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Paleoecology of Ancient Akrai/Acrae (SE Sicily): Evidence from Stable Isotope Analysis of Animal Remains

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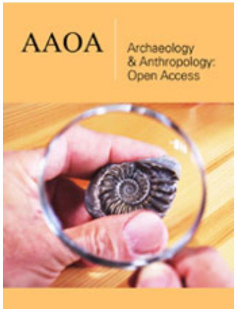

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Abstract

The ancient town of Akrai/Acrae (founded in 664/663 BC) is located in the SE Sicily in an area characterized by alluvial terraces and steep slopes cut by deep valleys. The area under the study was covered by Mediterranean wood lands, however, due to human activity, the forest began to gradually shrink around 2700 BC, putting pressure on the local fauna. Previous studies suggest that wild animals, especially red deer, inhabited open woodlands and grass-lands and their diet was rich in C4 plants. A wide range of δ15N values was attributed to seasonal differences in moisture availability. Twenty-eight faunal samples, dated between 3rd century BC and 8th century AD, collected within the Akrai/Acrae residential complex, were the subject of carbon and nitrogen stable isotope analysis. Seventeen samples met the standard quality criteria. The animal diet was based on C3 plants ($\delta^{13}C$ values of herbivores: -21.7 to -20.0‰; omnivores and carnivores: -20.0 to -19.1‰). The $\delta^{15}N$ values vary between 3.9 (fallow deer) and 7.9‰ (dog). The study confirms some earlier observations. Deer probably occupied the open woodlands relying on the C3 diet, however elevated $\delta^{15}N$ values were not detected in the study. The authors discuss whether the previously observed higher $\delta^{15}N$ values were due to the aridity or consumption of plants growing in the fertilized fields. High $\delta^{15}N$ values in combination with high $\delta^{13}C$ values could be an indicator of human induced changes deforestation and intensification of agricultural production.

Keywords: Carbon; Nitrogen; Collagen; Animal remains; Red deer; Paleoecology; Sicily

Introduction

The palaeoecological reconstruction in the Mediterranean is prone to simplification of otherwise complex matter (Stevens et al. 2006). Through the application of interdisciplinary studies to archaeology, various changes in human-environment relationships, habitat exploitation, and other phenomena have been better understood. Stable isotope analyses, which are frequently used in the examination of human bones for dietary and mobility reconstructions, are one of the elements of this kind of research [1,2]. However, stable isotope investigations of faunal remains are not as common, particularly for archaeological sites belonging to the ancient Greek and Roman periods. The latter turned out to be highly important for the reconstruction of the local ecosystem and biodiversity. For these types of investigations, bones of wild animals and species deemed inedible or unfit for human consumption (such as dogs and cats), can be used. The studied samples are derived from well-dated archaeological contexts, from which the analyzed samples are taken. Moreover, the data from archeozoological and archaeobotanical studies should be compared to these research. Research with both terrestrial and marine records have been done in Sicily, although it is mainly restricted to micro-regions and is far from comprehensive [3-5]. This paper aims to offer new biochemical data of carbon and nitrogen stable isotope analysis of animals from ancient Akrai/Acrae (SE Sicily) and examine and discuss them within the context of the paleoenvironmental reconstruction.

Stable Isotope Analysis

Carbon and nitrogen stable isotope analysis of bone collagen is a well-established method for reconstructing the past feeding ecology. The relationship between the synthesized collagen and the isotopic composition of the majority of the diet serves as the basement for this reconstruction. Accordingly, based on the stable isotope composition of collagen in the bones, one can estimate the stable isotope content in the food ingested [1]. Between terrestrial and marine environments, as well as between terrestrial plants utilizing Calvin (C_3) and Hatch-Slack (C_4) cycles for photosynthesis, there are differences in the carbon stable isotope ration ($\delta^{13}C$) [6,7]. Organisms in the marine habitats exhibit approximately 8‰ enrichment in heavier carbon isotopes [8]. Within the terrestrial ecosystems, C_3 plants, which compose most of the terrestrial flora, express low $\delta^{13}C$ values (mean of around -27‰), although C_4 plants (certain grasses, such millet) express high $\delta^{13}C$ values (mean of approximately -12‰) [7,9]. As a result, it is feasible to identify C_4 plant consumption in the environment where C_3 flora predominates.

