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RADIOCARBON CHRONOLOGIES OF HOLOCENE LACUSTRINE SEDIMENTS FROM THE SOUTHERN COAST OF BUENOS AIRES PROVINCE, ARGENTINA

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ABSTRACT. Two lacustrine sediment sequences, La Olla 1 and Laguna del Sauce Grande, on the southern coast of Buenos Aires Province, Argentina, were investigated for carbon reservoir effects, which may influence age-depth chronologies. Fruits of the submerged macrophyte *Ruppia* cf. *maritima* from the La Olla 1 sequence, and gastropod shells of *Heleobia parchappii* from the Laguna del Sauce Grande core, were radiocarbon dated. In addition, terrestrial plant remains and shells of living specimens were dated to assess the presence and magnitude of a reservoir effect. A reservoir age of about 800 ^{14}C yr is estimated for the aquatic plant samples of La Olla 1 for the early Holocene. The reservoir effect is attributed to the inwash of ^{14}C-deficient bicarbonate from the surrounding sand dunes. The decay of marine organisms and salt spray are likely the main sources of ^{14}C-deficient carbon. The magnitude of the reservoir effect is consistent with marine reservoir offsets reported for the region. The ^{14}C measurements on shells of living and fossil specimens of *Heleobia parchappii* indicate the absence of a reservoir effect at Laguna del Sauce Grande, which may be due to the large size and shallow nature of the lake. This study shows how the reservoir ages of 2 close-by lakes in very similar geological settings can be largely different. These results have significant implications for the interpretation of ^{14}C dates from lacustrine deposits in the region.

INTRODUCTION

The establishment of accurate chronologies of lake sediment sequences is of major importance for paleolimnological investigations. Precise age control enables correlations and comparison with other paleoclimatic records. The chronologies of lacustrine sediments are based mostly on radiocarbon dating of diverse material: plant macrofossil remains (e.g. Yu et al. 2003), gastropod shells (e.g. Abbott et al. 1997), bulk organic sediment (e.g. Melles et al. 1994), pollen (e.g. Kilian et al. 2002), and chironomids (e.g. Fallu et al. 2004). Even so, dating errors have been recorded in terrestrial plant macrofossils (Wohlfarth et al. 1998); they represent the most reliable material for dating. The occurrence of terrestrial plant macrofossils in certain sediment sequences such as those recovered in treeless environments is scarce. Therefore, other constituents of lake sediments are commonly used for ^{14}C dating, e.g. bulk sediment, gastropods, and aquatic plant remains. ^{14}C dating of non-terrestrial material often yields ages significantly older than dates obtained from terrestrial plant macrofossils, indicating the presence of ^{14}C-deficient carbon. Most common sources of ^{14}C-deficient carbon include the incorporation of old carbon into the lake sediments derived from detritus of older deposits, as well as the inwash of ^{14}C-deficient bicarbonate produced by the dissolution of carbonate rocks from the catchment area or from the calcareous bedrock (Olsson 1983, 1986; Björck and Wohlfarth 2001). Plants and animals incorporating ^{14}C-deficient carbon from environments that are in disequilibrium with atmospheric ^{14}C concentration will show apparent ^{14}C ages that are too old. The dating error obtained for these materials is referred to as the reservoir effect (Stuvier and Polach 1977). Furthermore, lacustrine deposits located near the sea may have been influenced by a marine reservoir effect because of temporary connection to the sea (Berglund 1971) or due to the incorporation of marine detritus into the lake sediments (Björck et al. 1991).

The Late Quaternary environmental and climatic history of the Pampean region in Argentina has been inferred mainly from pollen, calcareous microfossil, vertebrate, and archaeological records recovered from outcrop sections along river valleys; from loess sequences; and from lacustrine environments (e.g. Bertels and Martínez 1990; Flegenheimer and Zárate 1993; Quattrocchio et al. 1995; Prieto 1996; Tonni et al. 1999; Stutz et al. 2006). Paleoenvironmental conditions did not favor the preservation of organic matter in most of these deposits. Therefore, materials commonly used for dating are shells, inorganic calcium carbonate, and soil organic matter, and less frequently, bones and charcoal. Regardless of the dated material, post-depositional processes such as pedogenesis and faunal-bioturbation may also affect the age obtained for the horizon of interest (Flegenheimer and Zárate 1993). Thus, the certainty of results is difficult to assess and the comparison often only tentative.

Few studies have been carried out to estimate the carbon reservoir effect associated with terrestrial and freshwater mollusks from the Pampean region (Figini et al. 1985, 1995), while the marine reservoir effect has been assessed at different sites along the southwest Atlantic coast: southern Brazil (Nadal de Masi 2001; Eastoe et al. 2002; Angulo et al. 2005), Patagonia (Cordero et al. 2003), and Tierra del Fuego (Albero et al. 1986).

