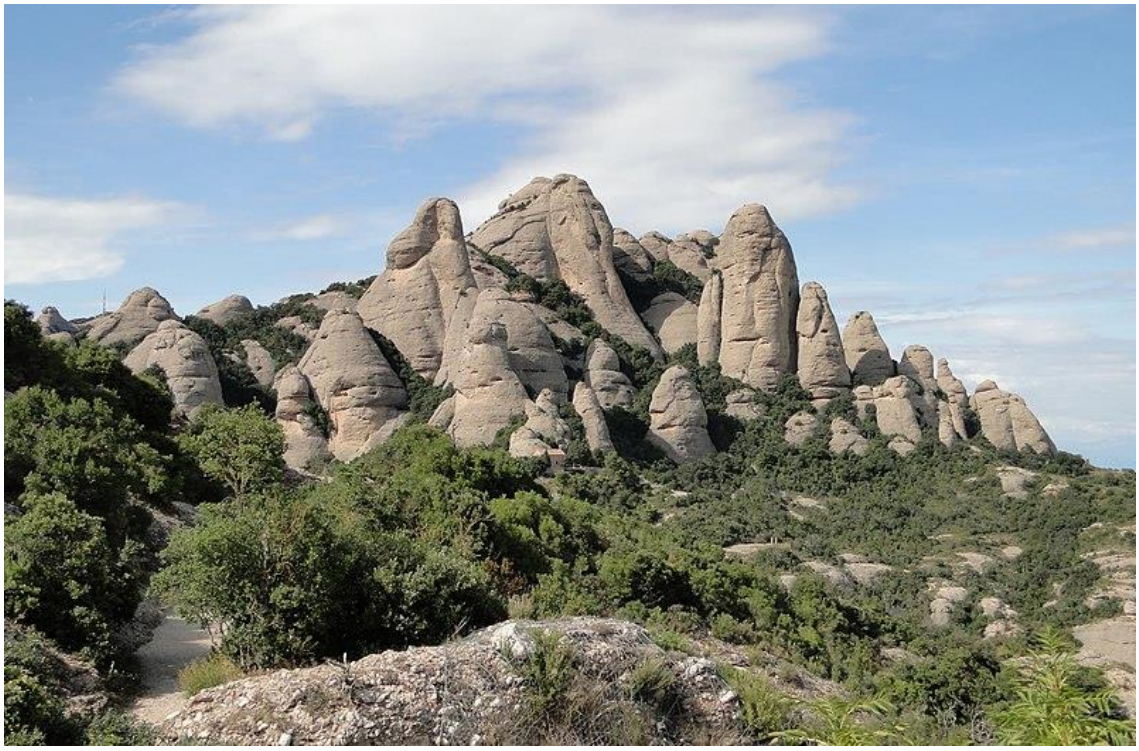
International Erasmus Mundus Master in
QUATERNARY AND PREHISTORY



The Paleoenvironmental reconstruction of Cova Gran using Stable Isotope Analysis

Mathias Brummelhuis

Supervisor: Carlos Tornero

Academic year 2023/2024

Cover photo: Photo of Monserrat (Bernard Gagnon)

Acknowledgements

Thank you to Carlos for accepting to invite me to his laboratory and learn collagen analysis

Thank you to Marie for introducing me to stable isotope analysis, a discipline which I hope to continue to contribute in

Thank you to Rafael who taught me different aspects of paleoenvironmental studies

Thank you to Juan Ignacio and Juan for allowing me to study this site and use their faunal remain

Table of Contents

Introduction

Cova Gran is a site part of the archaeological caves in the Monserrat Massif, located 30 km from Barcelona (Fig. 1). It contains layers from the Late Pleistocene to the Neolithic. The site contains relatively well-preserved faunal assemblages mainly dominated by caprines and leporids (Marin, in press) and sits at an altitude of 500m (Oms et al., 2019).

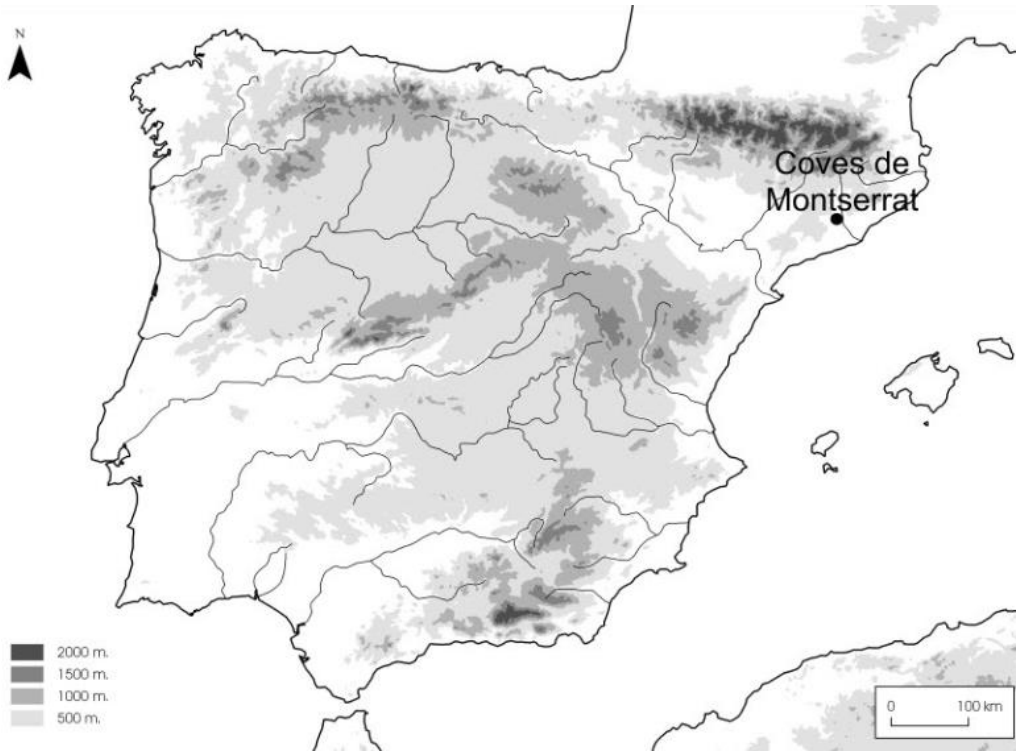


Fig. 1: Map of the archaeological caves in Spain (Oms et al., 2019)

Over the past decade stable isotope analysis has rapidly developed in order to reconstruct multiple aspects of animals' lives and their environment. This method continues to expand providing new ways of interpreting data and being applied to new taxa.

In the north-eastern Iberian Peninsula, there are already several stable isotope studies focusing on either diet (Garcia-Guixé et al., 2009; Drucker et al., 2021; Naito et al., 2022) or paleoenvironment during the Late Pleistocene (Stevens et al., 2014; Fernández-García et al., 2019; Pederzani et al., 2023).

Pastoralism and the seasonal altitudinal mobility of caprines have been a key activity in the north-eastern Iberian Peninsula as far back as the Neolithic (Tejedor-Rodríguez et al., 2021) This was likely inherited from the non-domesticated predecessors of *Capra* that naturally performed seasonal altitudinal mobility. This behaviour allowed animals to adapt to the different seasonal conditions throughout the year favouring higher altitudes during summer where more resources could be found and descending to the lowlands in winter for to milder climatic conditions.

Seasonal altitudinal mobility has been studied in sheep through the sequential isotope analysis of carbon and oxygen (Balasse et al., 2012, 2024) but little has been done for wild goats, especially during the Pleistocene. The presence of *Capra pyrenaica* (Ibex) remains in Cova Gran mountainous region this provides an opportunity to observe the seasonal altitudinal mobility of Ibex in the region. Simultaneously, this allows to check the validity of the method to study this mobility in areas with a lower differential in altitude considering the Monserrat massif culminating at 1 236m (topographic-map.com).

Another application of stable isotope analysis lies in its use in palaeoclimatological and paleoenvironmental reconstruction. Using stable isotopes has been shown to provide benefits over other forms of paleoenvironmental and palaeoclimatological reconstruction. The main advantages is that it offers a more local paleoenvironmental reconstruction that is less affected by errors induced by anthropic biases in other methods. The preferential accumulation of certain taxa in faunal assemblages is actually useful as this allows for the paleoenvironment to be directly associated to hominins (Pederzani et al., 2023). These factors allow for a better understanding of site-specific subsistence strategies (Britton et al., 2022). Stable isotope analysis has shown to be a good addition to paleoenvironmental reconstructions in tandem with other commonly used methods such as palynology or archaeozoological studies.

In stable isotope analysis many of the same large mammals are used as they are known to provide relevant information through this method. With time, this is also being applied to small mammals. *Oryctolagus cuniculus* (Rabbits) have been briefly used in stable isotope analysis showing links to certain palaeoclimatological and paleoenvironmental parameters, including temperature aridity and plant composition (Delgado Huertas et al., 1995; Garcia-Guixé et al., 2009; Somerville, 2015). But actual applications on archaeological remain are rare and have mainly been confined to studies in the Americas. In Europe, specifically around the Iberian Peninsula, these animals have not been used extensively despite the abundance of remains found on different sites and their potential as a paleoenvironmental marker. In Cova Gran, rabbit is one of the most abundant faunal taxa. In this paper, rabbits will be used as one of the main paleoenvironmental markers alongside ibex, providing variety in the taxa represented to avoid certain biases.

The objectives of this paper are three-fold: Firstly, to study the behaviour of *Capra pyrenaica* during the Late Pleistocene to see if seasonal altitudinal mobility can be observed through sequential analysis. Secondly, to see if *Oryctolagus cuniculus* can be used as a paleoenvironmental and palaeoclimatological marker during the Late Pleistocene in the Iberian Peninsula. Lastly, to

reconstruct the paleoenvironment and paleoclimate of the site of Cova Gran in order to better understand the subsistence behaviours observed at the site during the Late Pleistocene.

I. Context

I.1 Principle of Isotope Analysis

Stable isotope analysis began to gain popularity as a method in archaeology during the 1970s when it was used as an indicator of corn being introduced into the diet of Paleoindians over time on the site of Parmana (van der Merwe et al., 1981). From that point on, many different types of isotopes were used to answer questions concerning diet, mobility, paleoenvironmental and paleoclimatic parameters.

The main principle that allows for stable isotope analysis to be used on archaeological remains is known as isotopic fractionation. Due to isotopes of a same element being chemically identical but having a different weight they will react differently to certain biological phenomena. This will lead to a change in the proportion of a lighter and heavier isotope in materials. As such, this change in proportion can be linked to a biological phenomenon in some cases, such as the case for the stable isotope ratio carbon values that differ due to their photosynthetic pathways (Kohn, 2010) that is then passed along to herbivores when consumed.

Stable isotope values are represented using the notation "δ" and is defined by the following equation (using stable carbon isotopes as an example):

$$\delta^{13}C = \left\{ \frac{\left(\frac{^{13}C}{^{12}C}\right) sample}{\left(\frac{^{13}C}{^{12}C}\right) reference} - 1 \right\}$$

The two materials from which these stable isotopes will be extracted in this study are bone and tooth. From bone collagen, it is possible to extract $\delta^{13}C$, $\delta^{15}N$. Due to the characteristic of bone renewing itself over the course of an individual's lifespan, stable isotope analysis on bone gives a view on the last few years of an individual. In tooth, enamel is sampled from which it is possible to extract $\delta^{13}C$ and $\delta^{18}O$. Due to the mineralization process of tooth enamel after its formation the stable isotopes will not change; and after sedimentation, the effects of diagenesis tend to be minimal. As such this will give insight into the early years of an individual over a fixed period.

I.1.a Carbon

Carbon was the earliest isotope to be used in archaeological research through the ratio of $^{13}C/^{12}C$ in bone or teeth. This ratio is influenced by the diet of an individual and will be passed along the food chain. In the case of herbivores, the $\delta^{13}C$ of plants will be inherited and their ingestion and digestion of plants will lead to an isotopic enrichment. As such, the $\delta^{13}C$ of herbivores is dependent on that of plants (Thorp and van der Merwe, 1987). These plants $\delta^{13}C$ will vary according to their physiology as well as due to environmental conditions.

The variation in $\delta^{13}C$ due to plant type can be largely categorised into two groups: C3 and C4 plants. These plants differ in the photosynthetic process that takes place in the stomates. The stable carbon isotopes forming CO_2 used to form sugars in plants can vary according to environmental conditions. In more humid conditions, the stomates of the plant will be more open and thus be able to take in more CO_2. There is then a discrimination and lighter isotopes will be selected for making sugars ($^{12}CO_2$). However, in drier conditions where the stomates are more closed, CO_2 is harder to intake and thus less discrimination occurs, leading to a higher $\delta^{13}C$ (Kohn, 2010). Seeing as how these $\delta^{13}C$ values are then passed onto herbivores, it becomes possible to determine if an animal was in an open and drier climate or if it spent its time under a more humid or temperate climate. C3 plants tend to have a carbon isotopic range from -20 to -37‰ (Kohn, 2010). These values must be adjusted to a pre-industrial ecosystem (+1.5‰) (Friedli et al., 1986) There is also a third type of plant group known as CAM similar to C4 plants.

It is considered that Europe's vegetation cover has been composed almost completely of C3 plants throughout the Late Pleistocene (Ehleringer et al., 1997) . It should then be noted that the variation in $\delta^{13}C$ not only occurs between C3 and C4 plants but can occur within a same group. A leading cause of this effect is known as the "Canopy effect". If the stable isotope values of two herbivores are compared, with one living in a forested area with a closed canopy and the other one living in an open plain, the individual living in the forest will display a lower $\delta^{13}C$ (Drucker et al. 2008). This change in stable isotope values despite originating from the same plant group is due to several factors. Firstly, the decrease in light intensity under the canopy leads to a less productive photosynthesis, resulting in a higher fractionation and a decrease in the relative abundance of ^{13}C (Van der Merwe and Medina 1990; Bonafini et al., 2013). Secondly, in a closed environment there is a poor ventilation and recycling of ^{13}C depleted CO_2. This general decrease in the abundance of ^{13}C is then passed along the food chain (Drucker et al., 2008). A vertical gradient also exists in forests with the lowest isotopic values appearing at the forest floor allowing for a differentiation to be made

between grazing and browsing herbivores. Carbon isotope discrimination also found to decrease with increasing altitude (Korner et al., 1991) leading to an increase in $\delta^{13}C$.

Another application of $\delta^{13}C$ is it's use as a proxy for paleoclimate through mean annual precipitation (MAP). This was first discussed by Stewart et al. (1995) and later further refined in Kohn (2010) and Rey et al. (2013). Through these studies it was noted that a negative correlation could be observed between $\delta^{13}C$ and MAP, with higher $\delta^{13}C$ values being correlated to lower MAP and lower $\delta^{13}C$ values being correlated to higher MAP. This effect would start to flatten out in areas with a higher MAP possibly indicating that there was a near constant isotopic discrimination in wet environments. This non-linear regression can be used in animal bone and tooth to reconstruct paleoclimates, once $\delta^{13}C$ was adjusted for altitude, latitude and animal physiology. The method is more limited in areas with high precipitation or in forested areas where there isn't currently as much information. This is further discussed in the materials and methods section.

There are however limits to this method. Firstly, it is only applicable in an environment composed of C3 plants, this is because C4 plants, presenting higher $\delta^{13}C$ values, would naturally give values that resemble an area with low MAP. Additionally, in arid environments there are some cases in which the $\delta^{13}C$ of plants could be decreased despite not having a high MAP such as fog or plants in crevices in which water naturally accumulates. Another aspect to keep in mind is that it is better to look at several taxa within a locality and that only looking at one type of taxa will naturally bias the results as different taxonomic groups tend to eat specific plants (Kohn, 2010).

I.1.b Nitrogen

The isotopes of $^{15}N/^{14}N$ are observed when looking at $\delta^{15}N$. The fractionation of these isotopes is passed along the diet just like stable carbon isotopes and has often been used as a marker of diet and trophic levels. The value $\delta^{15}N$ is first influenced by plants and their ability to ingest nitrogen from their surroundings. In leguminous plants this is done with the help of symbiotic bacteria hosted in the roots allowing the plant to use nitrogen directly from the atmosphere, their $\delta^{15}N$ is generally close to the atmospheric standard (AIR) of 0‰ (Hoefs, 1997). Non-leguminous plants depend on the nitrogen sources present in soil such as ammonium or nitrate. Plant $\delta^{15}N$ has been shown to correlate with temperature, likely linked to the intensity of soil nitrogen cycling (Amundson et al., 2003). In colder environments, soil activity is generally reduced due to factors such as permafrost whereas in warmer climates more nitrogen moves from organic to mineral pools (Handley et al., 1999; Amundson et al., 2003; Stevens et al., 2014), this process is subject to the discrimination of ^{14}N through leaching, denitrification and ammonia volatilisation leading to a higher $\delta^{15}N$ in soil and plants (Austin and

Vitousek, 1998; Handley et al., 1999). Additionally, $\delta^{15}N$ has been shown to increase with altitude (Mariotti et al., 1980).

Following the interactions between plants and soil, the value of $\delta^{15}N$ will increase as it is passed down the food chain. Due to urea the lighter nitrogen isotopes (^{14}N) will be excreted and leave more of the heavy isotopes (^{15}N) within the animal. This process continues along the food chain with a spacing between 3-5‰ between each trophic level (Minagawa & Wada, 1984).

I.1.c Oxygen

When studying oxygen isotopes, the ratio of $^{18}O/^{16}O$ is studied. The values of $\delta^{18}O$ in large mammals are closely related to $\delta^{18}O$ values in local precipitation (Land et al., 1980; D'Angela and Longinelli, 1990). These $\delta^{18}O$ values change across seasons, with higher $\delta^{18}O$ precipitation values occurring in summer and lower $\delta^{18}O$ precipitation values occurring in winter (Rozanski et al., 1993). These cycles are recorded in tooth enamel during mineralization and depending on the growth period of an individual can record information between 1 and 2 years in large mammals. In the case of *Capra*, a study done on a feral group of goats from Scotland suggested that the m2 begins forming at 12 months and finishes at 24 months. and the m3 begins forming at the second year and finished at the age of three (Bullock and Rackham, 1982). Tooth growth rate is fixed within a species allowing for the seasonality of birth within a population to be studied, although some interindividual variability will be present due to slight differences in tooth eruption (Bryant et al., 1997; Balasse et al., 2003). Another aspect that affects $\delta^{18}O$ values is the altitude effect. As altitude increases, $\delta^{18}O$ will generally decrease due to ^{18}O being preferentially selected for condensation, leading to ^{18}O-depleted environments in high altitudes. This is further accentuated by the presence of melt water from surface snow that is also naturally be ^{18}O depleted (Rozanski et al., 1993).

Due to the link between the $\delta^{18}O$ of large mammals and the $\delta^{18}O$ of local precipitation, this isotopic ratio has also been used in paleoenvironmental studies to reconstruct paleotemperatures, specifically mean annual temperatures (MAT). The connection between the $\delta^{18}O$ of large mammals and local temperatures was first shown by Dansgaard (1964) and throughout time was further improved upon. The present study uses the refined results applied by Pryor et al. (2014). From this study Excel sheets were provided that could be used to replicate the methods on other assemblages.

Generally, paleoenvironmental studies use the phosphate moiety of tooth enamel as the vast majority of modern calibration data uses the $\delta^{18}O$ of phosphate (Pryor et al., 2014; Pederzani et al., 2023). However, in this study, the carbonate moiety of the enamel was used. Thus, a conversion must be made between carbonate values to phosphate values. In some studies, it has been shown that these

two values are closely correlated with an r^2 close to 1; thus, this conversion shouldn't incur many errors (Pryor et al., 2014). However, this is debated with some studies showing that errors of up to 1.5‰ can occur (Pellegrini et al., 2011). In the case of this study, as phosphate $\delta^{18}O$ values were unavailable, the conversion from $\delta^{18}O$ of carbonate was made but it should be noted that the paleotemperatures would only be approximations with the possible errors induced by the conversion from carbonate to phosphate values.

To convert $\delta^{18}O$ values to MAT a series of conversions must be done. Using $\delta^{18}O$ values obtained from bone or teeth, a species-specific conversion must be applied to obtain the $\delta^{18}O$ of local precipitation. The oxygen isotopic composition of meteoric water is affected by altitude, rainfall amount, temperature, humidity and seasonality to varying degrees. A selection of data points from the Global Network of Isotopes in Precipitation (GNIP) is then selected in accordance with the origin of the material being studied and at which scale the paleotemperatures will be compared. The data points from the GNIP will give an equation obtained from a linear regression that can then be used on the archaeological samples to obtain a temperature. The results may vary depending on which stations were chosen as well as what time frame was selected, such as the warmest or coldest months. These must be carefully considered depending on the study (Pederzani et al., 2023).

I.2 Ethology of *Capra pyrenaica*

Capra pyrenaica (Schinz, 1838), more commonly known as the Iberian Ibex is a medium sized Bovidae that distinguishes itself from other species of *Capra* by the morphology of its horns and the texture of its pelt (Granados et al., 2007).

The Iberian ibex is endemic to the Iberian Peninsula and populations of this species are found in scrublands or in areas with coniferous trees (Granados et al., 2007). The current distribution of Ibex is in the main mountain ranges of Spain and Portugal as well as certain parts of the Alps (Acevedo & Cassinello, 2009). The altitude at which the Iberian ibex can be found varies greatly, anywhere from sea level to 3 400 m has been reported (Villaret et al., 1997; Granados et al., 2007).

In terms of physical characteristics, the Iberian ibex weights 31 – 90 kg (Granados et al., 2007) shows a strong sexual dimorphism with females weighing 33.11 kg on average and males 54.51 kg (Fandos and Vigal., 1989). Additionally for males, their horns have an "S" shape as well as a mane and a beard whereas females will have a smaller more cylindrical lyre shaped horn (Granados et al., 2007). A difference in size has also been observed between Iberian ibexes from the North that tend to be larger than those in the South (Granados et al., 2007).

In terms of reproduction, the Iberian ibex has a fixed rutting season, around the end of Autumn and the start of Winter, with gestation lasting approximately 155 days and births generally occur between April and June (Alados and Escos, 1988; Granados et al., 2007). Females can begin reproducing at around 30 months and apart from rare cases only give birth to one individual per rutting season (Granados et al., 2007).