The carbon stable isotope ratio can be further affected by CO_2 recycling in more closed environments, among others. In closed canopy conditions, the mixing between CO_2 respired by plants and atmospheric CO_2 is limited. Therefore, the bio-available CO_2 can be depleted in heavier carbon isotopes, as can be the plant re-using depleted CO_2, and reduced sunlight adding to the factors. Consequently, compared to plants in open environments, forest plants can ex-press extremely low $\delta^{13}C$ values [10]. The ration of nitrogen stable isotope ($\delta^{15}N$) in plants is determined by the composition of biologically accessible nitrogen present in the soil [6]. This is affected by temperature, moisture availability [11], and manuring [12]. Since plants want to use all of the nitrogen that is available, the stable nitrogen isotope composition of plant tissue reflects the conditions under which the plant was growing as well as the isotopic signature of the pool of bioavailable Nitrogen [6].

Consumed food is the source of carbon and nitrogen for animals. A meta-analysis of several published control feeding experiments showed that average enrichment between collagen of the consumer and the diet is approximately 3.7±1.6‰ for $\delta^{13}C$ values and 3.6±1.3‰ for $\delta^{15}N$ [13]. In effect, animals in successive trophic levels will be enriched in heavier isotopes of both carbon and nitrogen by the enrichment factor. According to Michener & Kaufman [8], organism in aquatic ecosystems with more complex trophic relations can show high values of $\delta^{13}C$ and $\delta^{15}N$, atypical for terrestrial environments.

Paleoenvironment of Akrai/Acrae

The territory of ancient Akrai/Acrae was in majority covered by Mediterranean woodlands. Gradually, a forest habitat emerged in the interior pf the island and mountains regions, reaching its peak around 10.000 BC. The broad-leaved, evergreen trees persisted until 2700 BC, when human habitation caused the forest to gradually begin to di-minish [14]. Archaeological research suggests that forested sections in the mountainous areas of the island's interior appeared to have been covered by the forest for an extended period of time. The surrounding area of Akrai/Acrae was rich in wild animals and had dense, lush vegetation, according to archaeobotanical and archeozoological investigations [4,15] (Figure 1).

Figure 1: Map of Sicily with location of studied area.

The previous study on carbon and nitrogen stable isotopes of animal bone collagen [4] allowed for few observations. Deer displayed $\delta^{13}C$ values that suggested they were occupying open habitat, such as open woodlands, and that C_4 grasses had a significant presence. A solitary leproid was also observed for in this area. A wide range of $\delta^{15}N$ values (2.5-7.2‰) observed for herbivorous was explained as the outcome of variations in plant moisture availability or a physiological reaction to water stress. Collagen of a single dog was enriched in heavier carbon isotopes (-17.0‰) with moderate $\delta^{15}N$ values (8.0‰), indicating diet composed of terrestrial resources, with significant share of C_4 plants and/or proteins of animals feed with C_4 plants and/or marine resources [4].

Materials and Methods

The town Akrai/Acrae is situated in the Hyblaean Mountains, northwest of the modern town of Palazzolo Acreide. It is perched atop the Acremonte hill and is a part of an area made up of large plateaus with a landscape that is characterized by alluvial terraces, steep slopes traversed by deep valleys, and lower-lying areas that surround them [16]. Founded in 664/663BC, this Greek colony was for a long time associated with Syracuse, its metropolis, a wealthy town, and a sizeable port, from which Akrai/Acrae was around 35km away [17,18]. Since the Roman conquest in 212 BC, there have been gradual changes in this area. The town most likely continued to operate until the 8th century AD, with short gap in second half of the 4th century AD [18]. The presented data were collected within the excavated residential area. Materials dated between 3rd century BC and 8th century AD were discovered during the excavations between 2011 and 2020, painting a clear picture of the settlers' way of life. Constructed in the Late Hellenistic period, the residential complex saw use during the Republic and Imperial periods before being destroyed by natural disaster in the 50s-70s of 4th century AD, intentionally levelled at the end of 4th century AD, and repurposed for a variety of activities until 8th century AD [18] (Figure 2).