In order to reconstruct the Holocene vegetation history and environmental changes at the southern coast of Buenos Aires Province, Argentina, La Olla 1 and Laguna del Sauce Grande sediment sequences were investigated for pollen, calcareous microfossils, and plant macrofossil remains (Fontana 2004, 2005a). The chronological control of these sequences is based on submerged plant remains and gastropod shells. The aim of this paper is to examine the magnitude and origin of carbon reservoir effect associated with non-terrestrial materials from coastal lacustrine sediments. Furthermore, the ^{14}C ages are compared and discussed in a regional context.

STUDY AREA

Buenos Aires Province is characterized by a vast plain with slight undulations. The Tandilia and Ventania ranges comprise the mountain relief of the region, which stand abruptly up to 1200 m above the surrounding plain. The plain ends at the Atlantic in a coastal dune system. Local streams flow from the mountain ranges to the Atlantic Ocean, traversing the plain. Late Pleistocene-Holocene eolian deposits, loess and loessoid sediments, extend over the region as a cover of variable thickness (Zárate 2003). The study area is located to the south of Buenos Aires Province, in the southern Pampas region (Figure 1). The sediments have been classified as sandy loess and are of volcaniclastic composition. The main constituents are volcanic glass plagioclase feldspar, quartz, and volcanic rock fragments (Zárate and Blasi 1991, 1993; Zárate 2003). Calcium carbonate is found in the loess and loessoid sediments as calcite in 2 forms: 1) as small particles distributed in the sediments, at variable concentrations, from practically nothing up to 8%; and 2) as calcrete, locally termed *tosca* (Teruggi 1957). Tosca is an epigenic deposit that underlies the present soil at different depths (up to ~180 cm) and often outcrops at the surface. The $CaCO_3$ content of the tosca is highly variable (~7.5 to 50%) (Pazos and Mestelan 2002).

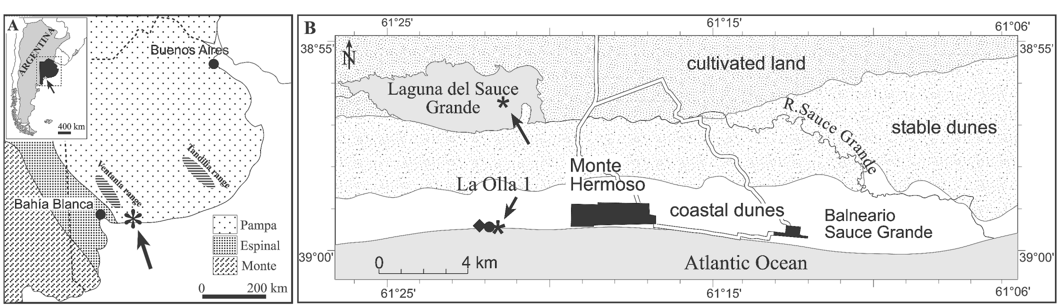

Figure 1 A) Map of the study area showing the phytogeographical regions according to Cabrera (1994). B) General overview of the coastal strip showing the location of the studied sites: La Olla 1 and Laguna del Sauce Grande (asterisks), and associated sites La Olla 2 (circle) and Monte Hermoso I (diamond) discussed in the text.

The coastal strip is characterized by flat sand beaches and dune systems that extend 4 to 5 km inland with an elevation of over 20 m above sea level (asl). The dune systems consist of active dunes adjacent to the beach and inactive (fossil) dunes further inland. Calcium carbonate from shell debris may represent up to 40% (mass) of their sediments (Jobbágy and Jackson 2003). Tosca fragments are also characteristic of the sand dunes. Dune soils along the coast of Buenos Aires Province are characterized by high pH values because of the high carbonate content derived from the decomposition of shells as well as from salt spray (Cabrera 1941; Jobbágy and Jackson 2003).

The regional vegetation is characterized by temperate subhumid grasslands known as *pampas* (Cabrera 1994), while characteristic sand-requiring vegetation grows on the dunes (Fontana 2005b). The natural vegetation has been modified by intensive agricultural activities during the last century. In the region, the cultivated land starts at about 5 km inland from the shore.

Precipitation and temperature in Buenos Aires Province decrease from the north-east to the south-west. Thus, the southernmost area, around Bahía Blanca, is the most arid and coolest (547 mm annual precipitation; 15.6 °C mean annual temperature). Here, the pampa grassland abuts the xerophytic forest known as *espinal* (Cabrera 1994).