Concerning feeding habits, the Iberian ibex is capable of both browsing and grazing depending on plant availability with a preference for grazing (Gradanos et al., 2007). The percentage of both types of resources have been linked to altitude (Martinez, 1994), geography (Granados et al., 2007), season and population density (Garcia-Gonzalez & Cuartas, 1992). They are known to compete for resources with other ungulates including goats (Alados and Escós, 2017)

One of the main characteristics of Iberian ibex distribution is its seasonal altitudinal mobility. During summer populations of this species can be found at high altitudes due to the high resource availability (Gonçales, 1982, as cited in Avecedo & Cassinello, 2009). During the other seasons, the ibex will descend from these high altitudes as conditions become colder, with snow forming and covering resources leading to living conditions becoming uninhabitable for these populations. Additionally, populations of male and female Iberian ibex stay separated up until rutting season. This has been attributed to a mix of factors: predation risk, forage selection and activity budget (Granados et al., 2007; Acevedo and Casinello, 2009) although some exceptions have been observed in smaller populations (Gonçales, 1982, as cited in Avecedo & Cassinello, 2009).

I.3 Ethology of *Oryctolagus* cuniculus

Oryctolagus cuniculus (Linnaeus, 1758) commonly known as the European rabbit is a small lagomorph that is a part of the Leporidae family. The earliest fossils of this species were found in the Iberian Peninsula, dating back to 0.6 Mya (Donard, 1982). This animal generally weights between 1 – 2 kg (Brambell, 1944; Villafuerte, 2007).

Rabbits have a high reproductive capability, females an give birth throughout the year, with the main factor contributing to females going into heat being protein intake. For males, spermatogenesis has been found to be influenced by photoperiod although this has been shown not to be a limiting factor at the latitudes of the Iberian Peninsula. Thus, reproduction in rabbits is generally dependent on the quality and quantity of food, as well as the temperature and intensity of rains (Villafuerte, 2007). The reproductive cycle lasts from November to June according to available literature but there are cases of birth that occur outside of this period. Additionally, female rabbits can give birth to up to 12 individuals, with an average of 2 – 4 individuals (Villafuerte, 2007).

They have a variable diet, capable of both browsing and grazing, adapting according to the plants available in their current habitat. This allows them to avoid competition with other herbivores, taking resources that are generally not consumed. They do have a general preference for gramineous plants, composite plants and legumes, all of small size (Villafuerte, 2007). In terms of hydration, rabbits are non-obligate drinkers (Delgado Huertas et al., 1995) and obtain most of the water necessary for their survival directly from plants.

They are a highly ecologically flexible species with a worldwide presence, present in all the Iberian Peninsula, southern France, the Canary isles, Balearic isles and Northern Africa. They have also spread to the British Isles, New Zealand, Australia, South Africa, and the Americas as well as other smaller Mediterranean, Atlantic and oceanic islands (Villafuerte, 2007). Several factors determine the suitability of a habitat for rabbits. Firstly, the terrain should allow for the construction of burrows. The size of these burrows depends on the size of the population and resources available. Secondly altitude plays an important role with rabbits becoming much rarer after 1 500m of altitude. Finally, rabbits are generally found in continental and mediterranean climates. The densest populations are found in pastures with bushes; generally, rabbits are more prosperous in warm and arid conditions (Villafuerte, 2007).

The ecological plasticity of this animal along with the fact that they tend to live within a smaller area of 1 – 2ha compared to large herbivores (Villafuerte, 2007; Wicks et al., 2015) and its reproductive capabilities likely contribute to its large presence on archaeological and paleontological sites therefore making it useful for paleoenvironmental reconstruction.

I.4 State of research on palaeoclimatological reconstructions

The paleoenvironment in the north-eastern Iberian Peninsula has been studied using many proxies including palynological records and faunal assemblages. Throughout the climatic cycles of the Pleistocene this region often had peculiarities compared to the rest of Europe, due to its position in the South just like the Balkans and Italy but also due to its mountainous geography (Fletcher et al., 2010). Due to the influence of both the Atlantic and mediterranean wind currents, this was also a zone with a high diversity in regional climates and vegetation (Sánchez Goñi et al., 2000)

The region has often had a milder climate during stadials and was one of the glacial refuge zones for fauna and hominins during periods such as the Last Glacial Maximum (LGM) or various Heinrich events (Sommer and Nadachowski, 2006). In certain areas, the cover of woodland would even be maintained to a certain degree (Fletcher et al., 2010a; Fletcher & Sánchez Goñi, 2008; Sommer & Nadachowski, 2006).

The end of the Late Pleistocene is of particular interest in this study as levels 201 and 200 of Cova Gran (12 033 – 11 847 Cal BP and 11 942 – 11742 Cal BP) were dated back to the middle and end of the Younger Dryas (12 900 – 11 700 BP) (Rasmussen et al., 2014), using radiocarbon dating. This was an arid onset and cold period (Fletcher et al., 2010b). This period has been shown to be separate from the Early Late Pleistocene and the Holocene with the strong presence of *Microtus arvalis-agrestris*, a taxon linked to open environments, and colder environments (Fernández-García et al., 2016). However, through the study of micro-faunal assemblages it was proposed that some open forests were maintained during this time, linked to the presence of *Apodemus sylvaticus* and *Eliomys quercinus* (Fernández-García et al., 2016). It is also worth noting that the site of Galls Carboners in the same region during the same period, showed a strong presence of *Apodemus sylvaticus*, a taxon linked to forested landscapes (Fernández-García et al., 2016) showing not all sites followed the regional pattern. In the transition from the Late Pleistocene to the Holocene, a warmer climate was observed, reintroducing forest covers in many areas however at higher altitudes, the environmental conditions were preserved for species living in open environments (Fernández-García et al., 2016) but it was pointed out in Fletcher et al (2010b) that during the Pleistocene – Holocene transition there was a large variability in temperature and moisture.

Following this pattern, it would be expected from the results of this study that levels 201 and 200 of Cova Gran would reflect a colder, more arid environment with possibly relatively warmer conditions being observed in level 200 as it was dated back to the end of the YD and close to the beginning of the Holocene. The results of outlier sites such as Gall Carboners and the effects of altitude on the environment should however be kept in mind as it is evidence that not all sites will follow a regional pattern in the paleoenvironment of north-eastern Iberia.

I.5 Subsistence strategies in during the Magdalenian in the NE Iberian Peninsula

Subsistence strategies during this period were dependent on the location of hunter-gather groups in Catalonia, although there are some general common points. The rabbit has always been a large part of the subsistence strategies of groups in the Iberian Peninsula during the late Pleistocene, being present in faunal assemblages during the Gravettian, Magdalenian and Azilian. A notable increase is to be noted during the Magdalenian (Fullola et al., 2012).

To the south of the latitude 42° N there is a predominance of red deer on site, with an absence of horse (*Equus caballus ferus*); also identified is the use of a terrestrial gastropod, *Cepaea nemoralis* that would eventually spread north during the Epipaleolithic (Fullola et al., 2012). To the north of this latitude, the red deer is still present but horse also appears in faunal assemblages. There is also an

occasional occurence of the reindeer (*Rangifer tarandus*) that would have needed to cross over from the Pyrenees to reach the region (Fullola et al., 2012). In terms of avian species, the bustard (*Otis tarda*) was shown to be hunted often (Fullola et al., 2012). Finally, at sites associated with high altitudes, at the base of mountainous regions, the iberian ibex can often be found. In these cases, sites are located at strategic points where populations of ibex would have had to pass through during their seasonal migrations; and the human populations occupying these sites were highly specialised hunters of ibex (Fullola et al., 2012).

I.6 State of research on rabbit isotopes

Using stable isotopes on rabbit remains a relatively new approach. Generally, rabbits have been used to tackle dietary questions of isotope analysis (Somerville et al., 2016, 2017) with few studies looking at the paleoenvironmental or palaeoclimatological reconstruction potential of this taxon. The main issue when using leporids in palaeoclimatological reconstruction is that they are non-obligate drinkers. This means they do not drink directly from rainwater but rather get sufficient hydration from water stored in leaves (Delgado Huertas et al., 1995). Because of this there is no correlation between the $\delta^{18}O$ of leporids and the $\delta^{18}O$ of precipitation (Delgado Huertas et al., 1995) and the usual methods to reconstruct MAT is not available.

Those that have done environmental studies mainly focus on North American or Central American sites (Passey & Cerling, 2006; Somerville, 2015; Somerville et al., 2018, 2020) and it has been shown that through rabbit remains many different factors can be studied: relative humidity (RH) (Delgado Huertas et al., 1995), temperature and MAP (Somerville, 2015), landscape composition (Smith et al., 2014; Wicks et al., 2015), soil salinity (Ugan and Coltrain, 2011). In the more recent works, these correlations have been used to compare the paleoenvironments between different sites and regions and some preliminary studies have shown that it was possible to look at temporal variations of paleoclimate and paleoenvironment on one site (Somerville et al., 2019).

In the case of Cova Gran, as only one site is being studied, this paper will further delve into the applications of stable isotope analysis of rabbits from one site across different layers. It is also worth noting that the main works on stable isotope analysis of leporids, for paleoenvironmental reconstructions, are generally done only taking those taxa into consideration. In this study, as caprines will also be analysed it will be useful to verify the validity of the results obtained from rabbit remains and will show if rabbits provide additional insights that would otherwise go unnoticed.

I.7 State of research on *Capra*

The altitudinal mobility of caprines has mainly been investigated through sheep remains and goat remains in different regions of the world including East Africa (Balasse and Ambrose, 2005), North America (Fisher and Valentine, 2013), Armenia (Tornero et al., 2016). Of particular interest are the studies done around the Pyrenees and northeastern Iberia (Knockaert et al., 2018; Tornero et al., 2018; Messana et al., 2023) due to their proximity with the study site; they note that seasonal altitudinal mobility has been observed in caprine populations present in the region at different points but only during the Holocene. In another significant study, Tornero et al. (2016) focused on populations of mouflon (*Ovis orientalis*) from Armenia; this is interesting due to the study of wild rather than domestic animals and it was done on a collection dating back to the Pleistocene. Finally, in Knockaert et al. (2018) an Iberian Ibex was also a part of the studied fauna and presented some interesting results that will be discussed further on .

These studies have focused on either modern populations to better understand the principles of studying seasonal altitudinal mobility through stable isotope analysis or archaeological populations to study the practice of transhumance and seasonal hunting in ancient human populations. These studies use the sequential stable isotope analysis of carbon and oxygen to look at two years early in the life of individuals through the second and third molars and characterise the presence of seasonal altitudinal mobility during an individual's life. This is observed by the inverse relationship of stable carbon and oxygen isotope curves. To understand why this inverse relationship occurs to individuals that move between summer and winter pastures, the effects of altitude on carbon and oxygen must be explained.

In the case of $\delta^{13}C$, carbon isotope discrimination was found to decrease with increasing altitude due to a decrease in CO2 atmospheric pressure (Korner et al., 1991) leading to higher $\delta^{13}C$. This effect however was found to be quite weak (Kohn, 2010) only increasing by 1.5‰ from 400 to 2500 m (Korner et al., 1988). Increased precipitation was found to have a stronger effect on $\delta^{13}C$ leading to an increase in discrimination and thus lower $\delta^{13}C$ (Kohn, 2010). This is due to the stomatal conductance of plants, which are more open in wet environments, this leads to an increase in carbon fixation from CO_2 leading to a higher discrimination of ^{12}C at the cost of an increase in water loss (Moreno-Gutierrez et al., 2012). On the other side of the spectrum, $\delta^{13}C$ is higher during dry seasons due to a reduction in stomatal conductance, the difference can be up to 2-3‰ (Farquhar et al., 1989). Thus, at higher altitudes, where precipitation and humidity are greater, the values of $\delta^{13}C$ are lower. At low altitudes carbon isotope discrimination is found to decrease. Two explanations are possible

for this decrease depending on the geography and climate. In a hot dry environment, the decrease can be explained by the presence of C4 plants that become less common as altitude increases (Tiezsen et al., 1979). In a temperate region, such as Europe, the increased aridity causes this discrimination to decrease (Kohn, 2010). In the case of Cova Gran, present in the Iberian Peninsula during the Pleistocene, when C4 plants are yet to be present in Europe (Ehleringer et al., 1997) it is most likely an increase in $\delta^{13}C$ at low altitudes can be attributed to aridity factors.

However, there are limits in the interpretation of $\delta^{13}C$ values and altitudinal mobility. Due to carbon values being lower in highlands and higher in valleys, it is unknown how the canopy effect would influence the enamel sequence. In theory, due to the canopy effect significantly lowering the $\delta^{13}C$ values in forests, and forests generally occurring at lower altitudes, it could lower the $\delta^{13}C$ values during winter and thus cause the carbon sequence to follow the seasonal variations of oxygen rather than oppose them, making it difficult to observe seasonal altitudinal mobility through an enamel sequence.

Generally, oxygen isotopes at higher altitudes are significantly depleted in ^{18}O due to the water cycle favouring the heavier isotope during condensation. This effect has been quantified with a decrease of 1-3 ‰/km (Rozanski et al., 1993). As such $\delta^{18}O$ values at higher altitudes should present lower values in animals. At both high and low elevations however, the seasonal variations in $\delta^{18}O$ still occur as normal with higher values in summer and lower values in winter. Seasonal altitudinal mobility has not been shown to influence seasonal variations in a significant manner (Tornero et al., 2018).

The principles behind the variation of $\delta^{18}O$ according to altitude are not fully understood however and there are somethings that aren't yet understood. The contribution of leaf water at high altitudes to $\delta^{18}O$ values is difficult to interpret as animals take in leaf water from plants and if this water has been fixed to the plant through fractionation it should follow seasonal variations. However, moisture present on the plant due to rainwater for example, in which fractionation has yet to occur, is also consumed. The influence of this $\delta^{18}O$ depleted moisture on the $\delta^{18}O$ present in enamel remains unknown at the present time (Makarewicz and Pederzani, 2017).

The validity of this seasonal altitudinal model has generally been used in areas with a large difference between ecological zones and in areas where the altitude difference may not be as high still need to be investigated (Tornero et al., 2018). In Knockaert et al. (2018) where one Iberian ibex was studied it was found that there was not an inverse relationship between stable carbon and oxygen isotope values, thus pointing to the fact that this individual did not undergo a seasonal altitudinal mobility. This is strange as the Iberian ibex is known to migrate seasonally. Multiple reasons can be

considered for this result, but it must be taken into consideration that only one individual was analysed thus making any interpretation far from definite (Knockaert et al., 2018). Considering the specimen was a modern individual, the influence of human activities could strongly influence the seasonal patterns of even wild animals. For Cova Gran, since the maximum altitude reaches 1 236 m it is also possible that the inverse relationship of carbon and oxygen would not be observed at such a small scale.

I.8 The site of Cova Gran

The site of Cova Gran is a small cave located 30km from Barcelona on the southern slope of the Montserrat massif. It is located right next to another archaeological site called Cova Freda. The excavation of these sites is a joint project but in the case of this study only materials from Cova Gran were studied. Originally, they were excavated in 1922 during which material from the first 25cm of sediment were taken from Cova Gran, this site showed importance at the time as it was one of the first sites excavated in the western Mediterranean to provide a ceramic cardial ware assemblage (Oms et al., 2019). A new project began in 2018. The first objective of this new project was to assess the degree of preservation on both sites; indeed, since the last excavation in 1922, the location became frequented by hikers and amateurs. Unfortunately, due to this activity, large amounts of prehistoric sediment had become disturbed and had to be subsequently removed. The second objective was to continue the excavation that had begun in 1922. During the first year, 3 soundings were made in the cave, two were made close to the entrance and measured 1m² and the third one was made further into the cave at first measuring 4m² but then later extended to 7m² (Fig. 2 and Fig. 3). The site shows a chronology spanning from the Late Pleistocene up to the Neolithic. In the Pleistocene layers many microliths and small nodules were found. In terms of faunal remains there was the presence of cervids, bovids and leporids that showed traces of human activity.

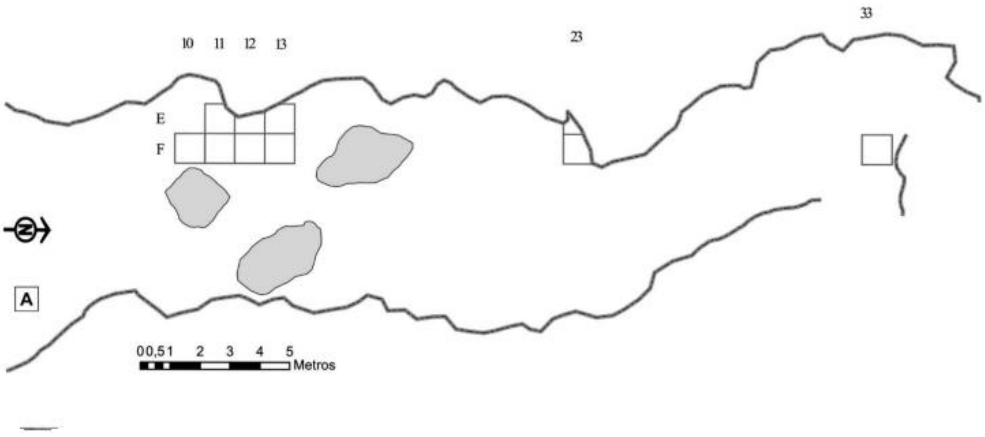


Fig. 2 Map of Cova Gran during the 2018 excavation (Oms et al., 2019)

The present study focuses on the Pleistocene layers of the site: 200 and 201. The layers were dated using charcoal and dated back to 12 033 – 11 847 Cal BP and 11 942 – 11742 Cal BP respectively and are attributed to the Magdalenian culture (Oms et al., 2019). These dates coincide closely to the Younger Dryas (YD) event and correspond to the end of the MIS 2.

Fig. 3: Map of level 200 and the location of the finds (Oms et al., 2019)

Since the excavation reopened in 2018, the site has shown many promising aspects regarding faunal remains. The preservation at Cova Gran is excellent with a taxonomic identification of 91.3% of the remains at level 200 and 88.5% at level 201. The two most common species found were Caprinae and Leporids both in terms of both NISP and MNI. This was followed by several bird species that have yet to be studied and identified. Other species are present but in very small quantity including *Cervus elaphus*, *Sus scrofa* some Felidae and Canidae (Fig. 4) (Marin, in press).

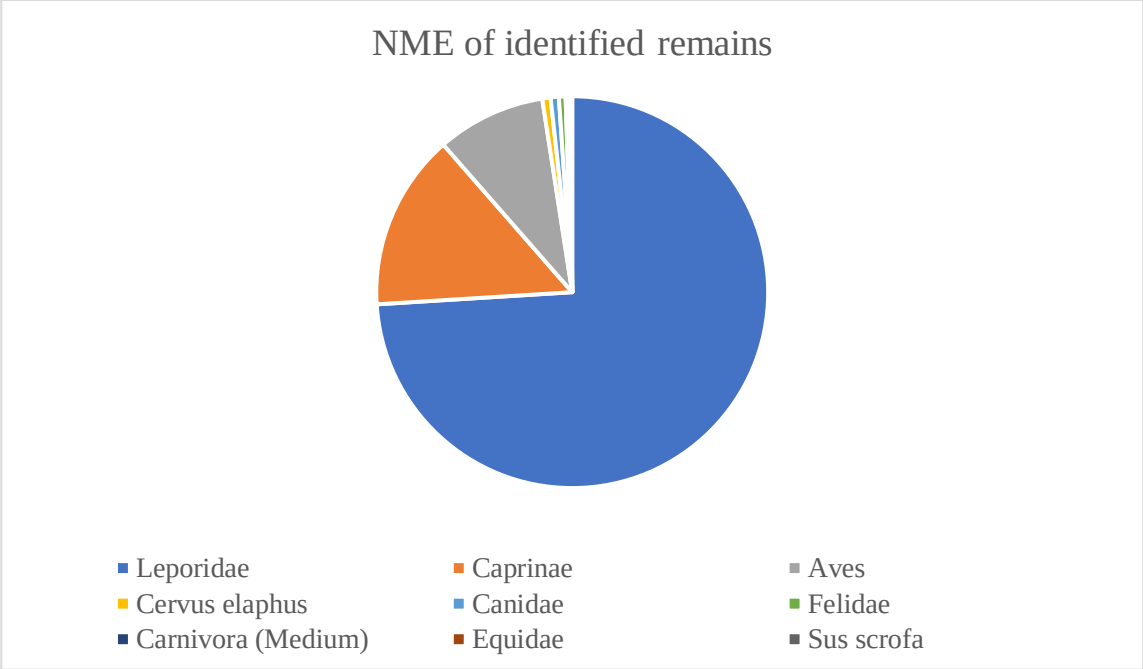


Fig. 4 Pie chart of the species found at levels 200 and 201 of Cova Gran (Marin, in press)

The anatomical distribution of level 200 show that all anatomical elements are present whereas in level 201, certain elements that usually have a high-survival rate such as the mandible, radius and femur were not recovered (Marin, in press).

In terms of age, juveniles and adults dominate the assemblage with no seniles being found indicating a low selection of prey based on age for the ungulates. However, in the case of ungulates the number of remains in which an age was attributed remains very low and prevents the results from being conclusive. In the case of Leporids, there seems to be a preferential selection for adult individuals (Marin, in press).

Cutmarks relating to the activities of skinning, disarticulation and defleshing were found on caprinae bones and alongside some burnt bones. Finally, some bones presented carnivorous activity (Marin, in press).

II. Materials and Methods

II.1 Enamel sampling

The enamel sampling was done on the remains of *Capra pyrenaica* and *Oryctolagus cuniculus*. The goal of this sampling was to remove any exogenic carbonates in order to only analyse the $\delta^{13}C$ and $\delta^{18}O$ found within the tooth enamel.

