Detecting Human Presence at the Border of the Northeastern Italian Pre-Alps. $^{14}$C Dating at Rio Secco Cave as Expression of the First Gravettian and the Late Mousterian in the Northern Adriatic Region

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Abstract

In the northern Adriatic regions, which include the Venetian region and the Dalmatian coast, late Neanderthal settlements are recorded in few sites and even more ephemeral are remains of the Mid-Upper Palaeolithic occupations. A contribution to reconstruct the human presence during this time range has been produced from a recently investigated cave, Rio Secco, located in the northern Adriatic region at the foot of the Carnic Pre-Alps. Chronometric data make Rio Secco a key site in the context of recording occupation by late Neanderthals and regarding the diffusion of the Mid-Upper Palaeolithic culture in a particular district at the border of the alpine region. As for the Gravettian, its diffusion in Italy is a subject of on-going research and the aim of this paper is to provide new information on the timing of this process in Italy. In the southern end of the Peninsula the first occupation dates to around 28,000 $^{14}$C BP, whereas our results on Gravettian layer range from 29,390 to 28,995 $^{14}$C years BP. At the present state of knowledge, the emergence of the Gravettian in eastern Italy is contemporaneous with several sites in Central Europe and the chronological dates support the hypothesis that the Swabian Gravettian probably dispersed from eastern Austria.

One of the most debated issue is whether the Gravettian developed from a local Aurignacian [5–8] or results from immigration or cultural diffusion processes through various corridors between European regions [4,9–11]. This paper will not enter into this broader issue, instead it will deal with the Northern Italian evidence and the role of two possible passageways, one from the west (France) and one from the east (Balkan region) [9,12–14].

The earliest Italian Gravettian groups is documented around 28,000 $^{14}$C BP in Paglicci Cave in the southern end of the Peninsula [15–17], and the majority of the sites, adjacent to the two opposite Italian coasts, are recorded at 26,000–24,000 $^{14}$C BP (Figure 1) [12].

All along the Tyrrhenian coast, the lithic assemblages described at Mochi rockshelter and La Cala Cave suggest an influence from the French Gravettian [9,12,18]. In contrast, the conspicuous Gravettian evidence from Paglicci Cave, in the South Adriatic area, shows discrepancy with the Tyrrhenian belt from a technological point of view. This indication suggest signatures of cultural influence from a possible eastern route starting from the Carpathian basin [9] and crossing the trans-Adriatic region, when
the sea level at that time was estimated at about 80 m lower than present day [19,20] (Figure 1). Nevertheless, evidence across the Adriatic coast is still too scanty, mostly due to ephemeral field researches, aside a reduced number of sites; e.g. Broion Rock-shelter and Fonte delle Mattinate and the above mentioned Paglicci Cave [11,21–23].

Moreover, Paglicci is not the key site to understand the issue of the local development of the Italian Gravettian because Aurignacian and Early Gravettian assemblages show an abrupt change with neither transitional nor formative characters [11,14].

As it is shown the Gravettian settlement of Italy is spatially sparse; in this context the recently investigated cave of Rio Secco, located in the northern Adriatic region, provides evidence on the late Mousterian and the earliest Gravettian, due to a set of new radiometric dates on bone and charcoal samples. Considering its geographic setting between the upper Adriatic Plain and the Pre-Alps, Rio Secco Cave holds a strategic position to investigate the mobility pattern of the Palaeolithic hunter-gatherers across the natural corridor between the Italian Peninsula and the Carpathian Basin.

The Site of Rio Secco Cave

Rio Secco Cave is situated in the northeastern portion of the Italian Peninsula, near the village of Clauzetto (Pordenone), at 580 m asl on the Pradis Plateau in the eastern part of the Carnic Pre-Alps. The Pradis Plateau comprise an area of 6 sq km, enclosed on three sides by mountains peaking from 1,148 m to 1,369 m and to the south by the foothills, facing the present-day Friulian Plain (Figure 2). Rio Secco Cave is a large sheltered cave opening on the left slope of a stream gorge at about 20 m above the present day stream bed. Facing south, the shelter has a wide and flat roof derived from the collapse of large slabs of the stratified limestone. The sheltered area is enclosed from the outside by a ridge of large boulders. The cave opens in the middle of the wall and continues as a gallery for 12 m until the sediments completely fill it up. In the outer area the fill forms a slope-waste deposit thickening along the present day drip line where the boulders define the original extension of a vast roof.