Diverse lakes and ponds of varying size occur between the dunes, and Pleistocene-Holocene deposits outcrop at the beach. Paleoecological investigations from these sediment records may provide valuable insight into environmental changes like the dynamic of the dune system and sea-level fluctuations. Therefore, the interpretation of sediment sequences from the area requires accurate chronologies.

SITE DESCRIPTION

La Olla 1

La Olla 1 (38°59′S, 61°22′W) represented a shallow-water and marginal-marine environment such as a littoral lagoon (Fontana 2005a). Today, the sediments are located in the coastal intertidal zone (Figure 1), usually covered by beach sand. It has been exposed only a few times and for brief periods, during exceptionally low tide. La Olla 1 sediments were deposited over a time span of 260 yr during the early Holocene, before 7600 cal BP (Fontana 2005a). The paleolagoon occurred most likely before the maximum transgression, during a time with sea levels somewhat lower than at present. A marine connection is recognized in the paleolagoon between 7850 and 7800 cal BP, which probably represented the occurrence of sea-level fluctuation of smaller magnitude. The site contains significant archaeological information about the use of marine resources by hunter-gatherers during the early Holocene (Politis and Bayón 1995; Johnson et al. 2000). Previous ^{14}C dates reported from La Olla 1, on sea mammal bones, yielded ages of 7315 ± 55 BP (AA-7972) and 6640 ± 90 BP (LP-303) (Politis and Bayón 1995).

La Olla 1 is spatially and temporally associated with La Olla 2 and Monte Hermoso I (Figure 1). La Olla 2 is located 50 m west of La Olla 1, with an associated date on sea mammal bone of 7400 ± 95 (AA-19292) (Bayón and Politis 1998). Monte Hermoso I is located 200 to 1000 m west along the beach. Hundreds of human footprints were preserved in the sediments with associated ^{14}C dates of 7125 ± 75 BP (AA-7974; on *Ruppia* fruits), 7030 ± 100 BP (LP-271; on seal scapulae), 6795 ± 120 (AA-8699; on unknown plant remains), and 6705 ± 80 (AA-8700; on *Ruppia* fruits) (Bayón and Politis 1996, 1998).

Laguna del Sauce Grande

Laguna del Sauce Grande (38°56′S, 61°21′W) is a shallow freshwater lake located 8 m asl and approximately 4 km from the Atlantic coast (Figure 1). The lake probably became established at ~3000 cal BP (Fontana 2005a). Today, it covers an area of 23 km^2, with a mean water depth of 1.1 m. The lake occupies an aeolian depression, receiving waters from the Sauce Grande River. The river originates in the Sierras Australes, a mountain range rising up to 1250 m asl, located 200 km north of the lake, and enters the Atlantic Ocean about 20 km southeast of the study site. The lake is elongated east-west. The northern shore is characterized by low escarpments of tosca, while the southern shore borders the dune system. The lake is surrounded by a narrow shore belt of *Schoenoplectus californicus* and *Typha dominguensis*.

MATERIAL AND METHODS

Aquatic plant remains and gastropod shells were dated by accelerator mass spectrometry (AMS) at the Tandem Laboratory, Uppsala University (Ua) and at NOSAMS, Woods Hole AMS facility (CURL). CURL samples were prepared at University of Colorado–INSTAAR Laboratory. Plant remains were recovered by wet sieving of sediment samples through 180-µm mesh without chemical treatment. The remaining material on the sieves was treated with hot dilute hydrogen peroxide, sieved again, and dried at room temperature. Calcareous microfossils were then picked from the residual material. Thus, diverse material suitable for dating was obtained from both sequences. Abundant ostracods, foraminifers, and macrophyte remains were recovered from the sediment of the La Olla 1 sequence. The samples from Laguna del Sauce Grande contained abundant ostracods, charophytes, cladocera ephippia, and gastropod shells throughout the core. Terrestrial plant remains were only present in the upper part of this sequence, usually in small quantities that were insufficient for dating. The organic matter of the bulk sediment consisted, among others, of a mixture of microscopic charcoal, different cladocera species, and charophyte remains with variable proportion through the sequence. In order to avoid differences in the magnitude of the potential reservoir effect between dated materials, the same species along each sequence were selected for ^{14}C measurements. Thus, fruits of *Ruppia* cf. *maritima*, a submerged macrophyte, were selected for ^{14}C dating at La Olla 1 and shells of *Heleobia parchappii* at Laguna del Sauce Grande. In addition, terrestrial plant remains from La Olla 1 and shells of living specimens of *H. parchappii* from Laguna del Sauce Grande were submitted for dating to evaluate the reservoir effect of the samples. Living specimens of *H. parchappii* were collected in 2002 from macrophyte roots occurring near the shore of the lagoon, at a water depth of about 50 cm. The organic matter of the gastropods was removed by heating with dilute hydrogen peroxide for 20 min.