II.1.a Selection of teeth

A preliminary selection was done on the collection by sampling teeth whose enamel from the occlusal surface down to the enamel root junction (ERJ) was preserved (Table 1). The teeth of *Capra pyrenaica* were first sorted according to their position in the mandible/maxillae. Lower m2 teeth were preferentially selected as they generally present the best-preserved enamel. Four lower m2 teeth were selected. However, due to the presence of lower m3 teeth belonging to the same individual in certain cases, allowing for a larger period of time to be covered when looking at the sequential enamel results, 2 lower m3 were also selected. Finally, due to the small sample size, another lower m3 as well as an upper M2 were added leading to a total of 8 *Capra pyrenaica* teeth being selected for sampling. Additionally, two teeth of *Oryctolagus cuniculus* were sampled for a bulk analysis.

It should also be noted that tooth "GC_*CAPRA*_03.M3" presented a hypoplasia in the form of a line at 11.59mm from the ERJ on the central lobe, and 11.67mm from the ERJ at the anterior lobe, recorded using the methods outlined by Ubex et al. (2012) (Fig. 5). Enamel hypoplasia has often been associated to some form of physiological stress during the dental crown development and is defined as a thinning in the dental enamel (Goodman & Rose, 1990). This physiological stress has been

associated to dietary or health deficiencies in many faunal or anthropological archaeological assemblages. Enamel hypoplasia is observed through different forms: with “lines” and “depressions” being most common, and “pits” being rarer (Upex et al., 2012).

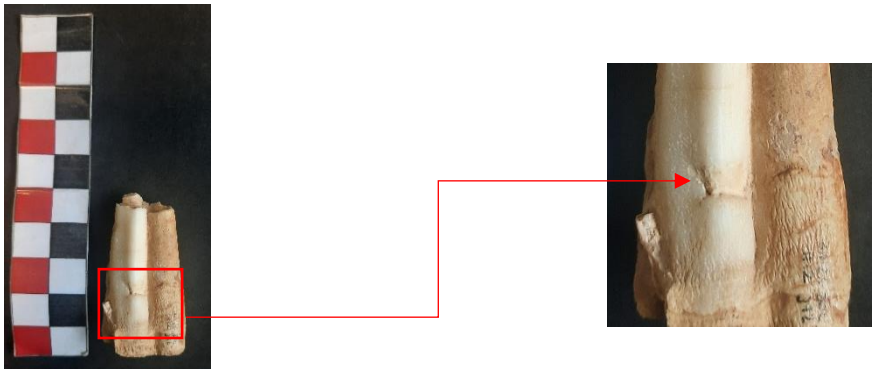


Fig. 5: photo of GC_CAPRA_03_M3 with the hypoplasia highlighted with the red square

Table 1: Selection of teeth from Cova Gran

Site	Level	Square	N°	Dentition	Code
Cova Gran	200	F11	22	M2	GC_*Capra*_01_M2
Cova Gran	200	F11	22	M3	GC_*Capra*_01_M3
Cova Gran	200	G11	42	M2	GC_*Capra*_02_M2
Cova Gran	200	G11	42	M3	GC_*Capra*_02_M2
Cova Gran	201	H12	372	M3	GC_*Capra*_03_M3
Cova Gran	200	F12	9	M2	GC_*Capra*_04_M2
Cova Gran	200	H13	60	M2	GC_*Capra*_06_M2
Cova Gran	200	G11	21	M2	GC_*Capra*_09_M2

II.1.b Sampling method

The sampling followed the protocol set out by Balasse et al. (2002). The end goal of this sampling method was to be left with endogenic carbonates only. For the lower and upper m2 teeth, the buccal side of the anterior lobe was always sampled. In the case of the m3 teeth, it was the central lobe that was sampled. Firstly, the teeth were cleaned by using a tungsten drill to remove the cementum present on the surface, this is because tungsten is strong enough to remove whilst not having sufficient hardness to carve into enamel. Following this, a diamond-encrusted drill would be

used to sample the tooth enamel. This was done in a sequential fashion starting near the occlusal surface and drilling every 2mm or so, stopping just before the ERJ (Fig. 6).

Fig. 6: Photo of GC_CAPRA_01_M2 (Left) and GC_CAPRA_01_M3 (right). The redline marks the enamel root junction (ERJ)

In the cases of teeth "GC_*CAPRA*_02.M3", "GC_*CAPRA*_03.M3" and "GC_*CAPRA*_06.M2" the sequential sampling would be stopped before reaching the ERJ (Fig. 7). This is because in these teeth the enamel had not completely mineralised, thus the isotopic values obtained from such a sample would not be representative. These peculiarities suggest that these individuals were quite young as their teeth hadn't fully matured. It is also interesting to note that tooth "GC_*CAPRA*_02.M2" was fully mineralised as oppose "GC_*CAPRA*_02.M3" despite being from the same individual.

Fig. 7: Photo of tooth GC_CAPRA_06_M2 that has not been fully sampled due to a part of the tooth not fully being mineralised, highlighted by the arrow showing the distance between the last sample and the ERJ.

The average spacing between each sample was 1.62mm. The number of samples per tooth varied from 14 to 22, depending on the size of the tooth and if full mineralisation had been reached. In total, 143 enamel samples were taken from the goat teeth. The weight of the samples varied between 4 and 9.2 mg. The position of each sample was taken according to its distance from the ERJ (Fig. 7).

II.1.d Chemical treatment

For the chemical treatment following the sampling process, the protocol of Tornero et al. (2013) was used. This entailed a four-hour treatment in 0.1M (0.1ml/mg) acetic acid (CH_3COOH). This was done to remove exogenic carbonates that could have polluted the sample. Following this, the samples were then put in a centrifuge and rinsed with distilled water five times to remove the acetic acid within the samples to prevent endogenic carbonates from being destroyed. Finally, the samples were put in an oven at 70°c for 48 hours in order to remove the remaining distilled water in the sample. This would leave the samples as pure as possible. The loss in weight which was of around 40% for the *Capra pyrenaica* teeth.

II.2 Sampling and chemical treatment of the rabbit teeth

The literature available on sampling rabbit enamel sampling is very scarce and the studies that do cover this topic pose one of two problems. The first problem is they use specific equipment unavailable to the laboratory in which the present study is conducted such as laser technology (Passey and Cerling, 2006); the second problem posed is that in some of these articles the authors do not go in depth in the way the enamel was sampled (Naito et al., 2022). As such, in an attempt to better understand how to sample and analyse rabbit enamel for this study an experimental approach was taken using the molars from three different individuals.

Before sampling, the teeth were cleaned using an ultrasonic bath to remove any sediment attached to the tooth. To sample the tooth enamel a mechanical drill was used with a diamond-encrusted tip of 1mm width. In order to avoid any bias in the results, the same molar was sampled for each individual and the same quantity of enamel was extracted (3.5 mg). The main complication when extracting rabbit enamel is the thickness of the enamel, as it is quite thin thus if one is not careful, one can accidentally sample the dentine below. However, rabbit enamel is present on both sides of

the molar (Schonfeld and Slavkin, 1997) as such both the buccal and lingual sides of the tooth were sampled.

Finally, the same chemical treatment used for the *Capra* teeth but it had been noted in analyses done of gerbillid teeth that acetic acid could easily destroy endogenic teeth much more quickly (Jeffrey et al., 2015) as such a precaution was taken and the three teeth underwent treatment but for a different amount of time: one for one hour, one for two hours and the last one for four hours. This was an experimental approach to measure the differential effects of more or less prolonged exposure to acetic acid. The samples were then rinsed with distilled water five times and put into the oven at 70°C for 48 hours. The treatment led to losses of 20% (1hr treatment); 25.7% (2hr treatment) and 28.5% (4hr treatment) showing that the chemical treatment for rabbit enamel did not lead to significant losses. Another method to separate the enamel from the dentine was also being worked on at the time of this study but was not completed in time and will likely only be used in a future study.

II.3 Isotopic analysis of enamel

Pre-treated samples were weighed out to about 600 µg using an automated carbonate preparation device (KIEL-III) interfaced to a Finnigan MAT 252 isotope ratio mass spectrometer (IRMS) at the Environmental Isotope Laboratory (Dept. of Geosciences), University of Arizona (USA)with scientific supervision from Dr. David Dettman. Powdered samples were reacted with dehydrated phosphoric acid under vacuum at 70°C. The accuracy and precision of measurements were checked and calibrated using NBS-19 and NBS-18 international standards. A mean analytical precision within each run and from replicate measurements of standards during analyses was 0.11‰ for $\delta^{18}O$ and 0.08‰ for $\delta^{13}C$ (1σ). Isotope composition is reported using the equation detailed in the section “Principle of Isotope Analysis” stating the deviation of the isotope ratio of V-PBD (Vienna Pee Dee Belemnite) standard for both carbon and oxygen values (McKinney et al., 1950; Gross, 2017).

II.4 Reversal of the dampening effect on enamel results

One of the issues with intra-tooth isotope profiles is that they were found to be time-averaged compared to the actual isotopic pattern, reducing the overall amplitude present within a tooth (Balasse, 2002). This is due to the fact that during amelogenesis, each layer of enamel will accumulate mineral over time. This means that every sample in a sequential analysis does not represent a fixed point in time but rather a period of time, close to several months thus reducing the actual isotopic

values (Balasse, 2002; Passey and Cerling, 2002, 2005); this is what is known as the damping effect. The accumulation of minerals in the enamel is also faster at the beginning and at the end of the tooth formation compared to the rest. Using an inverse method presented in Passey and Cerling (2005), it becomes possible to reverse the dampening effect on intra-tooth isotope profiles. This is important specifically for reconstructing paleotemperatures as the actual isotopic values for oxygen are necessary to get an accurate result. This was done using the files provided in Pederzani et al. 2023. The model was only applied to obtain the maximum and minimum values in the oxygen isotopic profiles. In the case of the mean values, this is considered unnecessary as the increase or decrease in maximum values will mirror that of the minimum values leading to a very similar mean value (Pederzani et al., 2023). The parameters concerning the geometry (length of apposition and length of maturation) of *Capra* teeth were obtained from Kohn (2004).

II.5 Modelling of the $\delta^{18}O$ intra-tooth sequences

In the results obtained from the sequential analysis, inter-individual variability can make it difficult to compare the seasonality of births between individuals. Thus, a model developed in Balasse et al. (2012) is used to normalise the results. The inter-individual variability in the position of $\delta^{18}O$max in tooth crown is measured after this model is used.

The model uses an equation derived from a cosine function and uses four parameters but in this study due to the effect of attenuation on the teeth it was deemed necessary to use eight parameters. The equation used is as follows:

(1) $\delta^{18}O \text{ model} = Ae^{(x-xB/xA)}*\cos(2\pi*(x-x0)/(X+b*x)+M+p*x)$.

The variables are as follows. (Balasse et al., 2012) (Fig. 8).

- X is the period (in mm) that is defined as the length of tooth crown potentially formed over a year.
- A is the amplitude equal to (max.- min)/2 (in ‰).
- x_0 is the delay (in mm) when $\delta^{18}O$ attains its maximum value.
- M is the mean (max.+ min)/2 (in ‰).
- p is the slope (in ‰/mm) of the mean, for when the sequence spans across more than a year, M might change from one year to another.
- xA and xB (in mm) relate to the attenuation of the model.

- b is related to the gradation of the period (no unit) for the cases where the growth rate of the tooth changes from the apex to the base.

Normally, interindividual variability in x0 is considered after normalizing x_0 by X, to eliminate variability in tooth size; but with the addition of parameter b, instead of normalizing by X, x_0 is normalized by X_{real} (=X+bX) . This was done in Microsoft Excel using an iterative method that would find the smallest sum of square differences between the model and the measured data via the solver function. The results suggested by the model would then be verified using the coefficient of correlation (r) of Pearson, with the result was considered valid when $r \geq 0.91$. These results represent the percentage of a year that has passed ranging from 0 to 1.

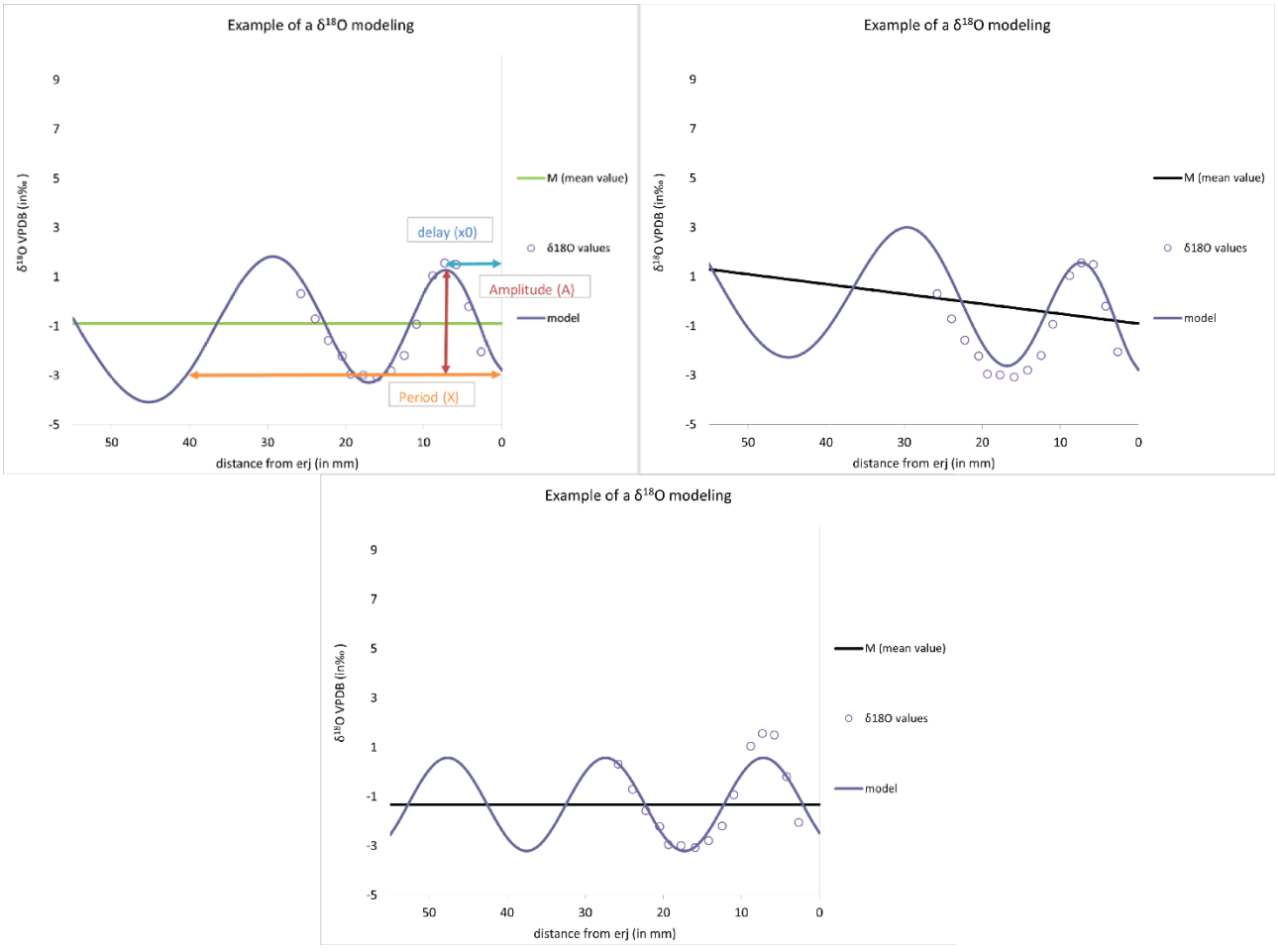


Fig. 8: Example of a modelled $\delta^{18}O$ sequence (using GC_CAPRA_01_M2). (A) shows the first four parameters: periods, delay, amplitude and mean. (B) highlights parameter p, which causes the angle of the sequence to change. (C) highlights the last 3 parameters: xA, xB and b, they have been set at their standard values as oppose to the values used in (A). These parameters cause the period to change as the tooth grows.

The interindividual variability x_0/X_{real} is used to determine season of birth as the delay, that represents the highest $\delta^{18}O$ value in the sequence thus representing summer, is a point that can b identified in all individuals and represents more or less the same point in time. Knowing this point in time and dividing it by the period, gives a point in a year. Depending on when an individual is born this point in time of summer will shift. An individual born in January will record this summer point later than an individual born in June. When possibly, using modern referentials, this x_0/X_{real} value can then be attributed to specific months by recording the birth of the individual and when harvesting, recording the x_0/X_{real} value (Balasse et al., 2024). In the case of this study, it was not possible but if there is a strong enough grouping of individuals then a natural season of birth could be highlighted.

II.7 Collagen sampling

II.7.a Selection of bones

19 samples of bone were selected from the available assemblage. Of these, 14 bones belonged to *Oryctolagus cuniculus*, 5 belonged to *Capra pyrenaica* (Fig. 9). All the bones that were selected were a part of the mandible. Due to the age and preservation of these bone samples around 0.7 – 1g of material was extracted. The selection of bones can be seen in appendix 1.

II.7.b Preparation of bones

Collagen samples were prepared in the stable isotope lab at the autonomous university of Barcelona (UAB). A small fragment of bone was cut and removed from each specimen using a Dremel diamond rotating wheel. The surface of the bone shards was cleaned by abrasion with a tungsten drill to remove any visible contaminants. Collagen extraction followed the protocol proposed by Longin (1971) and modified by Bocherens *et al.* (1991). The bone fragments were initially soaked in 0.5 M hydrochloric acid (HCl) for demineralisation, rinsed several times with distilled water, and soaked in NaOH (0.125 M) for 20 hours to remove potential organic contaminants. After another round of rinsing, the samples were diluted and gelatinised with 0.01 M HCl at 100°C for 17 hours (pH 2). Finally, collagen samples were microfiltered using 5 μm filters to remove any residues and subsequently frozen.

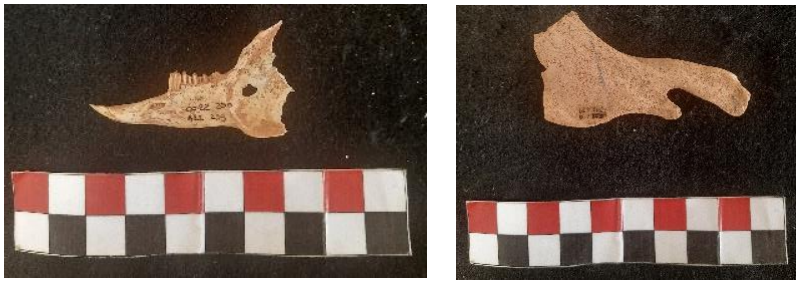


Fig. 9: photo of GC_ORYCTOLAGUS_08_BC (left) and GC_CAPRA_01_BC (right) bones that were used for collagen samples, both were mandibles

II.8 Isotopic analysis of collagen

The carbon and nitrogen isotopes were measured at the Institute of Environmental Science and Technology (ICTA-UAB) (Barcelona, Spain). This was done using a Thermo Flash 1112 elemental analyzer (EA) coupled to a Thermo Delta V Advantage IRMS with a Conflo III interface. The international standard of IAEA 600 was used for data calibration. Isotope ratio is reported in δ notation: $\delta^{13}C$ values are expressed relative to Vienna PeeDee Belemnite (V-PDB) standard and $\delta^{15}N$ values relative to air N2 (AIR).

II.9 Reconstructing mean annual temperature

As stated before, in order to reconstruct MAT from stable oxygen isotope values a series of conversions is necessary. In the case of the sequentially analysed teeth, the reversal of the dampening effect was done beforehand of course. Firstly, to convert from VPDB to VSMOW the equation defined in Coplen et al. (1983) is necessary:

(2): $\delta^{18}O_{VSMOW} = 1.03091\ \delta^{18}O_{PDB} + 30.91$; $r^2=1.00$

Following this, in order to convert $\delta^{18}O_{carbonate}$ values to $\delta^{18}O_{phosphate,}$ the equation defined by Iacumin et al. (1996) is used:

(3) $\delta^{18}O_{phosphate} = 0.98\ \delta^{18}O_{carbonate} - 8.5$

Once $\delta^{18}O_{phosphate}$ values are obtained it is then possible to use species-specific equations to obtain $\delta^{18}O$ precipitation values ($\delta^{18}O_{precip}$). In the case of goats, the equation from Delgado-Huertas

et al. (1995) was used: $\delta^{18}O_{phosphate} = 0.88\ \delta^{18}O_{precip} + 24.1$. Then by solving the equation for $\delta^{18}O_{precip}$, the following equation is obtained:

(4): $\delta^{18}O_{precip} = (\delta^{18}O_{phosphate}-24.1)/0.88$

Using these $\delta^{18}O_{precip}$ values, it can then be compared to modern datasets from the Global Network of Isotopes in Precipitation (GNIP) (IAEA/WMO, 2024). A selection was made from the available stations of the GNIP and was done using the same stations chosen in the study done on the Middle Paleolithic site of Axlor by Pederzani et al. (2023). The stations used in the previously mentioned study were of western, southern and central Europe as well as some stations outside Europe but in proximity with the Mediterranean with year-round precipitation. There are three equations in total (5 to 7) to make comparisons with the warmest, coldest and mean temperatures associated to the sequential analysis of the *Capra pyrenaica* teeth that present both the climatic maximums and minimums.

(5) $Temp_{MEAN}$ (°C) = $(\delta^{18}O_{precip} +13.64)/0.50$; $R^2 = 0.93$

(6) $Temp_{WINTER} = (\delta^{18}O_{precip} + 11.26)/0.52$; $R^2 = 0.84$

(7) $Temp_{SUMMER} = (\delta^{18}O_{precip} + 14.70)/0.46$; $R^2 = 0.87$

Errors for both the conversion from $\delta^{18}O_{phosphate}$ to $\delta^{18}O_{precip}$ and from $\delta^{18}O_{precip}$ to Temp were done using the equations outlined in Pryor et al. (2014) which takes into account, a variable ε that is the natural variance of animals that even under controlled conditions will still be present. It also accounts for the other parameters that led to the result being found (number of samples, the variables present in an y = ax + b equation and distance from the regression line).