The presence of Palaeolithic settlements at Rio Secco Cave was detected in 2002 after a test-pit [24] and an archaeological excavation has been carried out at the site since 2010.
Stratigraphy

The cave is filled with an ensemble of sedimentary bodies of differing volume, shape, composition and origin, grouped into four macro-stratigraphic units and separated by erosional and sedimentary discontinuities [25]. From the top, the macro-units are 1, which originated during historical times, BR1, BR2 and BIO1 (Figure 3).

Macro-unit BR1 includes layers 4 and an anthropic horizon containing Gravettian flint artifacts, layer 6. The most relevant features are angular to subangular stones, with fragments of karst limestone pavement that originated from the collapse of the vault. Layer 6, with organic matter and micro-charcoal has been exposed at the entrance of the cave shelter, approximately 20 cm below the top of BR2: it is thin, planar, discontinuous, and contains rare bones and lithics (Figure 3).

Macro-unit BR2 is a massive open-work stone-supported breccia made of angular boulders and randomly deposited stones. It lies in the external zone but ends 1 m behind the drip line in the SE zone of the cavity, where it seals the layer 5 top. Large patches have been reworked by marmots, as demonstrated by bones, an articulated skeleton found within the tunnels, several burrows and dens.

The sedimentary body below BR2 is composed of stones and loamy fine fraction and is labeled BIO1 due to the intense bioturbation caused by the activity of marmots, responsible for mixing, displacing portions of anthropic sediment, and scattering Mousterian flint implements, bones and charcoals. At the top of this macro-unit, one finds layer 5 top, a brown level of variable thickness with archaeological content. Due to its variable thickness, layer 5 top has been locally divided in two arbitrary cuts, I and II. Below, the loamy, dark yellowish-brown layer 7 has been found only in some squares under the cave vault and not in the external zone, where it is cut by the burrows. The upper boundary with layer 5 top is marked by an increasing frequency of bones and lithics, some of which also bear signatures of accidental heating. Sandwiched between the two anthropic horizons layers 7 and 8, layer 5 is made of stones and loamy fine fraction with dispersed bones and lithic implements frequently affected from post-depositional alteration. Layer 8 continues in the inner cavity and is best described as 10 cm thick, stony, with dark brown loamy fine fraction, frequent tiny charcoals, small and burnt bones. Layer 8 lies over layer 9, possibly a fifth macro-unit, made of stones and yellowish brown sandy-loam, with no charcoal or other finds.

Cultural Sequence

The archaeological contents of BR1 and BIO1 include numerous lithic artifacts ascribed to the Middle Palaeolithic (layers 5 top, 7, 5, 8) and Upper Palaeolithic (layer 6 and correlated arbitrary cuts 4c and 4d) and a few bone retouchers [25]. The Mousterian assemblages are characterized by the use of Levallois and discoid technologies (Figure 4). Layer 8 has yielded scrapers of variable type and size and flakes with patterns typical of Levallois technology. Layer 5 has produced evidence of the use of Levallois technology as well, represented by recurrent unipolar flakes and centripetal flakes and cores, of discoid technology represented from core-edge removal flakes and pseudo-Levallois points and retouched tools, mostly scrapers. Layer 7 has produced flakes and a few tiny scrapers. In layer 5 top lithic items are varied: Levallois and discoid flakes, short blades and short bladelet cores. The Upper Palaeolithic of layer 6 consists of a handful of pieces technologically characterized by blade/bladelet production. The tools are three burins on truncation made on blades and on rejuvenation blades (Figure 4). One of them shows remarkable negatives of several burin spalls, of which one was refitted and for this reason it should be interpreted as a bladelet core. In addition, there are two end scrapers produced on cortical flakes, one of which is thick and large. Among the projectile pieces, we count one backed bi-truncated bladelet, one possibly unfinished backed point and one undeterminable backed fragment.