^{14}C dates were calibrated against the Southern Hemisphere calibration curve, SHCal04 (McCormac et al. 2004) using the BCal online system (http://bcal.shef.ac.uk). The modeled offset used to estimate the SHCal04 calibration curve is about 56 yr, which is larger than the previously applied offset of 23 ± 4 ^{14}C yr during the calibration processes (Fontana 2005a). Thus, slight differences can be observed when comparing the calibrated ages calculated in this article with those obtained in Fontana (2005a).

Age-depth models were constructed using psimpoll software (Bennett 2006).

COMMENTS ON THE ECOLOGY OF THE TAXA USED FOR DATING

Ruppia maritima

Ruppia maritima, commonly known as widgeongrass or ditch-grass, is a submerged macrophyte with a cosmopolitan distribution. It occurs in temporary or permanent saline waters, mostly in coastal environments such as bays, estuaries, lagoons, small ponds, ditches, and rivers, but it may also occur inland in lakes and springs (Kantrud 1991). Different abiotic factors, such as water depth, salinity, pH, alkalinity, and nutrients, regulate the distribution and zonation of *Ruppia maritima*. It requires much sunlight and relatively high water transparency. Even so, it can grow in up to 4.5 m water depth; the largest biomass is found at about 0.4 m water depth (Costa and Seeliger 1989). Turbidity and shading caused by algae or epiphytes are important factors limiting its vertical distribution. *Ruppia maritima* tolerates a greater range in salinity than any other submerged angiosperm (Kantrud 1991). Its optimum growth in Cl-dominated waters is found at salinities of about 5–20 g/L, but it tolerates salinities of up to 390 g/L in lakes where $MgSO_4$ is the principal salt. *Ruppia maritima* occurs in waters with a pH of 6.0 to 10.4 (Kantrud 1991). It tolerates an extremely wide range of carbonate alkalinity. McCarraher (1977) found *Ruppia maritima* in highly saline lakes with total alkalinities up to 34.7 g/L and CO_3^- and HCO_3^- concentrations of up to 25.4 g/L and 9.3 g/L, respectively.

In saline waters, the availability of CO_2 for photosynthesis is low. In contrast, HCO_3^- concentration is high. Some aquatic plants have the ability to use HCO_3^- in addition to CO_2 as a carbon source for photosynthesis. Several studies showed that *Ruppia maritima* effectively uses HCO_3^- with high affinity (Sand-Jensen and Gordon 1984; Beer et al. 2002). Therefore, these plants are more likely to uptake carbon from old sources because of the equilibrium reactions between dissolved CO_2 from the air and HCO_3^- coming from the dissolution of carbonate rocks.

Heleobia parchappii

Heleobia (*Littoridina*) is a small gastropod (3–8.5 mm long) that occurs from Central America to southern Patagonia, as well as in a small region in the Atlantic coast of North America (Weyrauch 1963; Gaillard and Castellanos 1976). *Heleobia* species mostly inhabit freshwater, but also saline environments such as lakes, rivers, streams, and estuaries.

Heleobia parchappii occurs in the Pampean region of Argentina and Uruguay (Cazzaniga 1982). Although it is a freshwater species, occurring at salinities of <1‰, it was reported from a brackish channel (De Francesco and Isla 2004). *Heleobia parchappii* is typically found on submerged vegetation (e.g. *Potamogeton*, *Myriophyllum*, *Chara*).

Heleobia species have been recorded in high abundance in diverse Holocene sequences along the northern Atlantic coast of Argentina, and successfully used in the reconstruction of coastal environments and paleosalinities (e.g. Aguirre and Whatley 1995; De Francesco and Zárate 1999; Aguirre and Urrutia 2002; Espinosa et al. 2003). Inland, *Heleobia parchappii* has been recovered from late-Quaternary outcrops of river profiles of the Pampean region: e.g. Arroyo Tapalqué and Río Quequén Grande (Bonadonna et al. 1999).

RESULTS

Table 1 summarizes the ^{14}C dates from the sites La Olla 1 and Laguna del Sauce Grande.

Table 1 ^{14}C dates from La Olla 1 and Laguna del Sauce Grande. ΔR offset applied during the calibration process.