II.10 Reconstructing mean annual precipitation

In order to convert the $\delta^{13}C$ values of animal bones or teeth to MAP, $\delta^{13}C$ values must be converted to the $\delta^{13}C$ of diet. In the case of teeth, this has classically been done with an enrichment of 14,1‰ (Cerling and Harris, 1999) but more recent studies have shown that this enrichment cannot be applied to every species equally and specificities in body mass and digestive system have an effect of herbivorous animals (Tejada-Lara et al., 2018). The present study uses the equations proposed by Tejada-Lara et al. (2018) in order to get accurate isotopic enrichment values from $\delta^{13}C_{bone}$ to $\delta^{13}C_{diet}$

values, different equations are used according to whether the animal is a hindgut (8) or foregut fermenter (9).

(8) $e^* = 2.42 + 0.032\ (BM)$; $R^2 = 0.78$, p-value= 0.008

(9) $e^* = 2.34 + 0.05\ (BM)$; $R^2 = 0.74$, p-value= 0.003

In these equations e* is the diet-bioapatite enrichment and BM is the body mass. The body mass needs to be log transformed (ln) and e* will need to be inverted (e^x) to obtain a ‰ value. The average weight of a rabbit is 1.18kg showing little differences between the two sexes (Brambell, 1944). In the case of ibex, the weight averages at 54.51 kg for males and 33.11 kg for females (Fandos et al., 1989).

Using equation (8) on rabbit, a hindgut fermenter, a value of 11.3‰ is obtained. For ibex, a foregut fermenter, equation (9) is used and values of 12.37-12.67‰ are obtained. In the case of the diet-collagen enrichment, an offset value of -5‰ has been given (Ambrose & Norr, 1993) for both species.

Once the values of $\delta^{13}C_{diet}$ have been obtained, generally assumed to be close to the $\delta^{13}C$ of vegetation noted as $\delta^{13}C_{leaf}$ (Lécuyer et al., 2021), 3 different equations can be applied to determine MAP, each with their own peculiarities:

(10) $\delta_{13}C_{leaf} = -10.29+1.90*10^{-4}*$ Altitude (m) - 5.61*log10(MAP+300)-0.0124*Abs (Latitude, °) (Kohn, 2010)

(11) $\Delta = 2.01-1.98*10\text{^}-4*$Altitude (m) +5.88*log10(MAP+300) +0.0129* Abs (Latitude, °) (Kohn, 2010)

(12) $Log_{10}(MAP + 300) = 0.092*\Delta+1.148$ (Rey et al., 2013)

In the case of equations (11) and (12), $\Delta = (\delta^{13}C_{atm} - \delta^{13}C_{leaf}) / (1 + \delta^{13}C_{leaf}/1000)$. The other variable, $\delta^{13}C_{atm}$ is the value of atmospheric CO_2 at the time, measured in trapped air bubbles from the Vostok ice cores (Leuenberger et al., 1992). At the time of levels 200 and 201, this would have average out to a value of -6.755‰.

In the first equation, the relationship is directly between carbon isotope values of plants and the variables of MAP, altitude and latitude. In the case of the second equation the additional variable of $\delta^{13}C_{atm}$ is added into the relationship. The last equation takes into account $\delta^{13}C_{atm}$ but removes the variable of altitude and latitude from the equation.

The first two equations were proposed in an article by Kohn (2010) and were based on the values of modern plant samples followed by some applications on palaeoecological data. In the case of the last equation, this was an equation that was recalculated from the data shared in Kohn (2010) using a least square regression on remains from the Miocene (Rey et al., 2013) but it was also used again in a more recent article on Pleistocene remains (Lécuyer et al., 2021).

These equations, all differing slightly in the variables used, give slightly different results which are all relevant to be discussed.

III. Results

The results for the measurements of $\delta^{13}C$ and $\delta^{18}O$ in each tooth and bone are given in appendix 2 and are represented in Fig. 10 and Fig. 11.

III.1 Sequential enamel analysis

In the case of the teeth, the $\delta^{13}C$ values vary from -7.93‰ to -11.90‰ and the amplitude of intra-tooth variation varies from 3.97‰ to 0.80‰. The $\delta^{18}O$ values vary from 2.54‰ to -2.89‰ and the intra-tooth variation varies from 5.03‰ to 0.68‰. The isotopic profiles of oxygen in each tooth show a pattern close to that of a sinusoid. There is the exception of "GC_*CAPRA*_02_M2" which shows a very low amplitude making the sinusoidal pattern difficult to distinguish. "GC_*CAPRA*_06_M2" also only shows the maximum event. Each carbon profile and each oxygen profile are presented in Fig. 10 and Fig. 11. Two grpahs comparing each carbon and oxygen profile separately are presented in Fig. 12 and Fig. 13

The $\delta^{13}C$ sequences of Cova Gran show intra-tooth variation with "GC_*CAPRA*_01_M2" presenting a clear inverse relationship between $\delta^{13}C$ and $\delta^{18}O$, this is followed by "GC_*CAPRA*_01_M3" where the same pattern is no longer visible. Individuals "GC_*CAPRA*_03_M3" and "GC_*CAPRA*_09_M2" also show a less pronounced inverse relationship between the two isotopes with the latter displaying good results despite being an upper tooth rather than a lower tooth. Additionally, "GC_*CAPRA*_04_M2" whose carbon values decrease drastically before beginning to increase again at the end of the first winter event could also possibly present this

inverse relationship but as the entire sequence is unavailable it is difficult to tell. The rest of the individuals show small intra-tooth $\delta^{13}C$ variation. Individual "GC_*CAPRA*_02" shows very little variation both in the m2 and m3 sequence.

Regarding the bulk analysis on the teeth of *Oryctolagus*, at the time of handing in this thesis, these results were still unavailable.

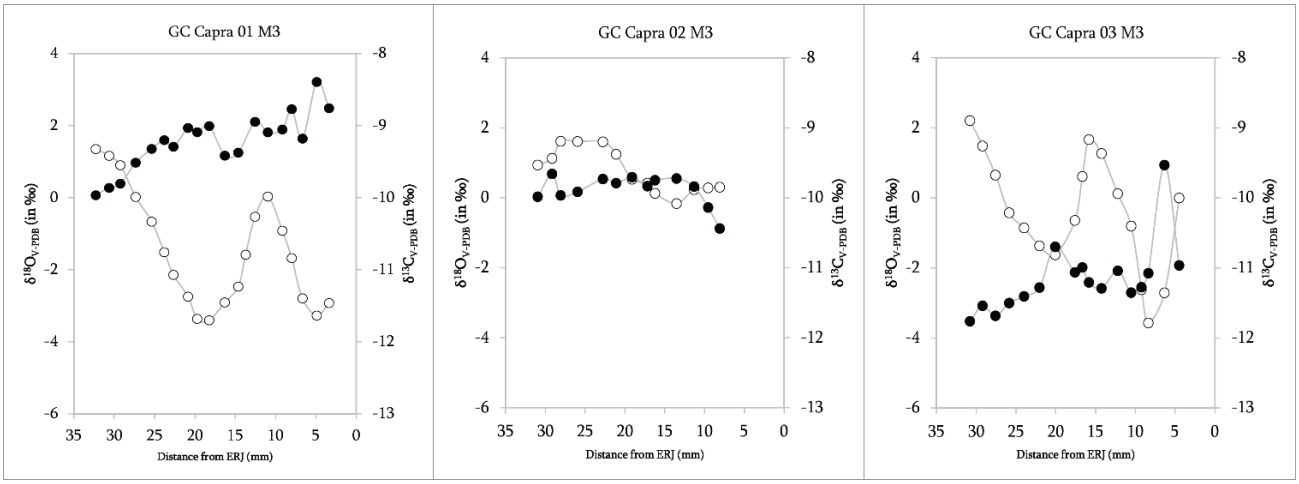


Fig. 10: Results from the sequential analysis of carbon ($\delta^{13}C$, in black dots) and oxygen ($\delta^{18}O$, in white dots) isotope ratios in enamel carbonate from the m3 caprine teeth from Cova Gran. Each value is located in the tooth crown according to the distance of the sample from the enamel root junction (erj) in mm

III.2 Oxygen modeling results

The results of the modelling of the intra-tooth sequences of $\delta^{18}O$ values are available in appendix 3. The eight different parameters used in the model have been summarised below for each tooth in Table 2. The x_0/X_{real} varies from 0.03 to 0.97. Individual "GC_*CAPRA*_06_M2" must be considered carefully, as it did not present a full sequence, thus only an estimation is possible. Also, individuals "GC_*CAPRA*_02_M3", "GC_*CAPRA*_03_M3" and "GC_*CAPRA*_09_M2" did not present their first maximum event (from ERJ = 0). Additionally, not all $\delta^{18}O$ values were used in the model. This is because either samples presented anomalous results or samples from the beginning or the end of the tooth were removed due to having a different growth rate when compared to the rest of the tooth.

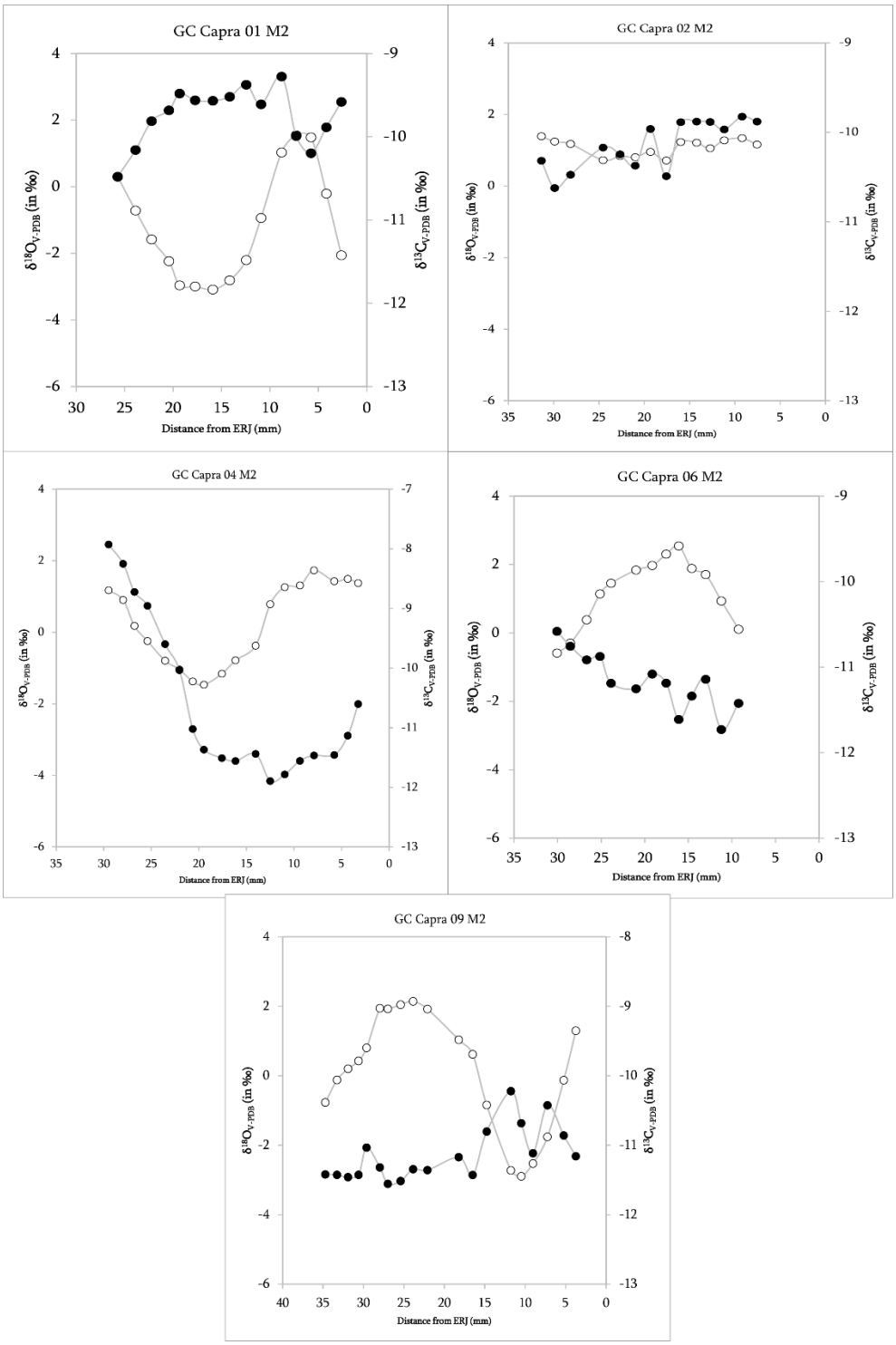


Fig. 11: Results from the sequential analysis of carbon ($\delta^{13}C$, in black dots) and oxygen ($\delta^{18}O$, in white dots) isotope ratios in enamel carbonate from the m2 caprine teeth from Cova Gran. Each value is located in the tooth crown according to the distance of the sample from the enamel root junction (ERJ) in mm

From the modelling a ratio of x_0/X_{real} was obtained and then used to represent the births of all the individuals in Fig. 14. It should also be noted that individuals "GC_*CAPRA*_01" and "GC_*CAPRA*_02" despite each having the m2 and the m3 from the same hemimandible display different results in x_0/X_{real}. By taking the difference between the largest (x_0/X_{real}=0.03) and smallest (x_0/X_{real}=0.97) value, a value of 0.94 is obtained. This means these *C. pyrenaica* were born over a period of 94% of a year equating to 11.28 months. This is quite a large birthing period however; only taking into account only the individuals that do not contain issues in their sequences, a value of 0.47 is obtained, equating to 5.64 months. These results however, should be taken in careful consideration as it is a small sample size of only six individuals, and the possibility of bias arises as it often does with archaeological assemblages.

Table 2: Results from the modelling of the intra-tooth sequences of $\delta^{18}O$ values (The parameters are defined in "Materials and Methods")

Nom	**GC01M2**	**GC01M3**	**GC02M2**	**GC02M3**	**GC03M3**	**GC04M2**	**GC06M2**	**GC09M2**
X	16.20	15.34	18.63	15.00	15.12	23.70	32.25	12.54
A	2.03	1.53	0.28	0.91	1.30	1.56	-2.01	2.52
x0	7.13	11.20	11.76	4.83	14.60	6.86	0.97	1.83
M	-0.90	-1.95	1.09	0.65	-0.24	0.24	0.26	-0.32
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
xA	100	1000	1000	1000	100	1000	1000	1000
xB	0.01	0.00007	0.00004	0.00004	0.01	0.00007	0.02	0.02
b	0.20	0.00	0.10	0.20	0.00	0.10	0.10	0.38
somme écart²	3.38	1.75	0.06	0.79	2.99	0.48	0.31	0.86
Xreal	19.44	15.34	20.49	18.00	15.12	26.07	35.48	17.32
x0/Xreal	0.37	0.73	0.57	0.27	0.97	0.26	0.03	0.11
Pearson	0.95	0.98	0.95	0.92	0.96	0.99	0.96	0.99

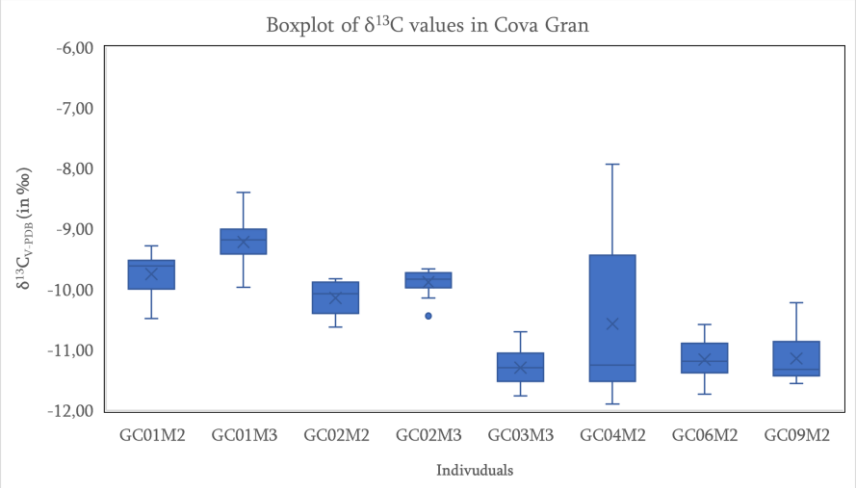


Fig. 12: Boxplot of the $\delta^{13}C$ values from the individuals in Cova Gran

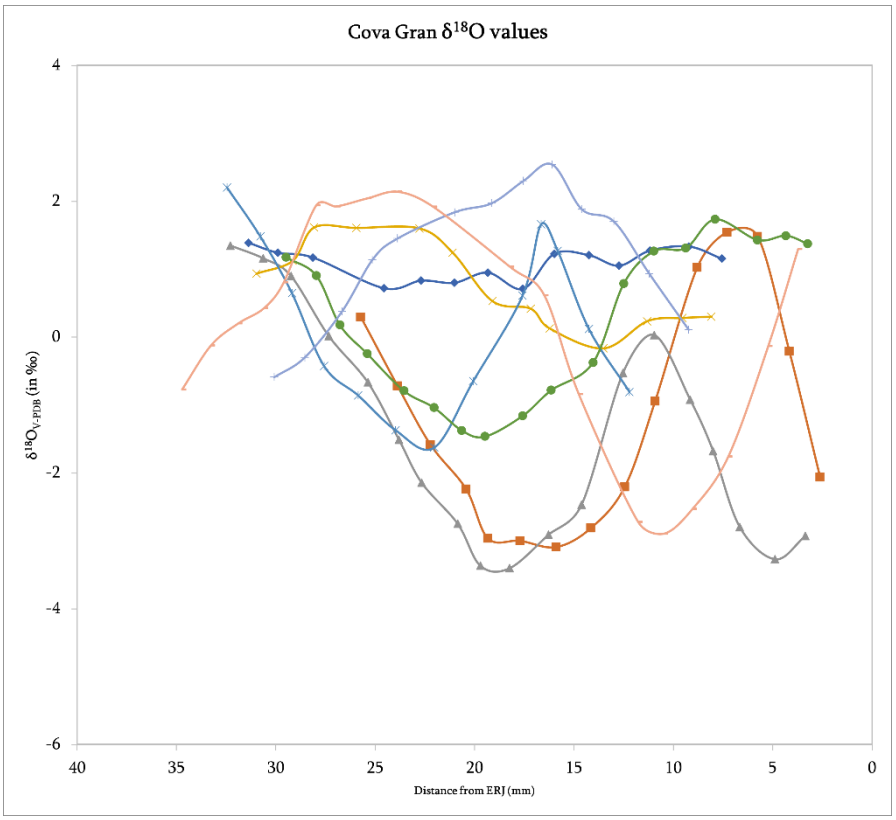


Fig. 13: Comparison of the $\delta^{18}O$ intra-tooth sequences measured in all Capra pyrenaica teeth from Cova Gran. Each value is located in the tooth crown according to the distance of the sample from the enamel root junction (ERJ) in mm.

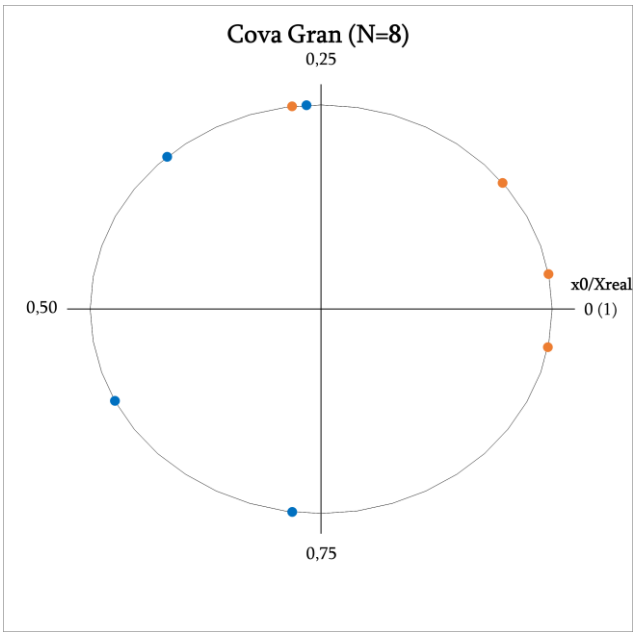


Fig. 14: The x0/X ratios of each tooth a on a circular graph, individuals that did not present a full sequence or the first maximum event are highlighted in orange

III.3 Collagen results

Of the 19 total bone collagen samples, 17 presented a good preservation with C:N ratio varying between 3.06 – 3.35. This is in line with the ratio presented by in vivo collagen (Van Klinken, 1999). For the three samples of *Capra*, the $\delta^{13}C$ values vary from -19.9‰ to -20.6‰ and the $\delta^{15}N$ values vary from 2.8‰ to 3.6‰. For the thirteen *Oryctolagus* samples, the $\delta^{13}C$ values vary from -21.6‰ to -20.5‰ and the $\delta^{15}N$ varies from 2.6‰ to 4.9‰. The $\delta^{13}C$ and $\delta^{15}N$ values showed little variation between levels 200 and 201. When using a two-sample t-test on the levels 200 and 201 with a null hypothesis meaning that both levels had the same mean and a risk $\alpha = 5\%$ it was found that in the case of $\delta^{13}C$ levels 200 and 201 presented similar means ($p = 0.58$). However, in the case of $\delta^{15}N$ the two levels were found to have different means ($p=0.02$). When taking into consideration the fact that level 200 has the three *C. pyrenaica* collagen samples that are not present in level 201, it was considered that this might bias the level 200. As such the test was done again this time taking out the three *C. pyrenaica* samples and the results showed that the $\delta^{15}N$ of levels 200 and 201 did not have significantly different means ($p=0.11$). Thus, purely from the *O. cuniculus* samples, it was found that both levels presented similar results in $\delta^{13}C$ and $\delta^{15}N$. All the results can be seen in appendix 4.

III.4 Reconstruction of MAT

For the reconstruction of mean annual temperature, the results can be seen in Fig. 16 and Table 3. The peak, trough and mean values were extracted from the sinusoidal profiles of $\delta^{18}O$ in order to learn about the summer, winter and mean temperature values at Cova Gran. The sinusoidal profiles were put through the inverse model of Passey and Cerling (2005) and, as noted by Kohn (2004) the effects of damping on teeth belonging to medium sized mammals such as *Capra* are quite small, close to 10%; where 0% would indicate a perfect preservation of the isotopic signal and 100% a complete loss of the sinusoidal pattern (Kohn, 2004), the differences are presented in Fig. 15.