Evidence for the use of fire has been found in layers 8 and 7 by tiny dispersed charcoals, burnt bones and heat-affected flints. In layer 6 two hearths have been brought to light, even if partially affected from post-depositional disturbances, labeled as US6_SI and US6_SII. The former is an agglomerate of charcoals mostly disaggregated around a large piece of charred wood (Figure 5). This hearth has been cut by illegal excavations in the back of the cave. Traces of ash are lacking, but there is a thin reddish horizon below the level of charcoals. The hearth US6_SII is a small agglomerate of charcoal largely disturbed by several interlaced burrows.

Faunal Remains

Every stratigraphic unit contained animal bone remains. The colonization of the cave fill by marmots is clearly documented by diagnostic signatures observed in BR1 and BR2, such as dens, chambers and articulated skeletons. There are fewer faunal remains in the Gravettian layers in comparison with the Mousterian.

The archaeozoological analysis, still in progress, reveals among the ungulates the presence of caprids (*Capra ibex* and *Rupicapra rupicapra*) and remains of *Bos/Bison* (*Bison priscus/Bos primigenius*). Traces of human modification on the bones include cut-marks on shafts of caprines, partly combusted, and on a marmot clavicle. One partially burned epiphysis of the scapula of *Castor fiber* has been found associated to the hearth US6_SI.

In the Mousterian sequence, carnivores (*bears, cave bears, mustelids and canids*) predominate over the ungulates, which rather than caprids (*chamois and ibex*) or hovids, consist more of cervids such as red deer, roe deer, elk and wild boar (Peresani et al., in press). Bones are mostly fragmented, due to post-depositional processes as well as human and carnivore activity. Human interest in ungulates is evidenced by cut marks on red deer. Also the remains of *Ursus spelaeus* and *Ursus sp.* from layers 7 and 5 top show traces of butchering, skinning and deliberate fracturing of long bones [26].

This faunal association with cervids and, in particular, deer, elk, roe deer and wild boar is indicative of forest vegetation and harsh environment somewhere in the Pradis Plateau. The presence of...
bovids and caprids suggest the existence of patchy woodland compatible with the mountain context. Cave bears were well adapted to this kind of environment, and used the cavities for hibernation, as suggested from the faunal assemblage recovered during the last field-campaigns.

**Materials and Methods**

**Ethics Statement**

All necessary permits were obtained from the Archaeological Superintendence of the Friuli-Venezia Giulia for the described study, which complied with all relevant regulations. The identification numbers of the specimens analyzed are: GRS13SP57-89, GRS13SP57-138, GRS13SP57-133, GRS13SP57-125, GRS13SP57-37, GRS13SP57-11, GRS13SP57-18, GRS13SP57-46, GRS13SP57-2, GRS13SP57-4.

Repository information: the specimen is temporary housed at the University of Ferrara, in the Section of Prehistory and Anthropology, Corso Ercole I d’Este Ferrara, Italy, with the permission of the Archaeological Superintendence of the Friuli-Venezia Giulia.

![Figure 3. Sketch map and section of the site. Position of the excavated area and the stratigraphic exposures: A – section showing portions of layer 6 embedded in macro-unit BR1; B - section showing the Mousterian layers from 5 top to 8; C – the main sagittal section exposed in 2010 with the reworked sediment sealing the Mousterian sequence from 5 top to 8 (after [25]).

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![Figure 4. Lithic implements from Mousterian layers 8, 7, 5 and 5 top. Mousterian layers 8 (1), 5 (6), 7 (2, 3) and 5 top (4, 5). Scraper (1), scraper shortened by distal truncation and thinned on the dorsal face (2), core-edge removal flake from discoid core (3), bladelet core (4), double scraper shortened by proximal truncation (5), Levallois centripetal core (6). Gravettian implements: burin with refitted burin spall (7), end-scraper on large retouched flake (8), possibly unfinished backed point (9), double truncated backed bladelet (10). Drawn by S. Muratori.

DOI:10.1371/journal.pone.0095376.g004](https://www.plosone.org/doi/10.1371/journal.pone.0095376.g004)
Samples Selection and Radiocarbon Pretreatment

We selected 10 well preserved thick cortical bone fragments with and without cut marks from each layer. Four bones from layer 7 (three of them with cut marks), four bones from layer 5 (three with cut marks) and two charcoal samples from the hearth SI of layer 6.