Sample depth (cm)	Material analyzed	Uncalibrated age (^{14}C yr BP)	Calibrated age weighted average/cal BP (2-σ interval)	ΔR	Lab nr
La Olla 1					
0.1–1	*Ruppia* cf. *maritima* fruits	7580 ± 60	7608 (7482–7713)	783 ± 55	CURL-4093
5.5–6.2	*Ruppia* cf. *maritima* fruits	7750 ± 60[a]	7673 (7578–7786)	783 ± 55	CURL-4094
8.3–8.9	*Ruppia* cf. *maritima* fruits	7635 ± 75	7718 (7614–7826)	783 ± 55	Ua-16106
22.1–23.1	Terrestrial macro remains	7040 ± 55[b]	7792 (7670–7929)	—	CURL-4095
33.7–34.4	*Ruppia* cf. *maritima* fruits	7920 ± 90	7869 (7691–8020)	783 ± 55	CURL-4096
Laguna del Sauce Grande					
	Living *H. parchappii* shells	105.4 ± 0.4 pM[c]	—	—	Ua-20985
66–67	*H. parchappii* shells	550 ± 40	533 (497–623)	—	Ua-20865
123–124	*H. parchappii* shells	1275 ± 50	1147 (1010–1276)	—	Ua-20866
170.5	*H. parchappii* shells	1740 ± 35	1597 (1521–1697)	—	Ua-20982
221	*H. parchappii* shells	2450 ± 65	2449 (2326–2691)	—	Ua-20983
264.5	*H. parchappii* shells	2600 ± 35	2628 (2490–2751)	—	Ua-20984

[a]50% outlier probability.
[b]100% outlier probability.
[c]Absolute modern % (pM).

La Olla 1

Dates obtained on *Ruppia* cf. *maritima* fruits from La Olla 1 show a near-linear relationship with depth (Figure 2a). The discrepancy between the dates obtained on *Ruppia* cf. *maritima* fruits and the terrestrial macrofossil suggests a reservoir effect for the aquatic material. The magnitude of the error was estimated as 783 ± 55 ^{14}C yr by fitting a line to the aquatic ^{14}C dates, and thus estimating an age for the depth at 22.60 cm. This offset was applied during the calibration of the samples from the La Olla 1 site. In addition, 2 dates were considered as outliers with prior probabilities of 50% and 100%, respectively (Table 1). These probabilities were assigned to the ^{14}C dates during the BCal calibration procedure.

Laguna del Sauce Grande

Shells of living specimens of *Heleobia parchappii* gave an absolute modern ^{14}C age (Table 1), so no correction for old carbon was applied to the ^{14}C dates of the Laguna del Sauce Grande core. The near-linear age-depth relationship for Laguna del Sauce Grande indicates continuous, even sedimentation (Figure 2b). Linear extrapolation from the age determinations towards the top of the sequence results in an age close to present, supporting the absence of a reservoir effect.

DISCUSSION

The accuracy of ^{14}C dates on submerged plant remains and gastropod shells may be subject to error as a result of reservoir effect. Therefore, it is important to test the dating reliability either by comparing dates of terrestrial and aquatic material from the same or nearby stratigraphic level or by measuring the ^{14}C activity of living specimens. In this way, the magnitude of the error, if present, can be calculated and applied. However, correction should be applied with caution. Several studies have shown that the magnitude of ^{14}C-deficient carbon may differ greatly through time within a sequence, as well as among the material dated (e.g. MacDonald et al. 1991; Björck et al. 1998; Geyh et al. 1998; Hedenström and Possnert 2001; Fallu et al. 2004).