The average values varied from 18.5°C – 24.2°C. The winter values varied from 7.6°C – 14.7°C and the summer values varied from 25.6°C – 32.3°C. For both teeth “GC_02_M2” and “GC_02_M3” it was decided not to include the summer and winter values, as a clear maxima and minima were not visible on the graphs and presented severely reduced amplitudes. These results were overlapped with the average, minimum and maximum temperatures obtained from the Spanish state meteorological agency (AEMET, 2024) based on observations between 1981 and 2010 and put on a spatial grid (Fig. 17).

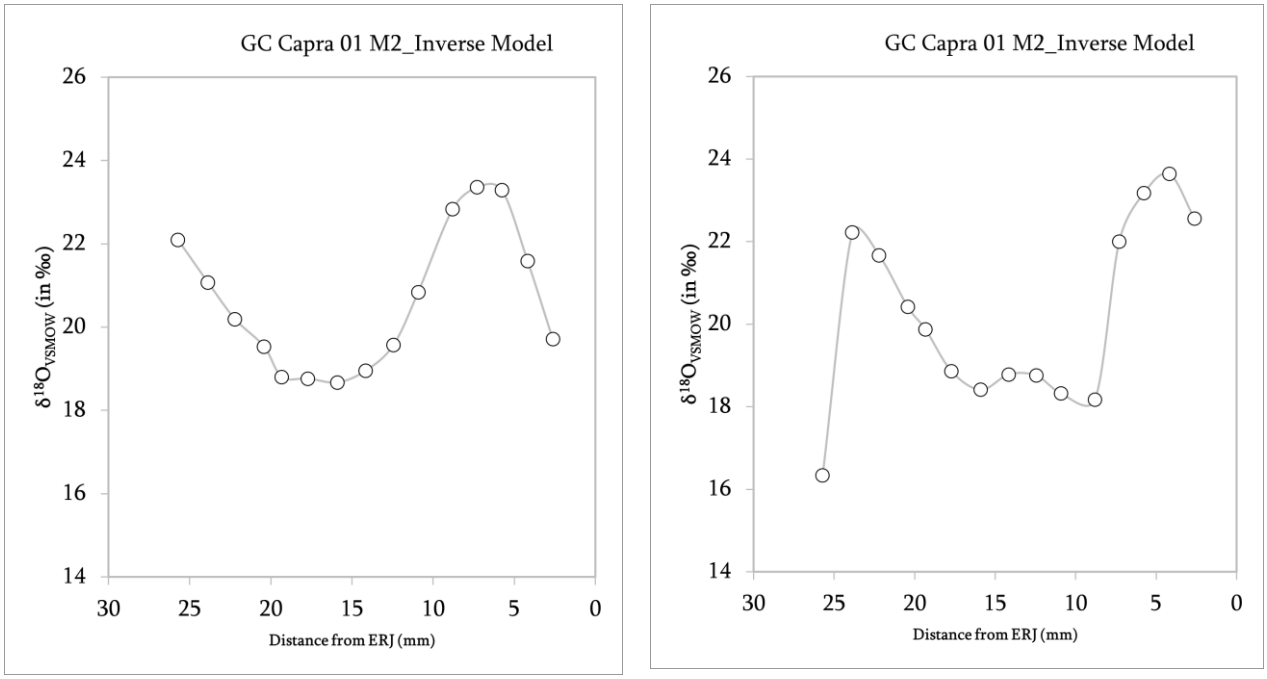


Fig. 15: Comparison of non-inversed oxygen sequence (left) and inversed sequence (right) (Passey and Cerling, 2005)

Table 3: Reconstructed $\delta^{18}O_{precip}$ and temperatures (T) from Cova Gran with their associated errors

Record type	$\delta^{18}O$ (in ‰)	$\delta^{18}O$ error (in ‰)	T (in °C)	T error (in °C)
Winter	-5.7	0.3	10.5	0.7
Mean	-2.6	0.4	21.8	0.9
Summer	-1.2	0.5	29.2	1.3

From the data provided by the Spanish state meteorological agency four parameters were registered for this study: average temperature, maximum temperatures, minimum temperature and average precipitation. These parameters were recorded within a 30km radius around the site to account for possible shifts in temperature due to the altitude of the Monserrat massif. Average temperature ranged from 10°C – 15°C; minimum temperatures varied from 2.5°C – 10°C; maximum temperature ranged from 17.5°C – 25°C; precipitation varied between 500 – 600 mm/year.

Regarding the errors in $\delta^{18}O$ and T, they are quite low only ranging from 0.3‰ – 0.5‰ and 0.7°C – 1.3°C respectively. The results were verified with a two-sample t-test (using PAST), where the null hypothesis was that modern and archaeological values have equal means and with a risk α = 5%. The winter values were similar to that of modern values (p_{winter}=0.145) but in the case of the mean and summer values these were different (p_{mean}=0.0001; p_{summer}=0.006) and indicated much

warmer conditions at the time. There was stronger seasonality between summer and winter but generally milder conditions.

For individual "GC_*CAPRA*_01" two teeth, the results were similar in terms of mean and winter values but the summer values showed a difference of 2.5°C, indicating that during the third year of its life this individual experienced a warmer summer than the previous. For the two teeth of "GC_*CAPRA*_02", only the mean values were taken, but they showed a difference of 2.4°C with this individual likely experiencing a colder year generally compared to its second year.

Lastly, the conversion from carbonate to phosphate values was shown to present some errors in certain studies (Pellegrini et al., 2011), this could have affected the paleotemperature results leading to either an overestimation or underestimation 1.5‰.

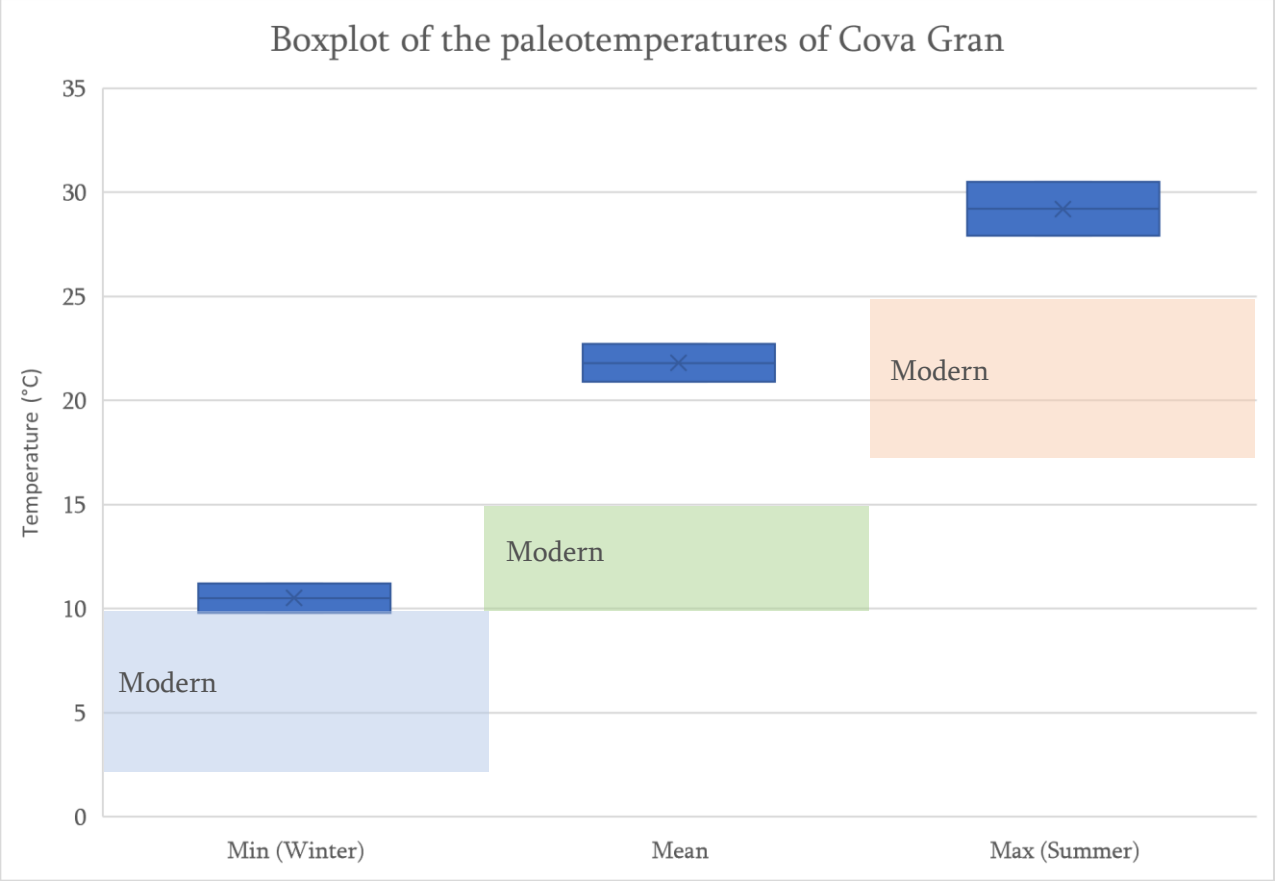


Fig. 16: Reconstructed paleotemperatures for winter, summer and mean values at Cova Gran compared to modern values (AEMET, 2024)

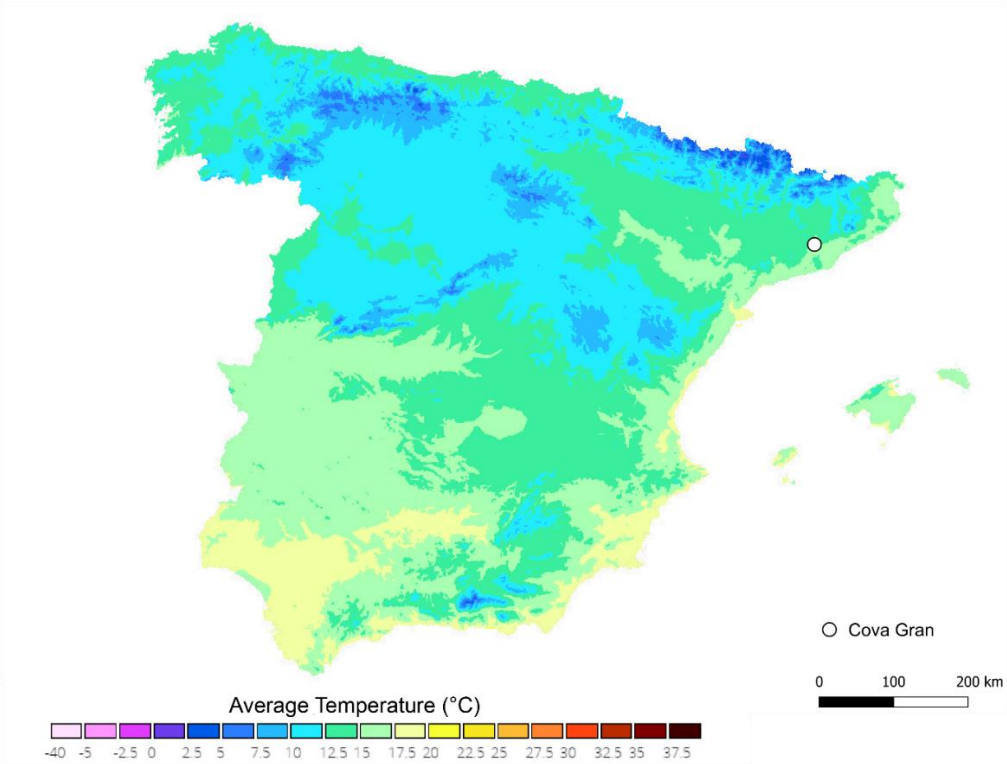


Fig. 17: Map of Spain showing the average temperatures across the different regions, modified with the white dot highlighting the position of Cova Gran (AEMET, 2024)

III.5 Reconstruction of MAP

The enamel and collagen results both showed values between -20‰ and -37‰ once converted from bone and tooth value to that of diet. It should be noted though, that in Kohn (2010) a cutoff of -23‰ is recommended as values above this can include lichen and non-C3 plants. Following this recommendation would indicate that “GC_01_M2”, “GC_01_M3”, “GC_02_M2”, “GC_02_M3” should be considered carefully as they present results above this proposed cutoff limit. But in general, this means that the reconstruction of MAP using the methods outlined by Kohn (2010) are applicable in this case. The results of MAP varied depending on which equation was used (Fig. 18)

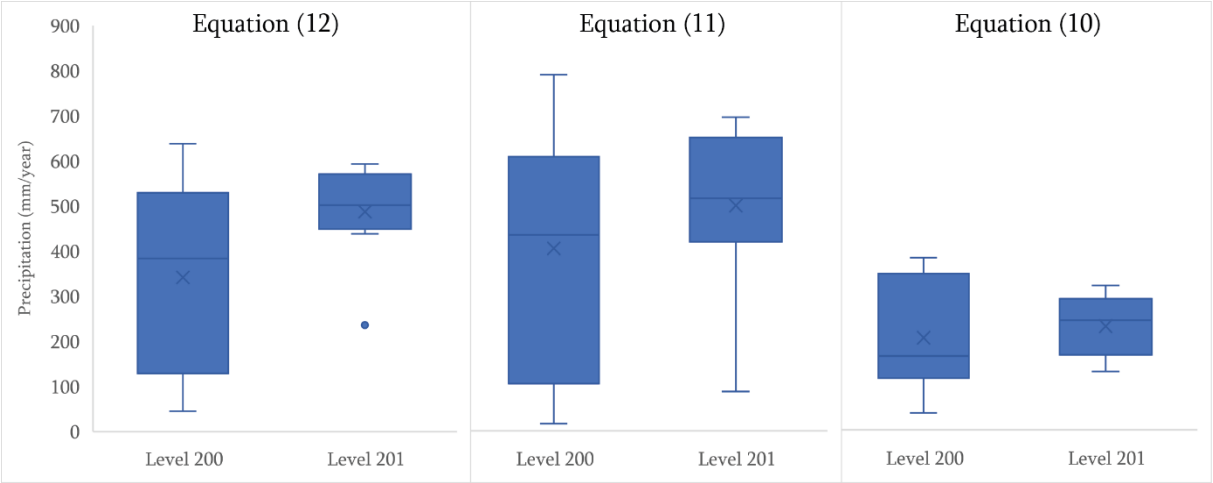


Fig. 18: Boxplot of the paleoprecipiations of levels 200 and 201 using the equations outlined in Kohn (2010) and Rey et al. (2013).

In the case of equation (12) an average MAP of 394 mm/year was given; using equation (11) an average MAP of 446 mm/year was found; with equation (10) an average MAP of 219 mm/year was found. Using two sample T-tests it was found that equation (10) differed from both equation (11) and (12) ($p_{10/11} = 0.0004$, $p_{10/12}=0.001$) and equations (11) and (12) were shown to have similar means ($p = 0.41$). Between levels 200 and 201 it is to be was noted that there is a larger variation in values in level 200. It is also worth pointing out that level 200 had more samples and the MAP results obtained from the teeth were significantly lower than that of the bone collagen results (Fig. 19) causing a higher variation. Removing the teeth from the paleoprecipitation causes the variation in level 200 to lower and resemble more closely level 201 (Fig.20).

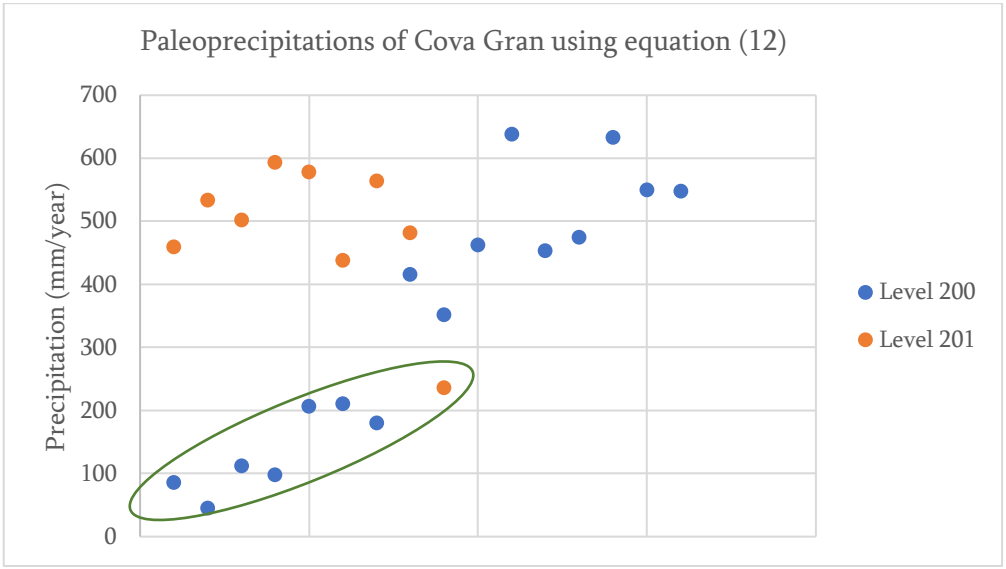


Fig. 19: Individual values for paleoprecipitations in Cova Gran, the green ellipsis highlight the values that were obtained using tooth enamel

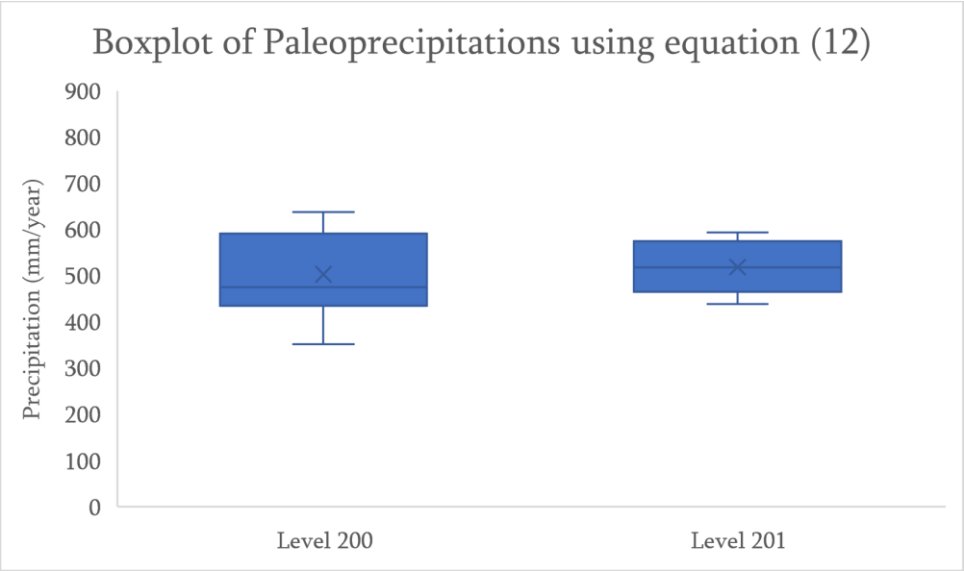


Fig. 20: Boxplot of paleoprecipitations using equation (12) but without the results obtained from tooth enamel

IV. Discussion:

IV.1 Ibex diet

The Ibex teeth have carbon values ranging between -7.93‰ to -11.90‰ and applying an isotopic enrichment of 12.67‰ leads to results varying between -20.6‰ and -24.57‰ in terms of plant value. This is within the limits of a complete C3 environment. However, this approaches the upper limits set out by Kohn (2010) of -20‰. Individuals "GC_*CAPRA*_01" and "GC_*CAPRA*_02" were shown to have the highest $\delta^{13}C$ values in the assemblage. This could indicate that both these individuals did not have completely C3 plants in their diet, with the possible inclusion of other plants as opposed to the other individuals (Fig. 12). The main possibility is the inclusion of lichen which is known to have a higher $\delta^{13}C$ value (Park and Epstein, 1960) and thus increase these values in the aforementioned individuals but possibly other CAM plants could also have this influence. Additionally, for the individuals that did not present an inverse relationship between carbon and oxygen, the little amplitude of $\delta^{13}C$ present indicates that these individuals mainly ate the same plant resource throughout at least the first two years of their lives. In a Neolithic context this has been explained by the use of stored agricultural products during winter, that would give similar isotopic values to the plants consumed during summer (Navarette et al., 2019) but in a pre-domesticated context, this was likely a sign of animals consuming perennial plants, that survive throughout the year and keep close to the same $\delta^{13}C$.

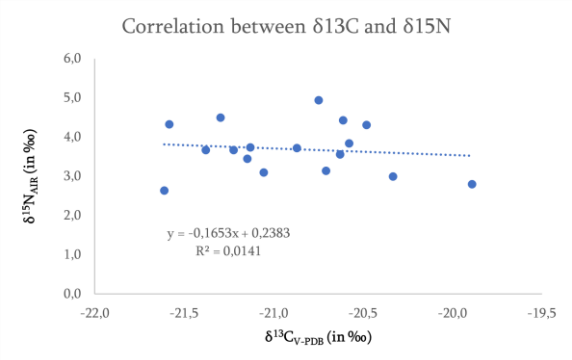
Lastly, individual "GC_*CAPRA*_03_M3", the only *C. pyrenaica* individual analysed from level 201, it presented a hypoplasia on the tooth enamel. This marker of physiological stress This could indicate the individual did not receive the necessary nutritional intake during its third year of life.

Regarding the collagen results, seeing as there was no significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between the *O. cuniculus* individuals from levels 200 and 201. It can therefore be assumed they occupied similar ecological niches through both levels.

