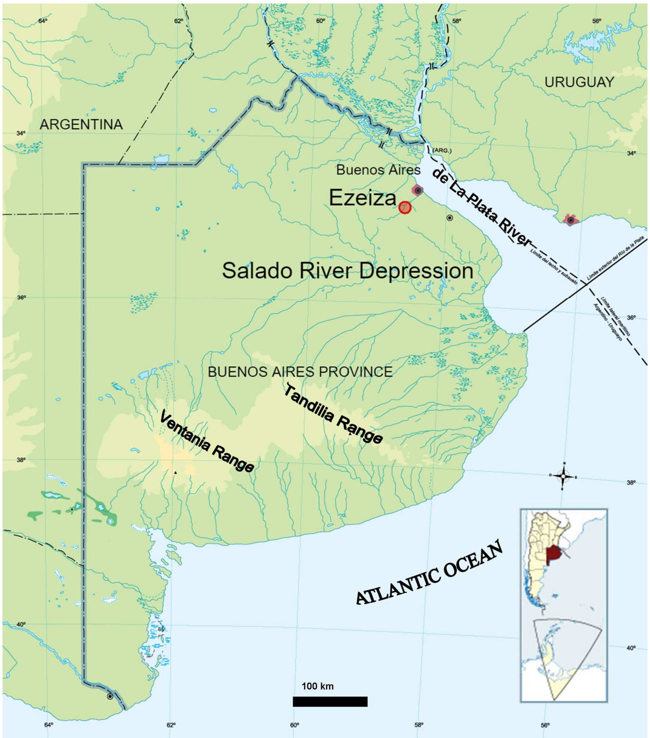


Figure 1. Location of Salado River Depression and the Ezeiza district.


Figure 2. Set-up sequence of the experiments: A) container conditioning; B) container filling; C) placing of *D. hybridus* remains on Container 1; D) placing of *G. gallus* remains on Container 2; E) vegetation layer; F) control of Container 1 in January.

Sediment humidity and vegetation cover were controlled as well.

A year after, in May 2017, the observations of Container 2 finalized in order to evaluate the processes that occurred until that moment; while Container 1 continued for six more months. Container 2 was dismantled by excavating the sediment in three artificial levels: 0-5 cm, 5-10 cm and from 10 cm to the sand layer (17 cm). The 11 cm difference between the initial depth and that at the end of the experiment will be explained in the "Discussion and final considerations" section. The content of each level was collected and the sediment was stored for future analysis. During the process, the appearance of earthworms, the location of the bones and other features (other invertebrate taxa, burrows) were recorded. The recovered bones were analysed by quantifying them, looking for modifications on the cortical surfaces and registering fractures. The criteria defined by Lyman (1994) and Fernández-Jalvo & Andrews (2016) were followed to identify and analyse taphonomic variables. Weathering stages proposed by Behrensmeyer *et al.* (2003) for avifaunal remains were also considered.

## Results

*The weekly record along one year*

Earthworms were recorded from the surface up to 12 cm deep in Container 1 and between 5 and 16 cm in Container 2, in horizontal, vertical and oblique positions. The greatest depths were noted during the second month (Container 2) and the fifth month (Container 1), respectively corresponding to winter and autumn seasons. Other *taxa*, such as woodlice, were also identified on the surface and a few centimetres deep. Despite not recording animals or casts in some occasions, burrows were visible through the sides.

In addition, vegetation changes were recorded throughout the experiment. There were periods of growth and renewal of green plants (*e.g.,* thistles) and periods of drying and decomposition that resulted in the formation of a putrefied vegetation layer (Figure 2F). Soil condition varied between more humid due to rainfall and dryer and compacted because of high temperature. These observations are presented with more detail in Tables 1A (for autumn and winter) and 1B (for spring and summer). It is important to note that after the first year of the experiment, the sediment depth was reduced from 27 cm to 15.5 cm in Container 1 and from 28 cm to 17 cm in Container 2.