Bone collagen was extracted at the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology (MPI-EVA), Leipzig, Germany, using the ultrafiltration method described in Talamo and Richards [27]. The outer surface of the bone samples was first cleaned by a shot blaster and then 500 mg of bone was taken. The samples were then decalcified in 0.5 M HCl at room temperature until no CO2 effervescence was observed, usually for about 4 hours. 0.1 M NaOH was added for 30 minutes to remove humics. The NaOH step was followed by a final 0.5 M HCl step for 15 minutes. The resulting solid was gelatinized following Longin (1971) at pH 3 in a heater block at 75°C for 20 h. The gelatin was then filtered in an Eeze-FilterTM (Elkay Laboratory Products (UK) Ltd.) to remove small (<80 μm) particles. The gelatin was then ultrafiltered with Sartorius “Vivaspin 15” 30 KDa ultrafilters [28]. Prior to use, the filter was cleaned to remove carbon containing humectants [29]. The samples were lyophilized for 48 hours.

The collagen extract was weighed into pre-cleaned tin capsules for quality control of the material. Stable isotopic analysis was evaluated using a ThermiFinnigan Flash EA coupled to a Delta V isotope ratio mass spectrometer.

The two charcoal samples were sent directly to the Klaus-Tschira-AMS facility of the Curt-Engelhorn Centre in Mannheim, Germany, where they were pretreated with the ABA method [30].

Results and Discussion

14C Results

At Rio Secco Cave the C:N ratio of all the samples are 3.2 which is fully within the acceptable range (between 2.9 and 3.6), and all of them displayed a high collagen yield, mostly ranging between 2.4 to 8.2%, substantially higher than 1% of weight for the standard limit [31,32] (Table 1).

Once these criteria were evaluated, between 3 and 5 mg of the collagen samples were sent to the Mannheim AMS laboratory (Lab code: MAMS), where they were graphitized and dated [30].

The radiocarbon results are listed in table 1. All dates were corrected for a residual preparation background (generally <
The uncalibrated radiocarbon dates of late Mousterian (layer 7) range from >49,120 to 44,560 \(^{14}C\) years BP. The four dates of layer 5 range from 45,740 to 43,210 \(^{14}C\) years BP. The uppermost layer (layer 6), which was identified as a Gravettian layer, ranges from 29,390 to 28,995 \(^{14}C\) years BP. There is no discrepancy between the results obtained on bones with cut marks and without cut marks.

### Discussion of Chronology

A series of radiocarbon dates were previously obtained from layers 8, 5 and 6 [24,25] (Table 2). The two dates in Layer 8 show a strong discrepancy in the results, in fact the ultrafiltered bone gives an age older than 48,000 \(^{14}C\) BP but the charcoal result, pretreated with ABOX-SC, displayed an age of 42,000 \pm 900 \(^{14}C\) BP. The main argument for this difference has to be found, as described above, in the stratigraphic entities of the layer, in fact it contains frequent tiny charcoals of undetermined origin, small bones and burnt bones. Moreover, deformations, removal and various crossings by marmots and other minor bioturbations affect this layer. In addition, a test-pit opened during the last field campaign (summer 2013) had detected no archaeological traces at 1.5 meters underneath this layer, thus excluding possible pollution from older deposits. For this reason we considered the youngest date (OxA-25336, \(^{14}C\) Age 42,000 \pm 900) as an outlier.

Layer 5 has produced an age that is too young compared with our new results (LTL-429A, \(^{14}C\) Age 37,790 \pm 360) [24]. The sample was selected from the test pit investigated in 2002 and at that time it was not possible to recognize bioturbation produced by marmots. This result is not included in the Bayesian model, discussed below.

Two other charcoal samples in layer 6 were dated at Poznan AMS laboratory pretreated using the ABOX-SC method; these results are consistent with our new results. We incorporate them in the Bayesian model for the distribution of ages.

### Comparison with Previous \(^{14}C\) AMS Results

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### Discussion of Chronology

The radiocarbon dates we produced were calibrated using OxCal 4.2 [33] and IntCal13 [34]. (Table 3). The Bayesian model, which was built using the stratigraphic information, includes a sequence of 3 sequential phases, the two Mousterian Layers 7 and 5 top and the Gravettian layer 6 (Figure 6).

The agreement indices were applied to show how the calibrated dates and the stratigraphic information; the results of the outlier detection method confirm ideal posterior probability for all the samples.