IV.2 Paleoenvironment

IV.2.a Mean Anuual Temperature (MAT)

The reconstruction of MAT and MAP have proven to be quite successful at Cova Gran, showing little error with the only limit being the sample size. However, there are certain factors that must be taken into consideration when interpreting these results. Firstly, in regards with the reconstruction of paleotemperatures, although temperature is a large factor in determining the value of $\delta^{18}O_{precip}$ there is also aridity, rainfall, altitude and the use of different water sources that may influence the values of $\delta^{18}O_{precip}$ and thus yield a different paleotemperature reconstruction. Each of these factors will now be discussed. In the case of variations in rainfall, it was found that looking at the correlation between $\delta^{18}O$ and $\delta^{13}C$ and $\delta^{15}N$ and $\delta^{13}C$ could indicate the influence of these parameters on each isotopic system. In the case that these values are correlated, this is indicative of changes in precipitation becoming a dominant factor on each isotope, and in the opposite case, it is more likely that temperature is the dominant effect (Richards et al., 2017, Pederzani et al., 2023). In the case of the assemblage from Cova Gran, it was shown that for the *C. pyrenaica* samples there was no correlation between $\delta^{18}O$ and $\delta^{13}C$ ($p=0.14$) and $\delta^{15}N$ and $\delta^{13}C$ ($p=0.65$) using Pearsons's correlation (Fig. 21). Thus, changes in precipitation are not the main drivers of both isotopic systems at Cova Gran.



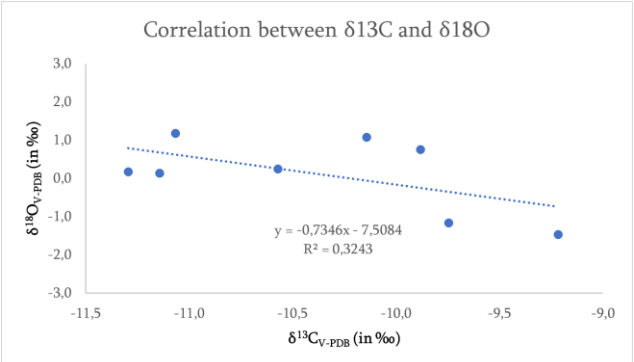


Fig. 21: plots of the correlations between $\delta^{18}O$ and $\delta^{13}C$ (right) and $\delta^{15}N$ and $\delta^{13}C$ (left)

Another case to consider would be the animals having access to different types of water sources that don't have the same values in $\delta^{18}O$ such as ground water, snowmelt or water coming from higher elevations. Water coming from higher elevations will be depleted in $\delta^{18}O$ and as such will present lower values than water sources from lower altitudes which could in turn affect the values of paleotemperatures. This would lead to a general underestimation of temperatures; in the case of glacial melt this would manly occur in the mean and summer temperatures as this would be when the ice would melt. But, considering the already elevated values in the mean and summer, an underestimation of temperatures seems unlikely. It is interesting to note that whilst in this thesis, the values of $\delta^{18}O$ from rabbits could not be analysed, considering they obtain all their water directly from plants they would not be affected as much by phenomena such as glacial melt.

It can be concluded that *C. pyrenaica* is a useful proxy for paleotemperatures during the end of the Pleistocene. The teeth experienced minimal damping (only 10%) and the error estimates when looking at $\delta^{18}O_{precip}$ and paleotemperatures were also quite small and didn't affect the results in a significant way. The influence of $\delta^{18}O$ from sources other than temperature still must be carefully considered especially as the GNIP measures $\delta^{18}O$ from precipitation. A way to avoid the influence of other $\delta^{18}O$ depleted sources affecting the $\delta^{18}O$ of animals would be to possibly directly sample river water (Pederzani et al., 2023), however in this case this was not an option.

It was unfortunately not possible to compare levels 200 and 201 using only these values as only one individual was analysed for $\delta^{18}O$ from level 201. It is interesting to note however, that this individual, GC_*CAPRA*_03_M3 presented the highest winter values and the lowest summer values. In this case, where there are not enough individuals from level 201 whose tooth enamel was analysed, there is another way to make a comparison of temperatures. $\delta^{15}N$ in leporids was found to correlate with temperature (Somerville, 2015) and as such, it is possible to compare the $\delta^{15}N$ between the two levels to see if there are any differences in temperatures. As it was previously shown the $\delta^{15}N$ of rabbits from level 200 and level 201 showed no significant difference, thus suggesting that the paleotemperatures of levels 200 and 201 are similar.

Generally, from the individuals analysed in Cova Gran it can be said that the seasonal variability is more pronounced with generally warmer conditions than that of modern condition. Winter values are the only ones to closely resemble modern conditions. Using the GNIP, the summer and mean values are closer to resemble the sites of Adana (Turkey) (28.5°C) and Sfax (Tunisia) (20.4°C) respectively, whilst the winter values more closely resemble values in Tortosa (Spain) (10.3°C), further confirming the winter values are similar to those in modern day Spain.

These warmer conditions also help to support the radiocarbon dates, dated back to the end of the Younger Dryas (12 033 – 11742 Cal BP) and could be a sign that the rapid warming that characterised the beginning of the Holocene had already begun. This goes against the general overview of the Iberian Peninsula that suggested cooler and dry conditions at 11800 BP (Fletcher et al., 2010b). This shows the advantage of stable isotope analysis for reconstructing local conditions, whereas palynological reconstructions, using marine cores are better at identifying climatic trends at the scale of the Iberian Peninsula.

IV.2.b Mean Annual Precipitation

From the reconstructed $\delta^{13}C$, it was noted that *C. pyrenaica* mainly fed on C3 plants with the exceptions of "GC_*CAPRA*_01" and "GC_*CAPRA*_02" both of which presented values close to the C3 limit, indicating the possible inclusion of lichen or non-C3 plants.

Before delving further into the analysis of these results, it is first necessary to discuss the use of the three different equations. Equation (10) (Kohn, 2010) was found to be the weakest equation of the three, this is because it does not take into account the $\delta^{13}C_{atm}$ at the time, thus leading to underestimations of the actual MAP. It also led to the most negative results, these were cases where the $\delta^{13}C$ values were too low for the equation and thus beyond its scope, none of the teeth analysed using this equation gave a positive precipitation value. Equation (11) takes into account the most parameters (altitude, latitude, $\delta^{13}C_{atm}$), it gave invalid results for individuals "GC_*CAPRA*_01" and "GC_*CAPRA*_02" but that was within expectations. Lastly, equation (12) is the only equation that did not take into account latitude or altitude, this equation was recalculated from the original dataset using a least square regression and only had one variable. It is not noted how exactly the dataset was recalculated in the article but the it is assumed the authors in Rey et al. (2013) left out the stagnating values that occur in high precipitations in the original article of Kohn (2010) were taken out of the dataset, thus leading to a more precise equation for precipitations less than 1500 mm/year. This was the only equation that didn't present any negative values although it does not make it the most apt equation to use, as there are still unknowns concerning how the equation came about. Thus, equation (11) seems more apt to use in areas that could have high precipitation and equation (12) is suited to identifying paleoprecipitations in areas with more arid conditions.

When considering the bone collagen used for paleoprecipitation reconstruction, it is important to take into account the isotopic offset value of -5‰ that was used for the conversion from bone collagen to diet values. This value was used as literature is unavailable for specifics concerning the offset value for leporids. It has been shown in other studies (Ambrose & Norr, 1993) that weight and the type of digestive system an animal has will affect it's offset value, with smaller animals having

smaller offset values. The value of -5‰ was given in an article by Ambrose and Norr (1993) as a general value for herbivores, and it should not heavily affect the values for *C. pyrenaica* but in the case of *O. cuniculus,* it is more difficult to say. Thus, it is important to keep in mind that the values of $\delta^{13}C_{diet}$ and MAP are likely overestimated for bone collagen, leading to lower actual precipitation. It also makes comparing the two taxa through bone collagen not possible, as using the same offset value for both does not change their differences in any way.

Comparing the values to modern values, using the AEMET provided data, it was found the MAP was considered slightly lower than that of the present-day area with precipitation varying from 500 – 600 mm/year now and 420 mm/year in Cova Gran during levels 200 and 201, although this value is likely lower leading to a more arid environment.

Considering these low precipitation values, it could lend support to the possibility that arid conditions masked the traces of seasonal altitudinal mobility in the *C. pyrenaica* teeth. Nontheless, tooth "GC_*CAPRA*_01_M2", where the seasonal altitudinal mobility pattern is clearest, also gives the lowest precipitation values from the assemblage. Thus, the effects masking seasonal altitudinal mobility remain uncertain.

From this it can be said that the hypothesis laid out in the beginning of the thesis, in which level 201 a would show a cold arid environment and level 200 would show warmer conditions, was shown to be invalidated. Instead, both levels 200 and 201 showed conditions warmer than modern day, with a low precipitation. Other sites in Spain dating to similar periods, like the site of El Miron in Cantabria have shown to display a colder climate similar to that of the Last Glacial Maximum (LGM), although the authors admit this goes against the general consensus and attribute this to the limited understanding of the relation between temperature and $\delta^{15}N$ with the region likely being cold but not to that degree (Stevens et al., 2014). In Fernandez Garcia et al (2016) through the analysis of microfauna, the authors interpret their data in northeast Iberia as a sharp increase in precipitation and temperature during this period. Both of these studies along with the present one highlight the differing local trends on the Iberian Peninsula, even within the same region. Cova Gran is a unique site displaying elevated temperatures but with a higher aridity than other sites in northeast Iberia. Additionally, in terms of comparisons with palynology, it is interesting to highlight the similarities with Fletcher et al (2010b), as whilst there is a discrepancy with temperature, there is a coherence in terms of aridity with both sites and that parameters would still lead to an open landscape, in line with palynological studies. This marks stable isotope analysis as a useful complement to palynological studies.

IV.3 Altitudinal mobility of *Capra pyrenaica*

Apart from the three individuals "GC_*CAPRA*_01", "GC_*CAPRA*_03" and "GC_*CAPRA*_09" the presence of seasonal altitudinal mobility, represented by the inverse relationship of $\delta^{13}C$ and $\delta^{18}O$ is difficult to observe due to the reduced amplitude of carbon and the incomplete mineralization of certain teeth. Even in the case of the two latter individuals the inverse relationship of oxygen and carbon stable isotope ratios is not as clearly pronounced as in the first individual.

Despite this, it seems unlikely that the absence of clear markers of this seasonal mobility be linked to a group of outliers. As these animals are wild, and it is unlikely that any sort of anthropic activity would have prevented them from undergoing this seasonal activity that is a part of their natural behaviour. Thus, what could explain this absence in the isotopic record? Two possibilities come forth: Firstly, one of the key factors in recording seasonal altitudinal mobility in the isotopic record is the effect of altitude on these isotopes: the Monserrat massif only reaches a maximal altitude of 1 236 m. Possibly the effects of altitude could not have been sufficient. As $\delta^{13}C$ decreases due to an increase in precipitation (Kohn, 2010), this is supposed to occur at higher altitudes. However, in the case that that the MAP was too low or the change in altitude was insufficient, this would mask the effects of seasonal altitudinal mobility. The second possibility is that these individuals largely consumed the same plant resources throughout their first year, these would have been perennial plants present at both higher and lower altitudes. Naturally, it is difficult to say what kind of plant it could be exactly, there are currently no available botanical or archaeobotanical studies done on the area. Naturally, it could be a combination of both possibilities.

IV.4 Seasonality of births:

IV.4.a *Capra*

As previously stated, the births of *C. pyrenaica* occurred over a length of 11.28 when including all individuals in the analysis and 5.64 when not taking into consideration individuals that presented problematic isotopic profiles. Naturally, these births did not occur in the same year. In either case, this birthing period is quite large, exceeding the natural birthing period of 3 months (Granados et al., 2007). It is difficult to compare these results as there are currently no other studies done on wild *Capra* from this period using this model, with other studies using it to study assemblages starting from the neolithic onwards (Balasse et al., 2012, 2024). Considering the results obtained for the paleotemperatures of Cova Gran, it should be considered that a possible reason for this extended birthing period is the warmer conditions at Cova Gran, as throughout the year the conditions would have generally been warmer, leading to less environmental constraints allowing for more spread out births. A key factor that makes interpretation difficult is the lack of individuals, with only six

individuals, in which four of the eight teeth presented different problems during the modelling sequence.

Of note is also individuals "GC_*CAPRA*_01" and "GC_*CAPRA*_02". These two individuals each had two teeth, but considering they come from the same individual, the x_0/X_{real} of the m2 and m3 should have similar results. This was not the case for both individuals. For "GC_*CAPRA*_02", a likely explanation for this difference would be linked to the fact that the isotopic profile of "GC_*CAPRA*_02_M3" was not fully mineralized and as such, a section of the isotopic profile was missing, thus changing the final result. For "GC_*CAPRA*_01", which displays a difference of almost half a year the reason is more difficult to elucidate. One possible explanation is diagenetic alteration of enamel, which while rare can still occur (Zazzo et al., 2004) but with the current sample size it is difficult to confirm this idea with certainty.

Whilst arid conditions may limit resources available, especially water, it was found in a study on the Nubian Ibex (*Capra ibex nubiana*) that arid conditions led to groups having two rutting periods rather than one (Massolo et al., 2008), it is possible this could have occurred in the case of *C. pyrenaica* and would further explain the spread-out birthing period present in the isotopic record in such warm and arid conditions.

IV.4.b *Oryctolagus*

In the case of *Oryctolagus*, whilst an in-depth discussion cannot be given on the seasonality of their births, what can be said is there was likely a higher occurrence of births in these populations when taking into account the higher temperatures that are a key factor in the reproductivity of these animals (Villafuerte, 2007).

IV.5 Influence on subsistence patterns

In the case of the humans living at the site of Cova Gran, it is important to see how these different paleoenvironmental factors would've affected their lives. Starting with temperatures, the warmer climate would have made this site at altitude inhabitable for a longer duration throughout the year. Additionally, taking into consideration the location of the site near the base of a mountainous region often associated in the region with sites specialised in hunting ibex (Fullola et al., 2012). Alongside this, effects of warmer temperatures on the reproduction of both *C. pyrenaica* and *O. cuniculus*, in the case of *C. pyrenaica* seeing as how the births were spread out more than their natural range, this would've led to a higher abundance of these taxa allowing for humans at the site to hunt more frequently. The possible second rutting reasons of the ibex would further accentuate this.

Conclusion

In conclusion, through the stable isotope analysis of $\delta^{13}C$, $\delta^{18}O$ and $\delta^{15}N$, the paleoenvironment of Cova Gran, the behaviour and diet of ibex and the influence of the former two on subsistence patterns by populations occupying the site were presented. It also allowed for a review of the methods underlying the calculation of MAP and for an assessment of the degree of validity using rabbits remains in the isotopic record.

In terms of paleoclimate, the surroundings of Cova Gran were influenced by a warm and arid climate, with temperatures higher than the present day. This contrasts the results found in palynological studies concerning temperature but were in line with the level of aridity (Fletcher et al., 2010b). Rapid warming is generally attributed to the end of the YD, at the beginning of the Holocene, but these results highlight that on a more local scale, warming had already begun at Cova Gran (12 033 – 11742 Cal BP). This would've reduced plant cover and water availability. This also highlights the diversity in local temperature and precipitation levels across the Iberian Peninsula and northeastern Iberia (Stevens et al., 2014, Fernandez Garcia, 2016), with other sites during this time exhibiting cooler conditions. It would also be interesting in the future to pair these analyses with the study of microfauna and palynological studies as they have shown to be complementary and provide interesting parallels and give interpretations at multiple scales.

Concerning the behaviour of the ibex, it was found to have a very large birthing period, between 5.64 and 11.28 months. This large birthing period can likely be attributed to two factors. Firstly, the warm conditions likely spreading out the births of these individuals and possibly creating a second rutting season. Secondly, the small sample size and the incomplete mineralization of certain teeth not allowing for clear results. In terms of diet, these individuals seem to have eaten mainly perennial plants with the exception of two individuals that could have consumed CAM plants or lichen leading to higher $\delta^{13}C$ values. Lastly, regarding the seasonal altitudinal mobility of these individuals it was interesting to note that it was not visible across the entire group, either due to the plant diet of these individuals or the fact that the altitudinal differential was not strong enough to be recorded in the tooth enamel.

The influence of these climatic parameters and animals on human behaviour would have likely encouraged humans to spend more time at the site, less influenced by cold periods thus allowing them to stay at a higher altitude site and the spread-out birthing period of ibex allowing them to hunt this species for a longer period.

The methods used to calculate MAP highlighted that equation (11) was applicable in more scenarios whilst equation (12) could give more precise results in contexts with precipitation inferior to 1500 mm/year.

The use of stable isotopes on rabbits remains showed to be quite useful in linking levels 200 and 201 in terms of temperature and aridity. The results of the tooth analysis which will soon be available were not yet integrated in the study; However, these preliminary results show promise for further development of stable isotope analysis on rabbit remains.

Following this thesis, further studies are planned on the collections of Cova Gran. One of the main limiting factors of this study was the number of individuals analysed. To remedy this a selection of 60 new samples has already been made, 30 samples from level 200 and 30 samples from level 201. This will help in getting a more equal distribution of information between both levels and allowing for a more in-depth comparison. These new samples include more teeth from *C. pyrenaica*, more bone and tooth samples from *O. cuniculus* and the addition of samples from *Cervus elaphus*. The addition of this last taxa was made to diversify the data available on paleotemperature reconstruction and account for potential biases induced by the prior use of a single species

These new additional studies will allow for a more complete picture of the paleoenvironment at Cova Gran and will hopefully provide new interesting results using rabbits as a proxy which, if successful, will likely become a staple in stable isotope analysis on the Iberian Peninsula.

Bibliography

Goñi, M. F. S., Turon, J.-L., Eynaud, F., & Gendreau, S. (2000). European Climatic Response to Millennial-Scale Changes in the Atmosphere–Ocean System during the Last Glacial Period. *Quaternary Research*, *54*(3), 394–403. https://doi.org/10.1006/qres.2000.2176

Acevedo, P., & Cassinello, J. (2009). Biology, ecology and status of Iberian ibex *Capra* pyrenaica: A critical review and research prospectus. *Mammal Review*, *39*(1), 17–32. https://doi.org/10.1111/j.1365-2907.2008.00138.x

AEMET, 2024. Valores climatológicos normales, Peninsula y Baleares. https:// www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos, accessed June 17, 2024.

Alados, C. L., & Escos, J. (1988). Parturition Dates and Mother-Kid Behavior in Spanish Ibex (*Capra* pyrenaica) in Spain. *Journal of Mammalogy*, *69*(1), 172–175. https://doi.org/10.2307/1381768

Ambrose, S. H., & Norr, L. (1993). Experimental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to Those of Bone Collagen and Carbonate. In J. B. Lambert & G. Grupe (Eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level* (pp. 1–37). Springer. https://doi.org/10.1007/978-3-662-02894-0_1

Amundson, R., Austin, A. T., Schuur, E. a. G., Yoo, K., Matzek, V., Kendall, C., Uebersax, A., Brenner, D., & Baisden, W. T. (2003). Global patterns of the isotopic composition of soil and plant nitrogen. *Global Biogeochemical Cycles*, *17*(1). https://doi.org/10.1029/2002GB001903

Austin, A. T., & Vitousek, P. M. (1998). Nutrient dynamics on a precipitation gradient in Hawai'i. *Oecologia*, *113*(4), 519–529. https://doi.org/10.1007/s004420050405

Balasse, M., & Ambrose, S. H. (2005). Distinguishing sheep and goats using dental morphology and stable carbon isotopes in C4 grassland environments. *Journal of Archaeological Science*, *32*(5), 691–702. https://doi.org/10.1016/j.jas.2004.11.013

Balasse, M., Chemineau, P., Parisot, S., Fiorillo, D., & Keller, M. (2024). Experimental Data from Lacaune and Merino Sheep Provide New Methodological and Theoretical Grounds to Investigate Autumn Lambing in Past Husbandries. *Journal of Archaeological Method and Theory*, *31*(1), 75–92. https://doi.org/10.1007/s10816-022-09600-7

Balasse, M., Obein, G., Ughetto, J., & Mainland, I. (2012). Investigating seasonality and season of birth in past herds: A reference set of sheep enamel stable oxygen isotope ratios. *Archaeometry*, *54*. https://doi.org/10.1111/j.1475-4754.2011.00624.x

Balasse, M., Smith, A. B., Ambrose, S. H., & Leigh, S. R. (2003). Determining Sheep Birth Seasonality by Analysis of Tooth Enamel Oxygen Isotope Ratios: The Late Stone Age Site of Kasteelberg (South Africa). *Journal of Archaeological Science*, *30*(2), 205–215. https://doi.org/10.1006/jasc.2002.0833

Balasse, M., Smith, A. B., Ambrose, S. H., & Leigh, S. R. (2003b). Determining Sheep Birth Seasonality by Analysis of Tooth Enamel Oxygen Isotope Ratios: The Late Stone Age Site of Kasteelberg (South Africa). *Journal of Archaeological Science*, *30*(2), 205–215. https://doi.org/10.1006/jasc.2002.0833

Bocherens, H., Fizet, M., Mariotti, A., Olive, C., Bellon, G., & Billiou, D. (1991). Application de la biogeochimie isotopique (13C,15N) a la détermination du régime alimentaire des populations humaines et animales durant les péeriodes antique et médiévale. *Arch Sci*, *44*, 329–340.

Bonafini, M., Pellegrini, M., Ditchfield, P., & Pollard, A. M. (2013). Investigation of the 'canopy effect' in the isotope ecology of temperate woodlands. *Journal of Archaeological Science*, *40*(11), 3926–3935. https://doi.org/10.1016/j.jas.2013.03.028

Brambell, F. W. R. (1944). The Reproduction of the Wild Rabbit *Oryctolagus* cuniculus (L.). *Proceedings of the Zoological Society of London*, *114*(1–2), 1–45. https://doi.org/10.1111/j.1096-3642.1944.tb00210.x

Britton, K., Jimenez, E.-L., Le Corre, M., Pederzani, S., Daujeard, C., Jaouen, K., Vettese, D., Tütken, T., Hublin, J.-J., & Moncel, M.-H. (2023). Multi-isotope zooarchaeological investigations at Abri du Maras: The paleoecological and paleoenvironmental context of Neanderthal subsistence strategies in the Rhône Valley during MIS 3. *Journal of Human Evolution*, *174*, 103292. https://doi.org/10.1016/j.jhevol.2022.103292

Bryant, J. D., Froelich, P. N., Showers, W. J., & Genna, B. J. (1996). A Tale of Two Quarries: Biologic and Taphonomic Signatures in the Oxygen Isotope Composition of Tooth Enamel Phosphate from Modern and Miocene Equids. *PALAIOS*, *11*(4), 397–408. https://doi.org/10.2307/3515249

Bullock, D. J, Rackham, J (1982). Epiphysial fusion and tooth eruption of feral goats from Moffatdale, Dumfries and Galloway, Scotland. In B. Wilson, C. Grigson, S. Payne (Eds.), Ageing and Sexing Animal Bones from Archaeological Sites, BAR, Oxford (1982), pp. 73-80.