Changes in bones were also registered. They exhibited soft tissue until the sixth month of the experiment, and changes in colour (green and black staining) were observed towards the end. As time went on, the bones' cortical surfaces were covered with mould; vegetation hid them as it grew but let them exposed again when it desiccated. The larger bones kept their original anatomical position, while the smaller ones disarticulated and detached. By the end of the experiment, the skull of the armadillo, some long bones and the coracoids process of the bird had got partially buried. Some other small bones and plates were displaced through the sides of the container. The observations made on bone elements are summarized in Tables 2A (for autumn and winter) and 2B (for spring and summer).

In order to establish relationships with the climatic context in which the experience was developed, the average maximum and

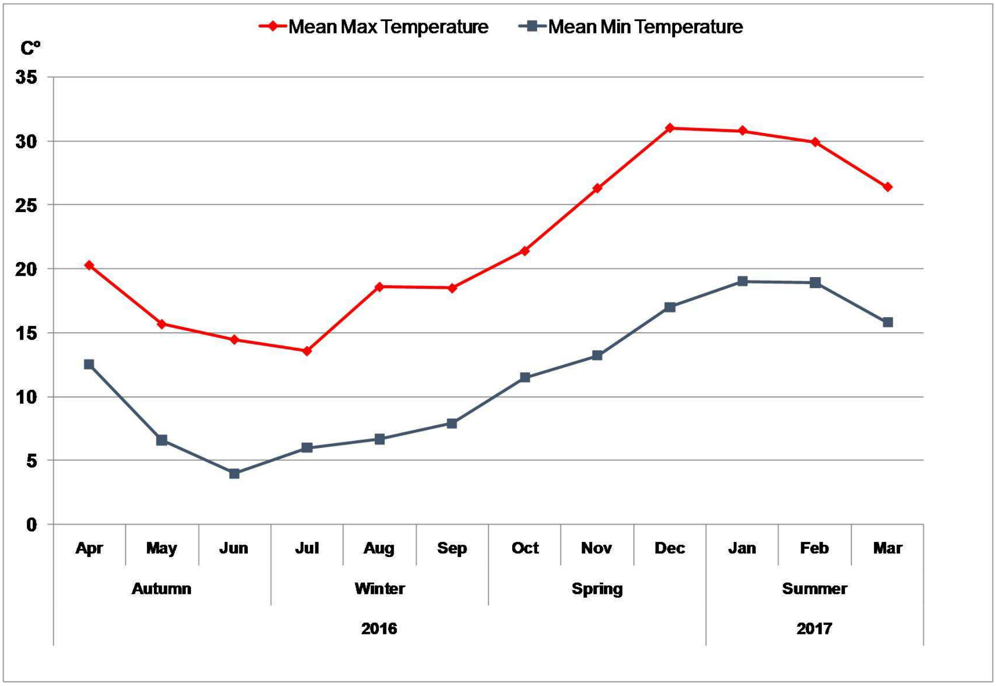


Figure 3. Mean maximum and minimum temperatures by month. Values are expressed in °C.

minimum temperatures for the registered months are plotted in Figure 3. The original data come from the meteorological station located at the "Ministro Pistarini" International Airport (Ezeiza, Buenos Aires, Argentina) and were provided by the Servicio Meteorológico Nacional. The graph shows that the lowest temperature occurred towards the end of autumn (June), while a sharp increase took place in August. This concurs with certain observations presented in Table 1A.