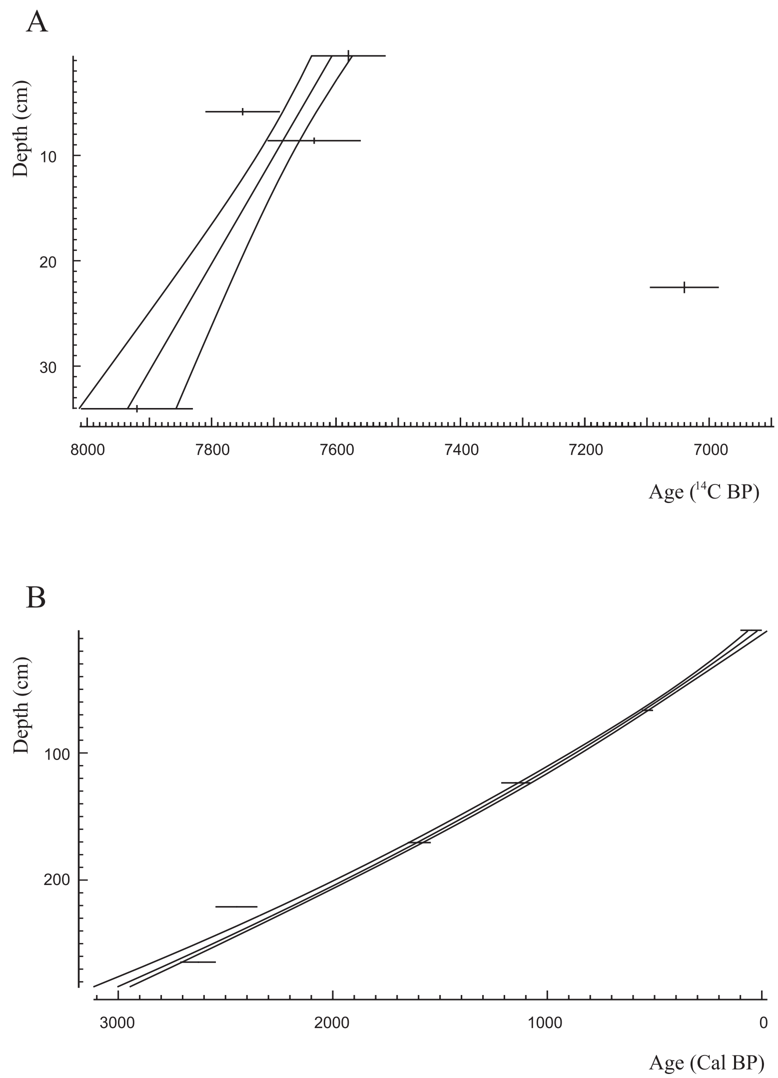

Figure 2 Age-depth model. A) La Olla 1, fitting a line to the aquatic ^{14}C dates (using uncalibrated ages) to estimate the offset between the aquatic samples and the terrestrial sample. B) Laguna del Sauce Grande, fitting a 3-term polynomial to the weighted average of the probability distribution for the calibrated age (Bennett 2006). The top sample was assigned an age of –50 ± 50.

Macrophytes

Living freshwater macrophytes have been used to evaluate the ^{14}C concentration of the water in several studies (e.g. Olsson et al. 1969, 1983; Olsson and Kaup 2001). Measurements of ^{14}C activity on recent submerged, floating, and emergent plants have yielded lower values than the atmosphere. Furthermore, different ^{14}C values were obtained from different taxa within a lake, among individuals of the same species at different lakes, and even in different organs of the same plant. Olsson (1983, 1986) concluded that the ^{14}C activity of macrophytes in a lake depends on the isotopic composition of the aquatic environment and its catchment area as well as on the different mechanism of the aquatic plants in uptaking carbon for photosynthesis. Marine macrophytes are also expected to be affected by reservoir effect because of the slow mixing of the reservoirs and the higher carbon content of deep water compared to the surface (Olsson 1986).

Plant macrofossil remains of *Ruppia* have been used for ^{14}C dating in several studies (e.g. Barnosky 1989; Geyh et al. 1998, 1999; Grosjean et al. 2001; Markgraf et al. 2003; Yu et al. 2003, 2005). The accuracy and reliability of these dates was assessed using different approaches, depending on the nature of the aquatic system and its catchment area. ^{14}C dates on samples of living *Ruppia* from the Atacama Desert in Chile have yielded ages of 1230 ± 250 ^{14}C yr BP at Laguna Miscanti and 1865 ± 95 ^{14}C yr BP at Laguna Lejía (Geyh et al. 1998). In contrast, ^{14}C dates on leaves of living *Ruppia* from Lago Cardiel, in the Patagonian region of Argentina, are reported as postmodern (Markgraf et al. 2003). Yu et al. (2003, 2005) applied a regional marine reservoir age anomaly R of –108 ± 24 yr (Berglund 1971) to correct the ^{14}C dates on brackish-water seagrasses, *Ruppia* and *Zannichellia*, from lake sediment sequences around the Baltic area in southern Sweden, before isolation due to land uplift.

The dates obtained on *Ruppia* cf. *maritima* fruits from La Olla 1 are most likely affected by the inwash of ^{14}C-deficient bicarbonate from the surrounding sand dunes. Sources of ^{14}C-deficient bicarbonate could have been the decomposition of debris from marine organisms, mainly as the dissolution of carbonate shells but also the decay of organic remains, which were affected by oceanic reservoir effect. The dissolution of tosca, commonly found in the modern dune environments, as well as ocean spray could equally well have affected these near-shore aquatic systems. These factors would suggest that the reservoir effect determined for the aquatic samples of the La Olla 1 site was mainly influenced by the reservoir effect of coastal marine waters.

The near-linear relationship observed between the ^{14}C dates of *Ruppia* cf. *maritima* fruits plotted against depth, seems to indicate that the reservoir effect did not change through time. However, the marine connection recognized in the paleolagoon between 7850 and 7800 cal BP (Fontana 2005a) could have had an influence on the reservoir effect through the incorporation of ^{14}C-depleted carbon from ocean waters.