Cerling, T. E., & Harris, J. M. (1999). Carbon isotope fractionation between diet and bioapatite in ungulate mammals and implications for ecological and paleoecological studies. *Oecologia*, *120*(3), 347–363. https://doi.org/10.1007/s004420050868

Coplen, T. B., Kendall, C., & Hopple, J. (1983). Comparison of stable isotope reference samples. *Nature*, *302*(5905), 236–238. https://doi.org/10.1038/302236a0

D'Angela, D., & Longinelli, A. (1990). Oxygen isotopes in living mammal's bone phosphate: Further results. *Chemical Geology: Isotope Geoscience Section*, *86*(1), 75–82. https://doi.org/10.1016/0168-9622(90)90007-Y

Dansgaard, W. (1964). Stable isotopes in precipitation. *Tellus*, *16*(4), 436–468. https://doi.org/10.1111/j.2153-3490.1964.tb00181.x

Delgado Huertas, A., Iacumin, P., Stenni, B., Sánchez Chillón, B., & Longinelli, A. (1995). Oxygen isotope variations of phosphate in mammalian bone and tooth enamel. *Geochimica et Cosmochimica Acta*, *59*(20), 4299–4305. https://doi.org/10.1016/0016-7037(95)00286-9

Donard, E. (1982). *Recherches sur les léporinés quaternaires (pleistocène moyen et supérieur, holocène)*. Université Bordeaux-I. Faculté des sciences.

Drucker, D. G., Bridault, A., Hobson, K. A., Szuma, E., & Bocherens, H. (2008). Can carbon-13 in large herbivores reflect the canopy effect in temperate and boreal ecosystems? Evidence from modern and ancient ungulates. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *266*(1), 69–82. https://doi.org/10.1016/j.palaeo.2008.03.020

Drucker, D. G., Naito, Y. I., Coromina, N., Rufí, I., Soler, N., & Soler, J. (2021). Stable isotope evidence of human diet in Mediterranean context during the Last Glacial Maximum. *Journal of Human Evolution*, *154*, 102967. https://doi.org/10.1016/j.jhevol.2021.102967

Ehleringer, J. R., Cerling, T. E., & Helliker, B. R. (1997). C4 photosynthesis, atmospheric CO2, and climate. *Oecologia*, *112*(3), 285–299. https://doi.org/10.1007/s004420050311

Fandos, P., & VIGAL, A. (1988). Body-Weight and Horn Length in Relation to Age of the Spanish Wild Goat. *Acta Theriologica*, *33*, 339. https://doi.org/10.4098/AT.arch.88-27

Farquhar, G. D., Ehleringer, J. R., & Hubick, K. T. (1989). Carbon Isotope Discrimination and Photosynthesis. *Annual Review of Plant Biology*, *40*(Volume 40, 1989), 503–537. https://doi.org/10.1146/annurev.pp.40.060189.002443

Fernández-García, M., López-García, J. M., & Lorenzo, C. (2016). Palaeoecological implications of rodents as proxies for the Late Pleistocene–Holocene environmental and climatic changes in northeastern Iberia. *Comptes Rendus Palevol*, *15*(6), 707–719. https://doi.org/10.1016/j.crpv.2015.08.005

Fernández-García, M., Royer, A., López-García, J. M., Bennàsar, M., Goedert, J., Fourel, F., Julien, M.-A., Bañuls-Cardona, S., Rodríguez-Hidalgo, A., Vallverdú, J., & Lécuyer, C. (2019). Unravelling the oxygen isotope signal (δ18O) of rodent teeth from northeastern Iberia, and implications for past climate reconstructions. *Quaternary Science Reviews*, *218*, 107–121. https://doi.org/10.1016/j.quascirev.2019.04.035

Fisher, J. L., & Valentine, B. (2013). Resource depression, climate change, and mountain sheep in the eastern Great Basin of western North America. *Archaeological and Anthropological Sciences*, *5*(2), 145–157. https://doi.org/10.1007/s12520-013-0124-9

Fletcher, W. J., & Sánchez Goñi, M. F. (2008). Orbital- and sub-orbital-scale climate impacts on vegetation of the western Mediterranean basin over the last 48,000 yr. *Quaternary Research*, *70*(3), 451–464. https://doi.org/10.1016/j.yqres.2008.07.002

Fletcher, W. J., Sánchez Goñi, M. F., Allen, J. R. M., Cheddadi, R., Combourieu-Nebout, N., Huntley, B., Lawson, I., Londeix, L., Magri, D., Margari, V., Müller, U. C., Naughton, F., Novenko, E., Roucoux, K., & Tzedakis, P. C. (2010a). Millennial-scale variability during the last glacial in vegetation records from Europe. *Quaternary Science Reviews*, *29*(21), 2839–2864. https://doi.org/10.1016/j.quascirev.2009.11.015

Fletcher, W. J., Sanchez Goñi, M. F., Peyron, O., & Dormoy, I. (2010b). Abrupt climate changes of the last deglaciation detected in a Western Mediterranean forest record. *Climate of the Past*, *6*(2), 245–264. https://doi.org/10.5194/cp-6-245-2010

Friedli, H., Lötscher, H., Oeschger, H., Siegenthaler, U., & Stauffer, B. (1986). Ice core record of the 13C/12C ratio of atmospheric CO2 in the past two centuries. *Nature*, *324*(6094), 237–238. https://doi.org/10.1038/324237a0

Fullola, J.-M., Mangado, X., Tejero, J.-M., Petit, M.-À., Bergadà, M.-M., Nadal, J., García-Argüelles, P., Bartrolí, R., & Mercadal, O. (2012). The Magdalenian in Catalonia (northeast Iberia). *Quaternary International*, *272–273*, 55–74. https://doi.org/10.1016/j.quaint.2012.02.051

García-González, R., & Cuartas, P. (1992). *Feeding strategies of Spanish Wild Goat in the Cazorla Sierra (Spain)*. https://digital.csic.es/handle/10261/36569

Garcia-Guixé, E., Martínez-Moreno, J., Torcal, R., Nunez, M., & Richards, M. (2009). Stable isotope analysis of human and animal remains from the Late Upper Palaeolithic site of Balma Guilanyà, southeastern Pre-Pyrenees, Spain. *Journal of Archaeological Science*, *36*, 1018–1026. https://doi.org/10.1016/j.jas.2008.12.001

Granados, J. E., Pérez, J. M., Márquez, F. J., Serrano, E., Soriguer, R. C., & Fandos, Y. P. (2001). *LA CABRA MONTÉS (Capra pyrenaica, SCHINZ 1838)*.

Gross, J. H. (2017). Isotopic Composition and Accurate Mass. In J. H. Gross (Ed.), *Mass Spectrometry: A Textbook* (pp. 85–150). Springer International Publishing. https://doi.org/10.1007/978-3-319-54398-7_3

Handley, LL., Austin, A., Robinson, D., Scrimgeour, C., Raven, J., Heaton, T. H. E., Schmidt, S., & Stewart, G. (1999). The ^{15}N natural abundance ($\delta^{15}N$) of ecosystem samples reflects measures of water availability. *Australian Journal of Plant Physiology*, *26*. https://doi.org/10.1071/PP98146

Hoefs, J. (2021). Isotope Fractionation Processes of Selected Elements. In J. Hoefs (Ed.), *Stable Isotope Geochemistry* (pp. 49–265). Springer International Publishing. https://doi.org/10.1007/978-3-030-77692-3_2

https://en-gb.topographic-map.com/map
k94mt6/Montserrat/?center=41.59708%2C1.81791&zoom=13, accessed on 15/08/2024

Iacumin, P., Bocherens, H., Mariotti, A., & Longinelli, A. (1996). Oxygen isotope analyses of co-existing carbonate and phosphate in biogenic apatite: A way to monitor diagenetic alteration of bone phosphate? *Earth and Planetary Science Letters*, *142*(1), 1–6. https://doi.org/10.1016/0012-821X(96)00093-3

IAEA/WMO (2024). Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: https://nucleus.iaea.org/wiser. Accessed on 15/08/2024

Jeffrey, A., Denys, C., Stoetzel, E., & Lee-Thorp, J. A. (2015). Influences on the stable oxygen and carbon isotopes in gerbillid rodent teeth in semi-arid and arid environments: Implications for past climate and environmental reconstruction. *Earth and Planetary Science Letters*, *428*, 84–96. https://doi.org/10.1016/j.epsl.2015.07.012

Knockaert, J., Balasse, M., Rendu, C., Burens, A., Campmajo, P., Carozza, L., Bousquet, D., Fiorillo, D., & Vigne, J.-D. (2018). Mountain adaptation of caprine herding in the eastern Pyrenees during the Bronze Age: A stable oxygen and carbon isotope analysis of teeth. *Quaternary International*, *484*, 60–74. https://doi.org/10.1016/j.quaint.2017.05.029

Kohn, M. J. (2004). Comment: Tooth Enamel Mineralization in Ungulates: Implications for Recovering a Primary Isotopic Time-Series, by B. H. Passey and T. E. Cerling (2002). *Geochimica et Cosmochimica Acta*, *68*(2), 403–405. https://doi.org/10.1016/S0016-7037(03)00443-5

Kohn, M. J. (2010). Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo)ecology and (paleo)climate. *Proceedings of the National Academy of Sciences*, *107*(46), 19691–19695. https://doi.org/10.1073/pnas.1004933107

Körner, Ch., Farquhar, G. D., & Roksandic, Z. (1988). A global survey of carbon isotope discrimination in plants from high altitude. *Oecologia*, *74*(4), 623–632. https://doi.org/10.1007/BF00380063

Körner, Ch., Farquhar, G. D., & Wong, S. C. (1991). Carbon isotope discrimination by plants follows latitudinal and altitudinal trends. *Oecologia*, *88*(1), 30–40. https://doi.org/10.1007/BF00328400

Lécuyer, C., Hillaire-Marcel, C., Burke, A., Julien, M.-A., & Hélie, J.-F. (2021). Temperature and precipitation regime in LGM human refugia of southwestern Europe inferred from δ13C and δ18O of large mammal remains. *Quaternary Science Reviews*, *255*, 106796. https://doi.org/10.1016/j.quascirev.2021.106796

Leuenberger, M., Siegenthaler, U., & Langway, C. C. (1992). Carbon isotope composition of atmospheric CO2 during the last ice age from an Antarctic ice core. *Nature*, *357*, 488–490. https://doi.org/10.1038/357488a0

Longin, R. (1971). New Method of Collagen Extraction for Radiocarbon Dating. *Nature*, *230*(5291), 241–242. https://doi.org/10.1038/230241a0

Makarewicz, C. A., & Pederzani, S. (2017). Oxygen (δ18O) and carbon (δ13C) isotopic distinction in sequentially sampled tooth enamel of co-localized wild and domesticated caprines: Complications to establishing seasonality and mobility in herbivores. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *485*, 1–15. https://doi.org/10.1016/j.palaeo.2017.01.010

Marin, J (in press). Archaeozoological analysis of the fauna at Cova Gran. IPHES.

Mariotti, A., Pierre, D., Vedy, J. C., Bruckert, S., & Guillemot, J. (1980). The abundance of natural nitrogen 15 in the organic matter of soils along an altitudinal gradient (Chablais, Haute Savoie, France). *CATENA*, *7*(1), 293–300. https://doi.org/10.1016/S0341-8162(80)80020-8

Martínez, T. (1994). *Dieta estacional de la cabra montes en los puertos de Tortosa y Beceite (área mediterránea del nordeste de España*. *8,* 373–380.

Massolo, A., Spalton, J. A., Tear, T. H., Lawrence, M. W., Said al Harsusi, L., & Lovari, S. (2008). Dynamic social system in Nubian ibex: Can a second mating season develop in response to arid climate? *Journal of Zoology*, *274*(3), 216–225. https://doi.org/10.1111/j.1469-7998.2007.00373.x

McKinney, C. R., McCrea, J. M., Epstein, S., Allen, H. A., & Urey, H. C. (1950). Improvements in Mass Spectrometers for the Measurement of Small Differences in Isotope Abundance Ratios. *Review of Scientific Instruments*, *21*(8), 724–730. https://doi.org/10.1063/1.1745698

Messana, C., Tornero, C., Madgwick, R., Lamb, A. L., Evans, J., & Colominas, L. (2023). Between valleys, plateaus, and mountains: Unveiling livestock altitudinal mobility in the Iron Age Iberian Peninsula (3rd c. BC) through a multi-isotope approach. *Frontiers in Environmental Archaeology*, *2*. https://doi.org/10.3389/fearc.2023.1245725

Minagawa, M., & Wada, E. (1984). Stepwise enrichment of 15N along food chains: Further evidence and the relation between δ15N and animal age. *Geochimica et Cosmochimica Acta*, *48*(5), 1135–1140. https://doi.org/10.1016/0016-7037(84)90204-7

Moreno-Gutiérrez, C., Dawson, T. E., Nicolás, E., & Querejeta, J. I. (2012). Isotopes reveal contrasting water use strategies among coexisting plant species in a Mediterranean ecosystem. *New Phytologist*, *196*(2), 489–496. https://doi.org/10.1111/j.1469-8137.2012.04276.x

Naito, Y. I., Belmaker, M., Jiménez Espejo, F. J., Simón Vallejo, M. D., Riquelme Cantal, J. A., Parrilla Giráldez, R., & Cortés Sánchez, M. (2022). *Evidence for Marine Consumption During the Upper Palaeolithic at "El Pirulejo" Inland Rock- Shelter (Southern Iberia Peninsula, Spain)*. https://doi.org/10.5334/oq.109

Navarrete, V., Tornero, C., Balasse, M., & Saña, M. (2019). Food management of early introduced caprine and bovine herds in the early Neolithic site of La Draga (Banyoles): An isotopic approach. *International Journal of Osteoarchaeology*, *29*(6), 986–998. https://doi.org/10.1002/oa.2812

Oms, F. X., Morales, J. I., Cebrià, A., Mestres, J., & Fullola, J. M. (2019). Nuevas intervenciones en la Cova Gran y la Cova Freda de Montserrat (Collbató, Barcelona) casi 100 años después. *Trabajos de Prehistoria*, *76*(2), Article 2. https://doi.org/10.3989/tp.2019.12241

Park, R., & Epstein, S. (1960). CARBON ISOTOPE FRACTIONATION DURING PHOTOSYNTHESIS. *Geochim. et Cosmochim. Acta, Vol: 21*. https://doi.org/10.1016/S0016-7037(60)80006-3

Passey, B. H., & Cerling, T. E. (2006). In situ stable isotope analysis (δ13C, δ18O) of very small teeth using laser ablation GC/IRMS. *Chemical Geology*, *235*(3), 238–249. https://doi.org/10.1016/j.chemgeo.2006.07.002

Passey, B. H., Cerling, T. E., Schuster, G. T., Robinson, T. F., Roeder, B. L., & Krueger, S. K. (2005). Inverse methods for estimating primary input signals from time-averaged isotope profiles. *Geochimica et Cosmochimica Acta*, *69*(16), 4101–4116. https://doi.org/10.1016/j.gca.2004.12.002

Passey, B. H., Robinson, T. F., Ayliffe, L. K., Cerling, T. E., Sponheimer, M., Dearing, M. D., Roeder, B. L., & Ehleringer, J. R. (2005). Carbon isotope fractionation between diet, breath CO2, and bioapatite in different mammals. *Journal of Archaeological Science*, *32*(10), 1459–1470. https://doi.org/10.1016/j.jas.2005.03.015

Pederzani, S., Britton, K., Jones, J. R., Pérez, L. A., Geiling, J. M., & Marín-Arroyo, A. B. (2023). Late Pleistocene Neanderthal exploitation of stable and mosaic ecosystems in northern Iberia shown by multi-isotope evidence. *Quaternary Research*, *116*, 108–132. https://doi.org/10.1017/qua.2023.32

Pellegrini, M., Lee-Thorp, J. A., & Donahue, R. E. (2011). Exploring the variation of the δ18Op and δ18Oc relationship in enamel increments. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *310*(1), 71–83. https://doi.org/10.1016/j.palaeo.2011.02.023

Pryor, A. J. E., Stevens, R. E., O'Connell, T. C., & Lister, J. R. (2014). Quantification and propagation of errors when converting vertebrate biomineral oxygen isotope data to temperature for palaeoclimate reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *412*, 99–107. https://doi.org/10.1016/j.palaeo.2014.07.003

Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., … Winstrup, M. (2014). A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: Refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews*, *106*, 14–28. https://doi.org/10.1016/j.quascirev.2014.09.007

Richards, M. P., Pellegrini, M., Niven, L., Nehlich, O., Dibble, H., Turq, A., & McPherron, S. J. P. (2017). Temporal variations in *Equus* tooth isotope values (C,N,O) from the Middle Paleolithic site of Combe Grenal, France (ca. 150,000 to 50,000 BP). *Journal of Archaeological Science: Reports*, *14*, 189–198. https://doi.org/10.1016/j.jasrep.2017.05.024

Rozanski, K., Araguás-Araguás, L., & Gonfiantini, R. (1993). Isotopic Patterns in Modern Global Precipitation. In *Climate Change in Continental Isotopic Records* (pp. 1–36). American Geophysical Union (AGU). https://doi.org/10.1029/GM078p0001

Schonfeld, S. E., & Slavkin, H. C. (1977). Demonstration of enamel matrix proteins on root-analogue surfaces of rabbit permanent incisor teeth. *Calcified Tissue Research*, *24*(1), 223–229. https://doi.org/10.1007/BF02223320

Smith, S., Mauldin, R., Munoz, C., Hard, R., Paul, D., Skrzypek, G., Villanueva, P., & Kemp, L. (2014). Exploring the use of stable carbon isotope ratios in short-lived leporids for local paleoecological reconstruction. *Open Journal of Archaeometry*, *2*. https://doi.org/10.4081/arc.2014.5306

Somerville, A. D. (2015). *Leporids, Landscapes, and Social-Environmental Dynamics in Arid North America: Stable Isotope Analysis of Rabbit and Hare Bones from Modern and Archaeological Sites* [UC San Diego]. https://escholarship.org/uc/item/7st1q82k

Somerville, A. D., Froehle, A. W., & Schoeninger, M. J. (2018). Environmental influences on rabbit and hare bone isotope abundances: Implications for paleoenvironmental research. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *497*, 91–104. https://doi.org/10.1016/j.palaeo.2018.02.008

Somerville, A. D., Nelson, B. A., Punzo Díaz, J. L., & Schoeninger, M. J. (2020). Rabbit bone stable isotope values distinguish desert ecoregions of North America: Data from the archaeological sites of Pueblo Grande, La Ferreria, and La Quemada. *Journal of Archaeological Science*, *113*, 105063. https://doi.org/10.1016/j.jas.2019.105063

Somerville, A. D., Sugiyama, N., Manzanilla, L. R., & Schoeninger, M. J. (2016). Animal Management at the Ancient Metropolis of Teotihuacan, Mexico: Stable Isotope Analysis of Leporid (Cottontail and Jackrabbit) Bone Mineral. *PLOS ONE*, *11*(8), e0159982. https://doi.org/10.1371/journal.pone.0159982

Somerville, A. D., Sugiyama, N., Manzanilla, L. R., & Schoeninger, M. J. (2017). Leporid management and specialized food production at Teotihuacan: Stable isotope data from cottontail and jackrabbit bone collagen. *Archaeological and Anthropological Sciences*, *9*(1), 83–97. https://doi.org/10.1007/s12520-016-0420-2

Sommer, R. S., & Nadachowski, A. (2006). Glacial refugia of mammals in Europe: Evidence from fossil records. *Mammal Review*, *36*(4), 251–265. https://doi.org/10.1111/j.1365-2907.2006.00093.x

Stevens, R. E., Hermoso-Buxán, X. L., Marín-Arroyo, A. B., González-Morales, M. R., & Straus, L. G. (2014). Investigation of Late Pleistocene and Early Holocene palaeoenvironmental change at El Mirón cave (Cantabria, Spain): Insights from carbon and nitrogen isotope analyses of red deer.

Palaeogeography, Palaeoclimatology, Palaeoecology, *414*, 46–60. https://doi.org/10.1016/j.palaeo.2014.05.049

Tejada-Lara, J. V., MacFadden, B. J., Bermudez, L., Rojas, G., Salas-Gismondi, R., & Flynn, J. J. (2018). Body mass predicts isotope enrichment in herbivorous mammals. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1881), 20181020. https://doi.org/10.1098/rspb.2018.1020

Tejedor-Rodríguez, C., Moreno-García, M., Tornero, C., Hoffmann, A., Lagrán, Í. G.-M. de, Arcusa-Magallón, H., Garrido-Pena, R., Royo-Guillén, J. I., Díaz-Navarro, S., Peña-Chocarro, L., Alt, K. W., & Rojo-Guerra, M. (2021). Investigating Neolithic caprine husbandry in the Central Pyrenees: Insights from a multi-proxy study at Els Trocs cave (Bisaurri, Spain). *PLOS ONE*, *16*(1), e0244139. https://doi.org/10.1371/journal.pone.0244139

Thorp, J. L., & Van der Merwe, N. J. (1987). Carbon isotope analysis of fossil bone apatite. *South African Journal of Science*, *83*(11), 712–715.