*Excavation of Container 2*

The vegetation cover was removed before dismantling and the bones on the surface recovered (n=22; sternum, coracoids process, clavicle, humerus, femur, radius, ulna, tibiotarsus, ilium, ischium, pubis, nine vertebrae, fused caudal vertebrae, and an undetermined articular surface). As previously mentioned, the coracoids process was partially buried and four other specimens (three vertebrae and a fragment of ischion), which had fallen through the sides, were recovered. Four earthworms, two of them in diapause (*i.e.,* entangled and immobile), were recorded in the first 5 cm of depth. In that same level, about 2 cm from the surface, three caudal vertebrae were recovered. In the second level (5-10 cm), one active earthworm and one in diapause were observed. Finally, an individual was registered towards the bottom of the deepest level (10-17 cm). In addition, in the first 10

*Table 1A. Record of earthworms, its related features and containers conditions (autumn and winter).*

| CON-TAIN ER | AUTUMN | | | WINTER | | |
|---|---|---|---|---|---|---|
| | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER |
| **1** | - Vegetable cover got dried.<br>- No vegetation growth.<br>- No worms recorded. | - A single worm was recorded 7 cm deep in vertical position.<br>- Some burrows were recorded.<br>- Surface vegetation growth. | - Vegetable cover in decomposition process.<br>- Two worms recorded on a side:<br>1. One 7.5 cm deep in vertical position.<br>2. Another 9 cm down from surface. | - Four worms recorded:<br>- 1 5 cm deep in vertical position.<br>2. 9.5 cm deep in oblique position.<br>3. 1 cm from surface to 10 cm in depth, vertical position.<br>4. From surface to 4.5 cm in depth, vertical position. | - Higher temperature and dry days.<br>- Sediment contracted after last weeks of heat.<br>- A single worm was recorded 12 cm deep. | - Dry sediment due to high temperature.<br>- No worms or burrows recorded. |
| **2** | - Vegetable cover got dried.<br>- No vegetation growth.<br>- No worms recorded. | - A single worm was recorded 16 cm deep.<br>- Surface vegetation growth.<br>- Some burrows were recorded. | - Vegetable cover in decomposition process.<br>- Two worms recorded:<br>1. One 9.5 cm down from surface.<br>2. One dead, then decomposed.<br>- Burrows recorded through sides. | - No worms recorded on surface nor through the sides.<br>- New specimens were added. | - Higher temperature and dry days.<br>- Many roots and vegetation growth make observation difficult.<br>- Two worms recorded:<br>1. One dead, 5 cm deep.<br>2. One out, between the nylon and the container. It was reintroduced. | - Dry sediment due to high temperature.<br>- No worms or burrows recorded due to the large quantity of roots. |

*Table 1B. Record of earthworms, its related features and containers conditions (spring and summer).*

| CON TAIN | SPRING | | | SUMMER | | |
|---|---|---|---|---|---|---|
| | OCTOBER | NOVEMBER | DECEMBER | JANUARY | FEBRUARY | MARCH |
| **1** | - Vegetation drying.<br>- Compact sediment.<br>- No worms recorded.<br>- Burrows recorded. | - The entire vegetation cover and thistle got dried due to high temperatures.<br>- Sediment somewhat wet.<br>- A single worm recorded 10 cm deep.<br>- Some burrows recorded. | - Vegetation is increasingly scarce due to high temperature.<br>- No worms or burrows recorded. | - New specimens were added.<br>- Dry vegetable cover and new growing vegetation.<br>- No burrows recorded. | - Two large worms were added.<br>- Wet and no so compact sediment due to previous rains.<br>- A lot of green vegetation covers the surface. Some dry thistles and leaves still remain.<br>- One single worm recorded 6 cm deep in horizontal position, close to vent hole.<br>- Some burrows | - Drying vegetation. Some roots seen through the sides.<br>- A single worm recorded 4 cm deep in vertical position.<br>- Some burrows recorded. |
| **2** | - Vegetation drying.<br>- Compact sediment.<br>- No worms nor burrows recorded. | - The entire vegetation cover and thistle got dried due to high temperatures, though there is some green weed.<br>- No worms recorded.<br>- A single woodlouse recorded 13 cm deep.<br>- Some burrows with horizontal and oblique orientation to the soil surfa-ce are recorded. | - Completely dry vegetation due to high tempera-ture.<br>- No worms or burrows recorded. | - New specimens were added.<br>- Dry vegeta-ble cover and new growing vegetation.<br>- No burrows recorded. | - Two large worms were added.<br>- Wet and no so compact sediment due to previous rains.<br>- A lot of green vegetation covers the surface. Some dry thistles and leaves still remain.<br>- One single large worm was recorded 15 cm deep in horizontal position.<br>- Some burrows recorded.<br>- Woodlice of different sizes recorded on surface and 4 cm deep. | - Drying vegetation.<br>- No worms recorded.<br>- A single woodlouse recorded 4 cm deep. |