The ^{14}C ages obtained on *Ruppia* cf. *maritima* fruits from La Olla 1 are in agreement with previous dates reported by Politis and Bayón (1995) for the same site, as well as with dates obtained at the neighboring sites La Olla 2 and Monte Hermoso I (Figure 3) (Bayón and Politis 1996, 1998). The 2 ^{14}C ages, reported by Politis and Bayón (1995) for La Olla 1, were obtained on sea mammal bones recovered from the upper sediments. One of these dates (AA-7972; obtained via AMS) is within 200 ^{14}C yr of the age obtained from *Ruppia* cf. *maritima* in the upper part of the sequence (Figure 3). However, the second date (LP-303; obtained by the conventional method) yielded an age about 950 yr younger. The discrepancy between these dates may be associated to different feeding patterns among the sea mammals (Dumond and Griffin 2002). The ^{14}C dates from Monte Hermoso I were carried out on different types of material: *Ruppia* fruits, sea mammal bones, and plant macro remains (Bayón and Politis 1996, 1998). Despite that, the dates showed a good linear relationship with depth (Figure 3). It is likely that an error of the magnitude measured on the aquatic plant samples from La Olla 1 affected also the other ^{14}C dates on sea mammals and *Ruppia* fruits at this site and at the neighboring sites.

^{14}C dating of sea mammal samples, as of other marine organisms, is affected by the reservoir effect of ocean waters (Olsson 1980; Erlandson et al. 1996; Dumond and Griffin 2002; Yoneda et al. 2002). The magnitude of this effect varies considerably across the globe. The pre-industrial global mean reservoir correction, $R(t)$, is estimated to be 400 yr (Reimer and Reimer 2001). However, local

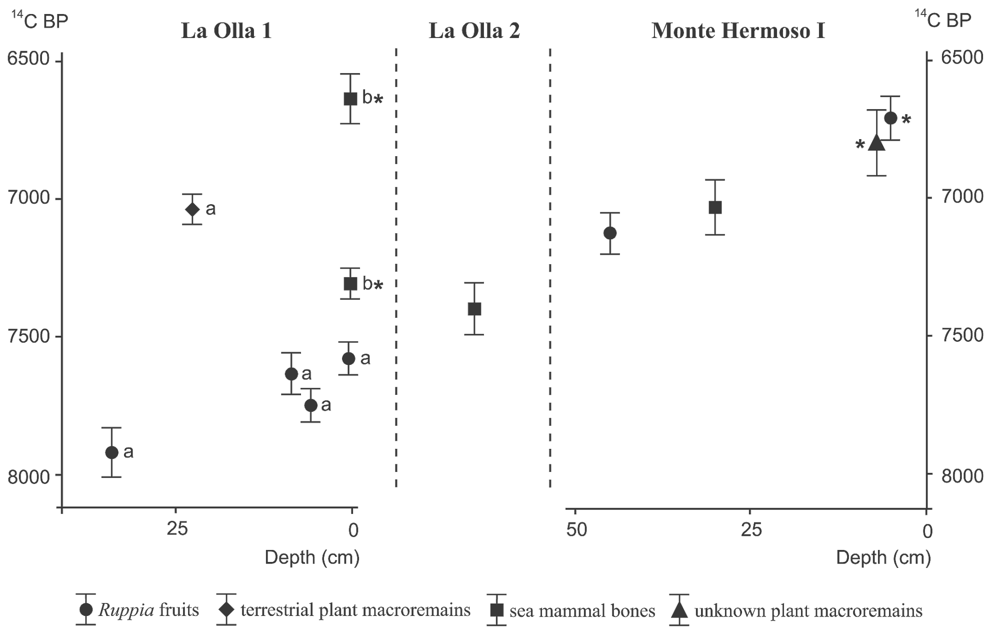

Figure 3 ^{14}C age comparison of samples from La Olla 1 (a: this study; b: Politis and Bayón 1995) and the neighboring sites La Olla 2 and Monte Hermoso I (Bayón and Politis 1996, 1998). The asterisk indicates samples with an approximate stratigraphic position.

variations (*R*) are in the order of several hundred years or more. In addition, temporal variations in the regional oceanic reservoir, as well as variations among species and among specimens of the same species, have also been recorded (Dumond and Griffin 2002; Fontugne et al. 2004; Hutchinson et al. 2004; Angulo et al. 2005).

Along the southern Atlantic coast, the magnitude of the modern marine reservoir effect varies considerably. Nadal de Masi (2001), Eastoe et al. (2002), and Angulo et al. (2005) measured reservoir ages at the southern and southeastern Brazilian coast, ranging from about 300 to 700 ^{14}C yr. For the Atlantic coast of Patagonia, ^{14}C offsets range from about 80 to 1100 ^{14}C yr (Cordero et al. 2003).