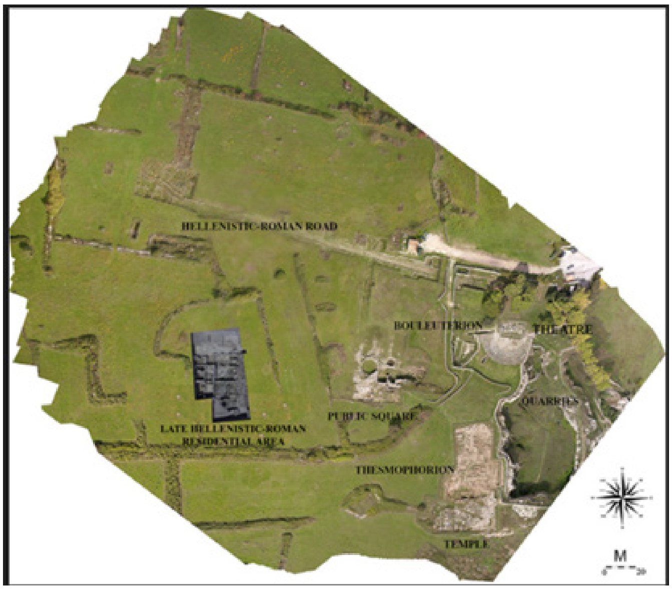

Figure 2: Photogrammetry of the archaeological site of Akrai with excavated area.

Three main stratigraphic blocks comprise the material under the current analysis. In the research provided, only samples obtained from the original occupation contexts which include layers dated from the 3rd century BC to the 50s-70s of 4th century AD and the reoccupied strata dated to the end of 4th-8th century AD, were employed here. Because of their extensive chronology and heavy mixing, the artefacts from the levelling layers are not suitable for providing accurate information about the paleoecology of Akrai/Acrae [18]. Majority of samples came from the levels dated back to the houses' foundation at the end of the 3rd century BC and continued through the end of 1st century BC and the beginning of the 1st century AD. There are just three samples from the layer dated to the end of 4th and mid-7th century AD, when the residential area was adopted for the secondary activities (i.a. metallurgical and craft). Collagen was extracted using method proposed by Brown et al. [19].

The samples were measured at the Department of Forest Ecology and Management at the Swedish University of Agricultural Sciences, Umea, Sweden using IRMS system Delta V connected to elemental analyzer Flash EA 2000 (Thermosphere Scientific, Bergen, Germany), against international standards (IAEA-600, IAEA-CH-6, IAEA-N-2, USGS40, and USGS41). Samples with high carbon (>30%), nitrogen (>10%), and the atomic C/N ratio between 2.9 and 3.6 were chosen for additional examination [19,20]. Only a few studies for Western Mediterranean provide reference data. The first archaeological site is Carrer Ampel, a necropolis situated within Barcelona (ancient Colonia Iulia Augusta Paterna Faventina Barcino) founded in 14 BC. The Mediterranean Sea coast, the Colterol Mountain range, and two rivers limited the town. There was cultivation of the land surrounding the town [21]. The second site is Velia (ancient Elea), a Greek colony located on the west coast of southern Italy, which was under Roman control since the late 3rd century BC. The area around the town was made up of hills covered by forest and river valleys used for agriculture. The town's inhabitants made substantial use of marine resources [22]. Last but not least, the necropolis at Isola Sacra, which was situated between Ostia and the port of Rome, was used between the 1st and 3rd century AD [23].

Result

Of the 28 samples, 17 satisfied the quality criteria. The results were obtained for six taxa (Table 1). The number of observations per taxon is low, allowing only for robust comparisons and observations for red deer and dog. Animals express $\delta^{13}C$ values typical of C_3 environment: herbivorous - $\delta^{13}C$ values between -21.7 and -20.0‰, while omnivorous and carnivorous, between -20.0 and -19.1‰. Herbivores (leporids and deer) express $\delta^{15}N$ values be-tween 3.9 and 5.3‰, omnivorous (dog and hedgehog) between 5.2 and 7.9‰, carnivorous cats between 7.2 and 7.3‰ (Table 2 & Figure 3). Deer of Akrai/Acrae express $\delta^{13}C$ values that are in the range between those from Velia and Carrer Ample, and δ15N values that are higher than those of the majority of deer from these two archaeological sites. The variation most likely results from varied ecological settings of the sites. Stable isotope values of dogs and cats overlap. Indicating that diet of dogs was abundant in animal proteins. In contrast to the dogs of Velia and Isola Sacra, dogs of Akrai/Acrae did not ingest significant amount of marine resources (Figure 3).