*Table 2A. Record of bone elements (autumn and winter).*

| CON-TAIN ER | AUTUMN | | | WINTER | | |
|---|---|---|---|---|---|---|
| | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER |
| **1** | - Bones with soft tissue, on the surface. They begin to lose fat. | - Fat loss continues.<br><br>- Bones emit stench. | - Bones continue to lose fat and have mould on their surface.<br><br>- The skin and hair of the tail begin to detach.<br><br>- The plates begin to detach from the caudal vertebrae. | - Pelvis completely covered with mould.<br><br>- All plates detached from tail.<br><br>- Tarsi and phalanges got separated from leg. | - The plates that covered the tail begin to introduce into the sediment through a side. | - Some plates visible through a side are being introduced into the sediment.<br><br>- There are mosquitoes on the bones.<br><br>- Below the vegetable cover, the ribs begin to detach from one another. |
| **2** | - Bones with soft tissue, on the surface. | - There is mould on cortical surface on some elements. | - There is mould on cortical surface of all elements. | - Long bones covered with mould.<br><br>- Pelvis begins to detach through symphysis.<br><br>- Vertebrae still with soft tissue, as if they were fresh.<br><br>- Bones covered with vegetation. | - Bones are under the thick vegetable cover. | - The vertebrae are still articulated, though no soft tissue is observed. |

*Table 2B. Record of bone elements (spring and summer).*

| CON-TAINER | SPRING | | | SUMMER | | |
|---|---|---|---|---|---|---|
| | OCTOBER | NOVEMBER | DECEMBER | JANUARY | FEBRUARY | MARCH |
| **1** | - Some bones are visible beneath the vegetation.<br>- Pelvis is clean without mould.<br>- Plates can be seen on the base of the container. | - A few dry tissues cover the pelvis and sacrum, which are exposed.<br>- Half-buried humerus through distal epiphysis.<br>- Half-buried pelvis.<br>- Pelvis and vertebrae detached from one another.<br>- Neither plates nor caudal vertebrae are visible. | - Bones exposed on surface. | - Half-buried femur through epiphysis.<br>- Right hemimandible is half-buried and covered with compact vegetation.<br>- Caudal vertebrae are buried.<br>- Half-buried skull. | - All bones covered by vegetation.<br>- Plates and caudal vertebrae fall through a side. Some can be seen 3 cm deep.<br>- Some ribs have lost their original anatomical position from the ribcage. | - Some greenish bones with mould. Most are covered by dry and decomposed vegetation.<br>- Half-buried caudal vertebrae and tail plates.<br>- Hal-buried carpal or tarsal bones. |
| **2** | - The epiphyses of the femur have mould.<br>- Vertebrae are completely detached from one another. | - Pelvis detached from vertebrae on surface.<br>- Half-buried femur. Coracoids on surface.<br>- Bones are exposed, without vegeta-tion cover. | - Bones exposed. Some exhibit moist due to humidity. | - Some half-buried vertebrae.<br>- Femur detached from epiphysis. | - All bones covered by vegetation.<br>- Half-covered coracoids. Proximal end has some mould.<br>- Humerus covered by decomposed vegetation. | - Some greenish and black stained bones with mould.<br>- Some vertebrae displaced and fell through the sides. |

cm of depth, woodlice of different life stages appeared; and up to fifteen centimetres down, red ants and small anthills were spotted. Worm burrow mouths were also recorded as the sediment was excavated.