The magnitude of the offset calculated for La Olla 1 (783 ± 55 ^{14}C yr) compares well with 2 offsets measured by Cordero et al. (2003) at the nearest localities: Punta Norte (566 ± 80 ^{14}C yr) and Golfo San José (surficial water; 856 ± 105 ^{14}C yr). The La Olla 1 offset is also in the same range as a reservoir effect of 620 ± 140 ^{14}C yr measured by Albero et al. (1986) for the mid-Holocene at the Beagle Channel, Tierra del Fuego Island. A large component of marine-derived ^{14}C-deficient bicarbonate to La Olla 1, through salt spray and the decay of marine organisms, would explain the good correspondence between the offset determined for the aquatic samples of La Olla 1 and the reservoir effect of coastal marine waters.

Gastropods

Studies on Recent non-marine mollusks, both terrestrial and aquatic, showed that the magnitude of the ^{14}C-age anomaly can be highly variable between taxa and among individuals of the same species (Goodfriend and Hood 1983; Goodfriend and Stipp 1983; Goodfriend 1987). These anomalies may be related to the different feeding strategies, shell size, or amount of available ^{14}C content in the substrate. However, recent studies showed that reliable ^{14}C ages could be obtained from a certain group of mollusks, "minute gastropods" (~3–10 mm), regardless of their taxonomy, life habitat, or shell morphologies (Brennan and Quade 1997; Pigati et al. 2004).

Heleobia shells have been used for ^{14}C dating of late Quaternary sediment sequences in several studies (Abbott et al. 1997; Golfieri et al. 1998; Bonadonna et al. 1999; Stutz et al. 2002; Espinosa et al. 2003; Tonni et al. 2003; Prieto et al. 2004). Apart from Abbott et al. (1997), no studies have been carried out to test the reliability of these dates. Abbott et al. (1997) estimated a contemporary reservoir age of 250 ^{14}C yr for Lake Titicaca, by measuring the ^{14}C activity on shells of living specimens of *Heleobia andecola*. In addition, they demonstrated that the reservoir effect remained nearly constant during the late Holocene, by measuring the ^{14}C activity of paired samples of *Heleobia andecola* and littoral sedge *Schoenoplectus tatora*.

The ^{14}C measurements on *Heleobia parchappii* shells from Laguna del Sauce Grande are surprisingly consistent, both the ^{14}C activity on shells of living specimens as well as the dates along the sediment sequence, indicating the absence of a reservoir effect.

Several factors would suggest that Laguna del Sauce Grande should be influenced by ^{14}C-deficient bicarbonate: the occurrence of tosca around the northern shore of the lake and in the catchment area, the presence of debris from marine organisms in the surrounding sand dunes, as well as salt spray. Most probably, the large size and the shallow nature of the lake render the influence of the catchment unimportant as the water is constantly well mixed and thus in isotopic equilibrium with the atmosphere (Geyh et al. 1998).

CONCLUSIONS

Interpretation and correction of ^{14}C dates on aquatic material have to be made with caution. Although ^{14}C dating of *Ruppia* and *Heleobia* samples has demonstrated to yield accurate dates in lakes that lack reservoir age problems, they can be susceptible to errors in the presence of ^{14}C-depleted carbon. Even so, no standard rule can be applied when dating aquatic samples from these particular taxa; it is essential to asses their reliability.

1. The reservoir age in the sequence of the paleolagoon La Olla 1 is ~800 ^{14}C yr, measured on *Ruppia* cf. *maritima* samples. The origin of the reservoir effect is attributed to ^{14}C-deficient bicarbonate inwashed from the surrounding sand dunes, which mostly derives from the decomposition of marine organisms and salt spray. The magnitude of this offset is consistent with marine reservoir offsets reported for the region.
2. A reservoir age of similar magnitude likely affected a ^{14}C date on sea mammal bone obtained in previous investigations, as well as the ^{14}C dates from the neighboring sites La Olla 2 and Monte Hermoso I.
3. The reservoir effect at Laguna del Sauce Grande is negligible, if present at all. Living specimens of *Heleobia parchappii* were found to be in equilibrium with the atmosphere. Furthermore, the age-depth relationship for the gastropod shells supports the absence of a reservoir effect. The large size and shallow nature of the lake ensure a good mixing of the waters and thus its isotopic equilibrium with the atmosphere.

This study provides relevant information on the chronology of lacustrine deposits in the south of Buenos Aires Province, permitting a more precise comparison and correlation with other Holocene deposits of the region. The study also provides an example of how the reservoir effect on aquatic remains may differ between lakes in the same geological setting.

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