The upper boundary of layer 7, calculated by OxCal, ranges from 49,120 to 47,940 cal BP (68.2%); the layer 5 top ranges from 47,940 to 45,840 cal BP (68.2%) (Table 3). Around the Alpine regions Neanderthal sites with comparable age ranges are rare [3,36]. In northern Italy four sites can be considered; Fumane Cave, San Bernardino Cave unit II, Broion Cave and Generosa Cave [3]. In Slovenia on the Škoflja Creek Plateau the Divje Babe I Cave is contemplated [37] and moving east, in the Drava basin, a layer chronologically consistent with Rio Secco, is found at Vindija Cave [38,39].

The charcoal samples, from the archaeological horizon US 6.1 located between layers BR2 and BR1 range from 33,480 to 30,020 cal BP (68.2%) (Table 3). These ranges clearly place the upper part of Rio Secco in the early Gravettian period and confirm its archaeological assessment.

It should be noted that the charcoal samples dated at Mannheim yielded consistent age with the previous radiometric dates obtained at Poznan for the same horizon.

Here it is useful to remember that strong progress has been achieved in the last decade on the radiocarbon method. Calibration is now possible back to 50,000 cal BP [34,40] and claims of fundamental limitations are not justified [41]. Moreover, sample selection and specific pretreatment procedures to remove modern contaminations have been significantly improved [27,42–44].

An accurate sample selection, more specialized pretreatment protocols, the control of isotopic values of bone collagen, in case the samples pretreated were bones and the requirement of several dated samples per layer are fundamental criteria that should be considered in order to establish the radiocarbon chronology of the archaeological sites.

Normally the risk of underestimating the true age of the samples is higher when the samples are at the limit of the radiocarbon method. However the chronological reassessment of Geißenklösterle, Abri Pataud, Fumane Cave and Mochi rockshelter sites [45–

### Table 2. Previous radiometric dates of Rio Secco Cave obtained in 2002.

<table>
<thead>
<tr>
<th>Context</th>
<th>Nature</th>
<th>Lab. Ref.</th>
<th>(^{14}C) age BP \pm 1\sigma Err</th>
<th>Cal. BP 1\sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>6, sq.J11, n.3</td>
<td>Charcoal</td>
<td>Poz-41207</td>
<td>27,080 \pm 230</td>
<td>31,240–30950</td>
</tr>
<tr>
<td>6, sq.J11, n.4</td>
<td>Charcoal</td>
<td>Poz-41208</td>
<td>28,300 \pm 260</td>
<td>32,600–31740</td>
</tr>
<tr>
<td>5, GRSI</td>
<td>Bone</td>
<td>LTL429A</td>
<td>37,790 \pm 360</td>
<td>42,360–41850</td>
</tr>
<tr>
<td>8, sq.H11V, n.17</td>
<td>Charcoal</td>
<td>OxA-25359</td>
<td>42,000 \pm 900</td>
<td>46,220–44560</td>
</tr>
<tr>
<td>8, sq.H12V, n.12</td>
<td>Bone</td>
<td>OxA-25336</td>
<td>&gt;48,000</td>
<td>Infinite</td>
</tr>
</tbody>
</table>

Calibrated ages at 1\sigma error, using OxCal 4.2 [33] and IntCal13 [34].

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which are comparable with the Rio Secco age range, (Table S1)
layer II, Brillenhöhle, Weinberghöhlen and Willendorf II layer 5,
sites of Dolní Vstonice II, Pavlov I, Prˇedmostí I and Krems
complex, named the Pavlovian, [54,55]. It is represented at the key
southern Poland one finds a second early Gravettian techno-

innovations from the Aurignacian substrate was suggested at
East [49], a local development of the Gravettian technological
have been detected with the Ahmarian assemblages of the Near
last phases of the Aurignacian [49]. Although some similarities
Carnic Pre-Alps [25]. However, further investigation is required.