All the recovered bones are from the left side, except for a fragment of a right ischion. Regarding the modifications on bone elements, the sternum was the only one in which two holes were observed (Figure 4). One of the holes, originated from a previous mark (possibly a result of meat consumption by people), collapsed into a fully circular hole of 3.9 mm of diameter that crossed the element through the lateral process (sector where it is thinner). The other hole –3 mm in diameter– is in the articular facet of the coracoids bone and had not been registered prior to the placement of the remains in the container. Root marks were recorded on the sternum's surface as well. Three long bones (humerus, ulna and tibiotarsus) showed scattered black staining. One of these elements (tibiotarsus) along with other remains (coracoids, radius and femur) exhibited surface discoloration. Finally, seven of the elements (sternum, tibiotarsus, ilium, ischium and three vertebrae) were greenish (Figure 4) and a few bones combined these modifications with weathering. Some characteristics of weathering stage 1 (*sensu* Beherensmeyer *et al.*, 2003), like cracking and flaking, were observed in sternum, ilium, ischium, femur and the proximal epiphysis of tibiotarsus.

Regarding cut marks, a deep and thin 4 mm cut was observed in the sternum –specifically in the breastbone– and another one in the distal end of the ilium. The first cut had been registered prior to the placement of the remains in the containers, but it was not possible to analyse it at that moment because it was partly covered by soft tissue. As for the fractures, one was detected in the fragment of undetermined


Figure 4. Ventral view of sternum: both holes and green staining (over the cranial edge) are observed.

articular surface, and another with irregular form was identified in the fragment of right isquion.

## Discussion and final remarks

The observations made during the first year of this experimental study account for the horizontal and vertical movement of earthworms, as exhibited in Table 1. The maximum depth (16 cm) was recorded during the colder months of May and July, and the orientation of burrows visible through the sides of the containers match with both anecic and endogeic behaviours. This concurs with other authors' remarks on *L. terrestris* (a species that has not been identified in the study area yet) and their experiences (Stein, 1983; Armour-Chelu & Andrews, 1994; Canti, 2009). It is also noticeable that surface casts were not detected, which could be explained mainly by the low visibility due to the amount of vegetation; though it cannot be ruled out that the specimens show, in general, an endogeic behaviour.

A lower activity record was observed during the warmest months (December and January) which could reflect the movement of these invertebrates towards the centre of the containers, where the temperature would not be as high as by the plastic surfaces. As stated by Stein (1983), some earthworm species' fecundity is affected by soil temperature, being 10 °C the optimum value. Conversely, "earthworms are rarely seen in soils where the mean annual air temperature is colder than 7 °C" (Stein, 1983:279). These data are consistent with the annual temperatures recorded in the area where the experiment was performed, being propitious for the development of earthworms. Also, the mean temperature in the Salado River Depression fluctuates between 7 and 10 °C during July (González, 2005), which explains the record of earthworms during field excavations.

Unlike epigeic species, which have a broad tolerance to temperature and moisture, anecic and endogeic species exhibit varied tolerances (Butt & Lowe, 2010). Thus, sediment moisture is another vital requirement for the earthworms that must be thoroughly controlled, being soils with good drainage usually adequate for this (Stein, 1983). In this sense, the contraction and expansion of the sediment resulted in a significant reduction of its depth and the vertical movement of some of the dermal plates of the armadillo. This could be explained by the succession of periods of drought and abundant rains, the presence of clays in the sediment and its compaction when extracted and resettled; and was also inferred in sites of the microregion from the observation of the cracking of the soil profile (González, 2005).

Another aspect of the experimental observations relates to the modifications that occurred in the faunal remains that were placed on the containers. To this respect, the aim was to evaluate if these earthworms left marks on the bony surfaces as suggested by Armour-Chelu & Andrews (1994) for *L. terrestris*. However, only a single circular hole was documented in the sternum of *G. gallus* whose origin could not be determined yet. The hole is in a sector of spongy tissue that, judging by its morphology, could be a consequence of the action either of roots or insects (*e.g.,* Dermestidae) (Figure 4). The former usually leave conical perforations with smoothly rounded edges; whereas the latter leave deep conical perforations due to their activity (Fernández-Jalvo & Andrews, 2016).