Tieszen, L. L., Senyimba, M. M., Imbamba, S. K., & Troughton, J. H. (1979). The distribution of C3 and C4 grasses and carbon isotope discrimination along an altitudinal and moisture gradient in Kenya. *Oecologia*, *37*(3), 337–350. https://doi.org/10.1007/BF00347910

Tornero, C., Aguilera, M., Ferrio, J. P., Arcusa, H., Moreno-García, M., Garcia-Reig, S., & Rojo-Guerra, M. (2018). Vertical sheep mobility along the altitudinal gradient through stable isotope analyses in tooth molar bioapatite, meteoric water and pastures: A reference from the Ebro valley to the Central Pyrenees. *Quaternary International*, *484*, 94–106. https://doi.org/10.1016/j.quaint.2016.11.042

Tornero, C., Bălăşescu, A., Ughetto-Monfrin, J., Voinea, V., & Balasse, M. (2013). Seasonality and season of birth in early Eneolithic sheep from Cheia (Romania): Methodological advances and implications for animal economy. *Journal of Archaeological Science*, *40*(11), 4039–4055. https://doi.org/10.1016/j.jas.2013.05.013

Tornero, C., Balasse, M., Bălăşescu, A., Chataigner, C., Gasparyan, B., & Montoya, C. (2016). The altitudinal mobility of wild sheep at the Epigravettian site of Kalavan 1 (Lesser Caucasus, Armenia): Evidence from a sequential isotopic analysis in tooth enamel. *Journal of Human Evolution*, *97*, 27–36. https://doi.org/10.1016/j.jhevol.2016.05.001

Ugan, A., & Coltrain, J. (2011). Variation in collagen stable nitrogen values in black-tailed jackrabbits (*Lepus californicus*) in relation to small-scale differences in climate, soil, and topography. *Journal of Archaeological Science*, *38*(7), 1417–1429. https://doi.org/10.1016/j.jas.2011.01.015

van der Merwe, N. J., & Medina, E. (1991). The canopy effect, carbon isotope ratios and foodwebs in amazonia. *Journal of Archaeological Science*, *18*(3), 249–259. https://doi.org/10.1016/0305-4403(91)90064-V

van der Merwe, N. J., Roosevelt, A. C., & Vogel, J. C. (1981). Isotopic evidence for prehistoric subsistence change at Parmana, Venezuela. *Nature*, *292*(5823), 536–538. https://doi.org/10.1038/292536a0

van Klinken, G. J. (1999). Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science*, *26*(6), 687–695. https://doi.org/10.1006/jasc.1998.0385

Villafuerte, R. (2007). *Oryctolagus* cuniculus, Linnaeaus, 1758. In *En: L. J. Palomo, J. Gisbert y J. C. Blanco (eds). Atlas y Libro Rojo de los Mamíferos Terrestres de España. Dirección General para la Biodiversidad -SECEM-SECEMU, Madrid* (pp. 487–489).

Villaret, J. C., Bon, R., & Rivet, A. (1997). Sexual Segregation of Habitat by the Alpine Ibex in the French Alps. *Journal of Mammalogy*, *78*(4), 1273–1281. https://doi.org/10.2307/1383070

Wicks, T. Z., Thirumalai, K., Shanahan, T. M., & Bell, C. J. (2015). The use of δ13C values of leporid teeth as indicators of past vegetation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *418*, 245–260. https://doi.org/10.1016/j.palaeo.2014.11.017

Zazzo, A., Lécuyer, C., Sheppard, S. M. F., Grandjean, P., & Mariotti, A. (2004). Diagenesis and the reconstruction of paleoenvironments: A method to restore original δ18O values of carbonate and phosphate from fossil tooth enamel1. *Geochimica et Cosmochimica Acta*, *68*(10), 2245–2258. https://doi.org/10.1016/j.gca.2003.11.009

Table of Illustrations

Tables:

Figures:

Appendix:

Site	Level	Square	N°	Bone	Code	Init. Wt.
Cova Gran	200	J12	534	Man	GC_*Capra*_01_BC	1.4658
Cova Gran	200	H12	120	Man	GC_*Capra*_02_BC	1.8678
Cova Gran	200	G12	45	Man	GC_*Capra*_03_BC	2.0754
Cova Gran	200	J14	200	Man	GC_*Oryctolagus*_01_BC	1.3123
Cova Gran	201	H12	364	Man	GC_*Oryctolagus*_02_BC	1.0277
Cova Gran	201	H12	260	Man	GC_*Oryctolagus*_03_BC	1.0172
Cova Gran	201	H12	369	Man	GC_*Oryctolagus*_04_BC	1.0424
Cova Gran	200	J14	181	Man	GC_*Oryctolagus*_05_BC	0.7661
Cova Gran	200	J14	182	Man	GC_*Oryctolagus*_06_BC	0.9602
Cova Gran	200	H12	197	Man	GC_*Oryctolagus*_07_BC	1.1621
Cova Gran	200	H12	233	Man	GC_*Oryctolagus*_08_BC	1.0955
Cova Gran	200	H12	241	Man	GC_*Oryctolagus*_09_BC	0.6901
Cova Gran	201	H12	397	Man	GC_*Oryctolagus*_10_BC	0.8389
Cova Gran	201	H12	407	Man	GC_*Oryctolagus*_11_BC	0.7443
Cova Gran	201	H12	441	Man	GC_*Oryctolagus*_12_BC	0.8458
Cova Gran	201	H12	337	Man	GC_*Oryctolagus*_13_BC	1.1777
Cova Gran	201	H12	389	Man	GC_*Oryctolagus*_14_BC	0.7685

Appendix 1: Table of the origin of each bone studied from Cova Gran

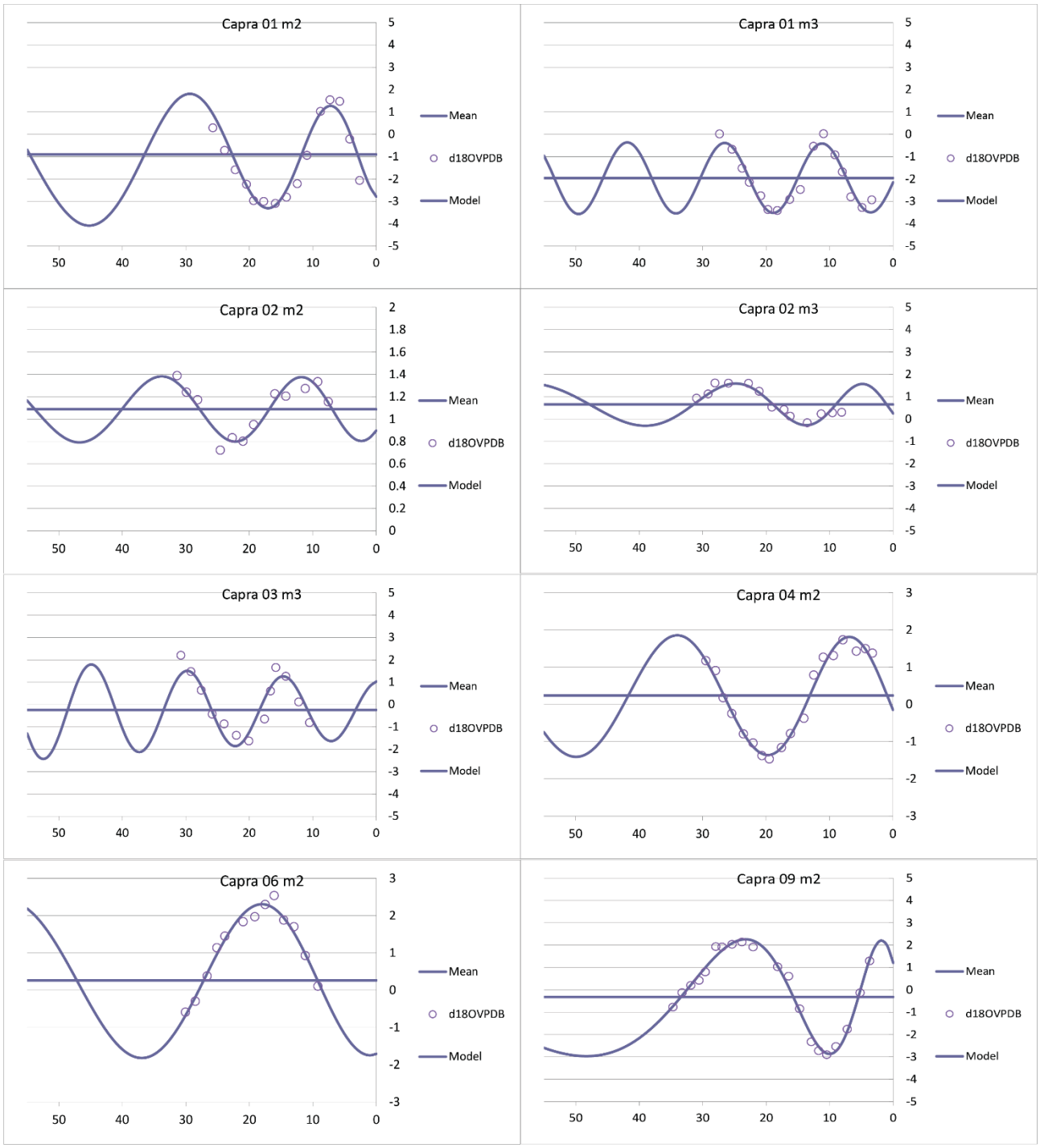
GC01M2			
GC_CAPRA_01_M2.1	25.73	-10.48	0.30
GC_CAPRA_01_M2.2	23.88	-10.16	-0.72
GC_CAPRA_01_M2.3	22.22	-9.81	-1.58
GC_CAPRA_01_M2.4	20.43	-9.68	-2.24
GC_CAPRA_01_M2.5	19.33	-9.48	-2.96
GC_CAPRA_01_M2.6	17.72	-9.56	-3.00
GC_CAPRA_01_M2.7	15.9	-9.57	-3.09
GC_CAPRA_01_M2.8	14.15	-9.52	-2.81

GC_CAPRA_01_M2.9	12.45	-9.38	-2.20
GC_CAPRA_01_M2.10	10.92	-9.61	-0.94
GC_CAPRA_01_M2.11	8.8	-9.28	1.03
GC_CAPRA_01_M2.12	7.29	-9.99	1.55
GC_CAPRA_01_M2.13	5.76	-10.20	1.48
GC_CAPRA_01_M2.14	4.17	-9.89	-0.21
GC_CAPRA_01_M2.15	2.62	-9.58	-2.06
GC01M3			
GC_CAPRA_01_M3.1	32.29	-9.97	1.35
GC_CAPRA_01_M3.2	30.64	-9.86	1.16
GC_CAPRA_01_M3.3	29.24	-9.81	0.90
GC_CAPRA_01_M3.4	27.34	-9.52	0.02
GC_CAPRA_01_M3.5	25.37	-9.32	-0.67
GC_CAPRA_01_M3.6	23.8	-9.20	-1.51
GC_CAPRA_01_M3.7	22.66	-9.29	-2.14
GC_CAPRA_01_M3.8	20.85	-9.03	-2.75
GC_CAPRA_01_M3.9	19.71	-9.09	-3.36
GC_CAPRA_01_M3.10	18.24	-9.01	-3.40
GC_CAPRA_01_M3.11	16.28	-9.42	-2.91
GC_CAPRA_01_M3.12	14.62	-9.38	-2.47
GC_CAPRA_01_M2.14	12.54	-8.95	-0.53
GC_CAPRA_01_M2.15	10.96	-9.09	0.03
GC_CAPRA_01_M2.16	9.16	-9.05	-0.92
GC_CAPRA_01_M2.17	8	-8.77	-1.68
GC_CAPRA_01_M2.18	6.66	-9.18	-2.80
GC_CAPRA_01_M2.19	4.88	-8.39	-3.27
GC_CAPRA_01_M2.20	3.36	-8.76	-2.93
GC02M2			
GC_CAPRA_02_M2.6	31.37	-10.32	1.39
GC_CAPRA_02_M2.7	29.9	-10.62	1.24
GC_CAPRA_02_M2.8	28.14	-10.48	1.17
GC_CAPRA_02_M2.10	24.56	-10.17	0.72
GC_CAPRA_02_M2.11	22.69	-10.25	0.83
GC_CAPRA_02_M2.12	21.01	-10.37	0.80
GC_CAPRA_02_M2.13	19.33	-9.96	0.95
GC_CAPRA_02_M2.14	17.57	-10.49	0.71
GC_CAPRA_02_M2.15	15.99	-9.89	1.23
GC_CAPRA_02_M2.16	14.24	-9.88	1.21
GC_CAPRA_02_M2.17	12.73	-9.88	1.05
GC_CAPRA_02_M2.18	11.18	-9.97	1.27
GC_CAPRA_02_M2.19	9.22	-9.82	1.33
GC_CAPRA_02_M2.20	7.56	-9.88	1.16
GC02M3			
GC_CAPRA_02_M3.1	30.97	-9.99	0.94
GC_CAPRA_02_M3.2	29.15	-9.66	1.13
GC_CAPRA_02_M3.3	28.07	-9.96	1.62
GC_CAPRA_02_M3.4	25.95	-9.91	1.61

GC_CAPRA_02_M3.6	22.78	-9.73	1.60
GC_CAPRA_02_M3.7	21.1	-9.79	1.24
GC_CAPRA_02_M3.8	19.11	-9.70	0.53
GC_CAPRA_02_M3.9	17.18	-9.83	0.42
GC_CAPRA_02_M3.10	16.22	-9.75	0.13
GC_CAPRA_02_M3.12	13.52	-9.72	-0.16
GC_CAPRA_02_M3.13	11.32	-9.84	0.24
GC_CAPRA_02_M3.14	9.55	-10.14	0.28
GC_CAPRA_02_M3.15	8.09	-10.44	0.30
GC03M3			
GC_CAPRA_03_M3.1	32.46	N/A	N/A
GC_CAPRA_03_M3.2	30.78	-11.76	2.21
GC_CAPRA_03_M3.3	29.19	-11.54	1.48
GC_CAPRA_03_M3.4	27.57	-11.68	0.65
GC_CAPRA_03_M3.5	25.85	-11.50	-0.43
GC_CAPRA_03_M3.6	23.97	-11.41	-0.86
GC_CAPRA_03_M3.7	22.04	-11.28	-1.37
GC_CAPRA_03_M3.8	20.07	-10.70	-1.63
GC_CAPRA_03_M3.9	17.59	-11.06	-0.65
GC_CAPRA_03_M3.10	16.65	-10.99	0.61
GC_CAPRA_03_M3.11	15.82	-11.21	1.66
GC_CAPRA_03_M3.12	14.25	-11.29	1.27
GC_CAPRA_03_M3.13	12.21	-11.04	0.12
GC_CAPRA_03_M3.14	10.51	-11.35	-0.81
GC04M2			
GC_CAPRA_04_M2.1	29.48	-7.93	1.17
GC_CAPRA_04_M2.2	27.96	-8.25	0.91
GC_CAPRA_04_M2.3	26.77	-8.72	0.18
GC_CAPRA_04_M2.4	25.4	-8.96	-0.24
GC_CAPRA_04_M2.5	23.55	-9.60	-0.79
GC_CAPRA_04_M2.6	22.04	-10.04	-1.04
GC_CAPRA_04_M2.7	20.64	-11.02	-1.37
GC_CAPRA_04_M2.8	19.47	-11.37	-1.46
GC_CAPRA_04_M2.9	17.57	-11.51	-1.16
GC_CAPRA_04_M2.10	16.14	-11.56	-0.78
GC_CAPRA_04_M2.11	14.03	-11.44	-0.37
GC_CAPRA_04_M2.12	12.49	-11.90	0.79
GC_CAPRA_04_M2.13	10.97	-11.78	1.27
GC_CAPRA_04_M2.14	9.37	-11.56	1.31
GC_CAPRA_04_M2.15	7.89	-11.47	1.73
GC_CAPRA_04_M2.16	5.76	-11.46	1.43
GC_CAPRA_04_M2.17	4.34	-11.13	1.49
GC_CAPRA_04_M2.18	3.24	-10.60	1.38
GC06M2			
GC_CAPRA_06_M2.1	30.08	-10.58	-0.59
GC_CAPRA_06_M2.2	28.54	-10.76	-0.30
GC_CAPRA_06_M2.3	26.67	-10.91	0.38

GC_CAPRA_06_M2.4	25.14	-10.87	1.14
GC_CAPRA_06_M2.5	23.88	-11.19	1.45
GC_CAPRA_06_M2.7	21	-11.25	1.84
GC_CAPRA_06_M2.8	19.15	-11.08	1.97
GC_CAPRA_06_M2.9	17.54	-11.19	2.30
GC_CAPRA_06_M2.10	16.1	-11.61	2.54
GC_CAPRA_06_M2.11	14.61	-11.34	1.88
GC_CAPRA_06_M2.12	13	-11.14	1.71
GC_CAPRA_06_M2.13	11.21	-11.73	0.93
GC_CAPRA_06_M2.14	9.23	-11.42	0.11
GC09M2			
GC_CAPRA_09_M2.1	34.72	-11.42	-0.77
GC_CAPRA_09_M2.2	33.27	-11.43	-0.12
GC_CAPRA_09_M2.3	31.9	-11.46	0.20
GC_CAPRA_09_M2.4	30.6	-11.43	0.43
GC_CAPRA_09_M2.5	29.61	-11.03	0.80
GC_CAPRA_09_M2.6	27.97	-11.32	1.94
GC_CAPRA_09_M2.7	26.97	-11.56	1.93
GC_CAPRA_09_M2.8	25.4	-11.51	2.04
GC_CAPRA_09_M2.9	23.86	-11.34	2.14
GC_CAPRA_09_M2.10	22.09	-11.36	1.92
GC_CAPRA_09_M2.12	18.22	-11.17	1.04
GC_CAPRA_09_M2.13	16.5	-11.43	0.62
GC_CAPRA_09_M2.14	14.76	-10.80	-0.84
GC_CAPRA_09_M2.16	11.77	-10.22	-2.72
GC_CAPRA_09_M2.17	10.48	-10.68	-2.89
GC_CAPRA_09_M2.18	9.04	-11.12	-2.53
GC_CAPRA_09_M2.19	7.24	-10.43	-1.76
GC_CAPRA_09_M2.20	5.23	-10.86	-0.13
GC_CAPRA_09_M2.21	3.73	-11.16	1.30

Appendix 2: Table of the $\delta^{13}C$ and $\delta^{18}O$ enamel values at Cova Gran. The samples that were not taken into account during the $\delta^{18}O$ modelling were not included.



Appendix 4: Results from the $\delta^{18}O$ modelling of the ibex teeth from Cova Gran

		Pes (mg)	δ13C	%C	δ15N	%N	C:N
GC_Capra_02_BC	200	0.386	-20.3	44.75	3.0	15.59	3.35
GC_Capra_03_BC	200	0.367	-19.9	22.68	2.8	8.52	3.10
GC_Capra_01 BC	200	0.377	-20.6	40.71	3.6	14.76	3.22
GC_ORYCTOLAGUS_05_BC	200	0.378	-21.6	41.85	2.6	15.37	3.18
GC_ORYCTOLAGUS_06A_BC	200	0.362	-20.6	40.69	3.8	15.23	3.12
GC_ORYCTOLAGUS_06B_BC	200	0.376	-20.7	33.57	3.1	12.63	3.10
GC_ORYCTOLAGUS_07_BC	200	0.355	-21.6	39.59	4.3	14.52	3.18
GC_ORYCTOLAGUS_09_BC	200	0.379	-21.1	32.44	3.5	12.23	3.10
OC_ORYCTOLAGUS_01_BC	200	0.381	-21.1	42.01	3.7	15.82	3.10
GC_ORCYTOLAGUS_04_BC	201	0.346	-20.6	35.83	4.4	13.51	3.09
GC_ORCYTOLAGUS_12_BC	201	0.366	-21.1	31.02	3.1	11.79	3.07
GC_ORYCTOLAGUS_13_BC	201	0.394	-20.9	46.83	3.7	17.24	3.17
GC_ORYCTOLAGUS_02_BC	201	0.37	-21.4	34.35	3.7	12.90	3.11
GC_ORYCTOLAGUS_03_BC	201	0.378	-21.3	21.75	4.5	8.30	3.06
GC_ORYCTOLAGUS_10_BC	201	0.359	-20.5	41.57	4.3	15.59	3.11
GC_ORYCTOLAGUS_11_BC	201	0.385	-21.2	34.29	3.7	12.82	3.12
GC_ORYCTOLAGUS_14_BC	201	0.359	-20.7	36.12	4.9	13.60	3.10

Appendix 4: Table of the $\delta^{13}C$ and $\delta^{15}N$ bone collagen values at Cova Gran.

Abstract

This study reports on the results of stable isotope analysis done on the enamel and bone collagen remains of eight *Capra pyrenaica* teeth, three *C. pyrenaica* bones and thirteen *Oryctolagus cuniculus* bones from the site of Cova Gran (Catalonia, Spain), dating back to the end of the Younger Dryas. The stable carbon isotopes ($\delta^{13}C$) in the tooth enamel were measured in order to better understand the diets of *C. pyrenaica*. This was also measured in the tooth enamel and bone collagen in order to get estimates on mean annual precipitation (MAP). The stable oxygen isotopes ($\delta^{18}O$) in tooth enamel were used to reconstruct the seasonality of births of C. pyrenaica and estimate mean annual temperatures (MAT). $\delta^{13}C$ and $\delta^{18}O$ were also used in tandem to observe the seasonal altitudinal mobility of *C. pyrenaica.* Lastly, the stable nitrogen isotopes ($\delta^{15}N$) were measured on *O. cuniculus* and *C. pyrenaica* bones as a means of comparing temperatures between two stratigraphic levels. All of this was done in order to get an idea of the paleoclimate of Cova Gran and its effects on human subsistence patterns at the site. This study is also one of the few to use stable isotope analysis on rabbits, and shows its potential use as a paleoclimatic proxy on the Iberian Peninsula.

The results showed the paleoclimate of the site was warm and arid, more so than the present day. These conditions suggest that the warming associated to the Pleistocene – Holocene transition was already occurring on a more local level. The *O. cuniculus* bones showed similar temperatures between both the stratigraphic levels studied at Cova Gran. In terms of seasonality of births for *C. pyrenaica*, the individuals were born between a 5.64 and 11.28 month period. This large birthing period was likely influenced by the warmer conditions and possibly the arid conditions led to two rutting seasons developing. *C. pyrenaica* likely consumed mainly C3 plants but with a possible influence of CAM plants for certain individuals. The seasonal altitudinal mobility was only recorded in the isotopic record for certain individuals. This is possibly linked to the climatic conditions and the plant diet of these animals. Eating perennial plants would mask this behaviour from the isotopic record.