The appearance of the early Gravettian in Europe predates the
last phases of the Aurignacian [49]. Although some similarities
have been detected with the Ahmarian assemblages of the Near
East [49], a local development of the Gravettian technological
innovations from the Aurignacian substrate was suggested at
Geißenklösterle in layer AH II [50] and at Abri Pataud in layer 6
[51]. Generally speaking the Gravettian might be interpreted as a
macro techno-complex characterized by different and synchronic
graphic variants [52]. To the north of the Alps, the key
Swabian Gravettian facies include the lithic assemblages of the
sites Geißenklösterle layer AHI, Hohle Fels layer II, Sirgenstein
layer II, Brillenhöhle, Weinberghöhlen and Willendorf II layer 5,
which are comparable with the Rio Secco age range, (Table S1) [53].

In central Europe between northern Austria, Moravia and
southern Poland one finds a second early Gravettian techno-
complex, named the Pavlovian, [54,55]. It is represented at the key
sites of Dolní Vstonice II, Pavlov I, Prˇedmostí I and Krems
[49,56], which are contemporaneous with Rio Secco layer 6
(Table S1) [57]. This cultural entity differs from the Swabian
Gravettian due to the presence in the toolkit of geometric
microliths, micro-burins and Pavlovian points [53].

Furthermore, in the Italian Peninsula local developments of the
Gravettian have not been recorded so far [11] and the similarities
documented in the lithic assemblages of level 23 of Paglicci Cave
and Kostenki 8/II [16,58] draw attention to the broader
Gravettian diffusion from central Europe.

Current evidences make us inclined on the cultural diffusion
hypothesis, and the Rio Secco site provides new insight on the two
natural corridors used to reach the Italian Peninsula, the Adriatic
southern coast from Croatia [9,20] and the bridge to the north-
est from the Carpathian regions. Further researches on the raw
materials provenance will shed light on the exploitation of

southern or eastern Alpine outcrops determining the foraging
radius of these earliest Gravettian groups.

Conclusion

At the junction between the North Adriatic Plain and the
eastern Alps, the chronometric refinement of a new site, Rio Secco
Cave, contributes to enhance the investigation of the prehistoric
human occupation during the mid-Late Pleistocene. Although not
completely explored, Rio Secco Cave fills an important chrono-
logical gap and preserves an archive of potential interest for
understanding the study of the late Neanderthals, the dispersal of
Mid-Upper Palaeolithic populations and the diffusion of the
Gravettian culture. Nevertheless, the new set of dates does not
cover the millennia of the Middle-Upper Palaeolithic transition in
the second half of MIS3, a period chronometrically secured from
key-sequences in neighboring regions [45]. Before claiming human
ecological or economic factors leading to this dearth of evidence,
more data are required from the study of the stratigraphic
sequence. The detection of possible stops in the gradation
processes of the cave deposit, which may have produced
alterations, consolidations, weathering or, alternatively erosions,
could explain the complete removal of traces of Aurignacian
occupations.

The continued implementation of the project with fieldwork
and laboratory studies will provide new elements necessary to
better understand the settlements in this area, previously
considered so marginal in comparison with the North Adriatic
Plain, extending towards the south. At the present stage of
research, the Gravettian archaeological record at Rio Secco Cave
is scarce compared with the Mousterian one, due to the thinning
of layer 6 and its partial reworking produced by illegal excavations
in the inner cavity. We cannot exclude that the rockfall that
occurred after the late Middle Palaeolithic transition of
the early Gravettian time period. At the present state of
knowledge, with our new 14C dates, the emergence of the early
Gravettian in eastern Italy is contemporaneous with the Swabian
Gravettian and the Pavlovian.

The broad expansion of Swabian Gravettian and Pavlovian
 techno-complexes is explained by high mobility patterns of the
hunter-gatherers with transport of exogenous raw materials up to
Figure 6. Calibrated ages and boundaries. Calibrated ages and boundaries calculated using OxCal 4.2 [33] and IntCal13 [34]. Rio Secco ages are in black and the previous radiometric results from Poznan (Lab. code Poz-) are in red. The results are linked with the (NGRIP) δ18O climate record. doi:10.1371/journal.pone.0095376.g006
 Supporting Information

Table S1 Radiocarbon dates on key Gravettian sites [1–12].

Acknowledgments

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Author Contributions

Conceived and designed the experiments: ST. Performed the experiments: ST. Analyzed the data: ST. Contributed reagents/materials/analysis tools: MP MR RD CJ NN A. Picin MV A. Pastors GCW. Wrote the paper: ST MP JJH MR A. Picin RD CJ NN.