Nevertheless, considering the size of the hole, if it were attributed to an insect, it would be a large one.

The black staining recorded in the form of patches over long bones may be related to manganese oxide, which indicates contact with very moist sediment. However, it cannot be ruled out that they resulted from the action of fungi –as stated by Fernández-Jalvo & Andrews (2016)– observed throughout the records (especially, during the first months of the experimentation). In the archaeofaunal assemblages of the Salado River Depression, spots generated by manganese oxide are often recorded; but in these cases, they are more extended over the remains, which may be caused by their being contained in very moist sediments and the time elapsed (for more detail see González, 2005; Escosteguy, 2011 & Escosteguy *et al.*, 2015).

Regarding other natural modifications, the weathering stage documented on a few bones is consistent with the time required to reach the first stage. So, those bones that do not show evidence of alterations must have been protected by the thick vegetation. This agent is also responsible for the greenish coloration registered on bones, as it was studied in forensic contexts (Dupras & Schultz, 2013), stating that green staining from moss and algae is the result of pigments such as chlorophyll. Other bones showed discoloration (or white coloration) due to sun bleaching.

So far, the first year of experimental observation showed that the action of earthworms vary in rate along seasons, being temperate weather the period of more activity. The registered movement through their burrows will be a clue to know the behaviour of the species present in the study area and their possible incidence in the dispersal of zooarchaeological remains –especially those of small animals that are recorded in the sites of the Salado River Depression. It was also revealed that other factors such as roots, woodlice, ants and soil compaction may alter the cortical surfaces or arrangement of bones belonging to small vertebrae like birds. According to Balek (2012), woodlice can bring material to the surface but in a very low proportion compared to earthworms (an average of 30 mm within a 1000-year period *vs.* 7000 mm for earthworms). So, the incidence of this species on the experiment would be minimal though not inexistent. Regarding ants, some authors have addressed the role of certain species in forming biomantles and making mounds (*e.g.,* Richards, 2009) and the consequences of the turnover effect on the sinking of archaeological material (*e.g.,* Johnson & Johnson, 2010).

As a future agenda, new experiments are being developed with other types of archaeological materials recovered in the sites of the Salado river microregion (lithic, ceramic and small rodent carcasses) to further deepen the knowledge of the effects of different earthworm species on the archaeological record. For this purpose, sediment extracted from both containers and samples from archaeological sites of the study area will also be analysed in searching for $CaCO_3$ granules, an indicator of earthworm activity (Canti, 2009).

Moreover, replication of this series of experiments will be done with other edaphic macrofauna species that were also spotted during excavations (*e.g.*, *Chilopoda*, *Diloboderus abderus*) and with woodlice and ants. This data will refine the interpretations of the natural formation processes dynamics in biomantles and, therefore, will be useful as a frame of reference for the understanding of the taphonomy of the archaeological sites of the Salado River Depression.

## Acknowledgments

This research was granted from PICT 2013-0411 and UBACyT 20020130100134BA. A preliminary version of this paper was presented in the Symposium "*Perspectivas actuales de la tafonomía actualística en Argentina: limitantes, contribuciones e implicancias arqueológicas*", organized and chaired by Dr. María Clara Álvarez and Lic. Daniela Alunni during the IV National Congress of Argentine Zooarchaeology. This event was held at CADIC-CONICET (Ushuaia, Tierra del Fuego, Argentina) in October 2016. The authors are indebted to Dr. Liliana Falco for providing with bibliography; Drs. Mónica Salemme and Romina Frontini for their critical reading and useful comments on a previous draft; Dr. María Paula Villegas for her English grammar and language revision; Noelia Escosteguy and Prof. Miranda Rivas Gonzalez for their assistance with photographing; and both reviewers for their remarks and suggestions that helped improve the original version. Nonetheless, the authors are the solely responsible for mistakes and/or omissions in the ideas presented here.

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