Table 1: Results of the carbon and nitrogen stable isotope analysis of animal remains from Akrai/Acrae.

Sample	Taxon	Common Name	Element	Chronology	%C	%N	C/N	$\delta^{13}C$	$\delta^{15}N$
1.1 a	*Felis silvestris f. catus*	Cat	Cranium	End of 4th-mid 7th century AD	47.7	16.1	3.4	-19.1	7.2
1.1 b	*Felis silvestris f. catus*	Cat	Cranium	End of 4th-mid 7th century AD	47.5	15.9	3.5	-19.3	7.3
1.2	*Canis lupus f. familiaris*	Dog	Cranium	End of 4th-mid 7th century AD	47.0	15.9	3.5	-19.2	7.2
1.3	Dama dama	Fallow deer	Radius	End of 4th-mid 7th century AD	47.0	15.5	3.5	-20.0	3.9
3.1	*Canis lupus f. familiaris*	Dog	Calcaneus	Mid 3rd century BC - 1st century AD	47.1	15.7	3.5	-19.6	6.7
4.1	*Leporidae*	Leproid	Mandible	3rd century BC	46.6	15.4	3.5	-21.7	4.0

5.1	*Cervus elaphus*	Red deer	Radius	3rd century BC	46.3	15.4	3.5	-21.5	5.5
5.2	*Erinaceus europaeus*	Hedgehog	Mandible	3rd century BC	45.5	15.0	3.5	-20.0	5.2
6.1	*Leporidae*	Leproid	Molar	2nd-1st century BC - Octavian August reign	46.1	15.3	3.5	-21.5	4.3
6.2	*Cervus elaphus*	Red deer	Humerus	2nd-1st century BC - Octavian August reign	43.7	14.5	3.5	-21.6	5.3
6.3	*Cervus elaphus*	Red deer	Mandible	2nd-1st century BC - Octavian August reign	47.2	15.4	3.6	-20.4	5.0
9.1	*Cervus elaphus*	Red deer	Radius	End of 3rd century BC-beginning of 1st century AD)	47.1	15.8	3.5	-21.1	4.3
9.2	*Cervus elaphus*	Red deer	Phalanx 1	End of 3rd century BC-beginning of 1st century AD)	46.7	15.6	3.5	-21.3	4.8
11.1	*Canis lupus f. familiaris*	Dog	Ulna	End of 3rd-end of 1st century BC	47.5	16.0	3.5	-19.2	7.9
12.1	*Canis lupus f. familiaris*	Dog	Humerus, proximal epiphysis	End of 3rd-end of 1st century BC	46.9	15.6	3.5	-19.4	7.4
12.2	*Canis lupus f. familiaris*	Dog	Humerus, distal epiphysis	End of 3rd-end of 1st century BC	47.3	15.7	3.5	-19.4	7.3
12.3	*Cervus elaphus*	Red deer	Os metatarsale	End of 3rd-end of 1st century BC	48.1	16.0	3.5	-21.7	4.6

Table 2: Summary statistic for carbon and nitrogen stable isotope analysis in animal remains form Akrai/Acrae.

Taxon	Common Name	N	δ13C			δ15N		
			Min	Median	Max	Min	Median	Max
Cervus elaphus	Red deer	6	-21.7	-21.4	-20.4	4.3	4.9	5.5
Canis lupus f. familiaris	Dog	5	-19.6	-19.4	-19.2	6.7	7.3	7.9
Felis silvestris f. catus	Cat	2	-19.3		-19.1	7.2		7.3
Leporidae	Leproid	2	-21.7		-21.5	4		4.3
Dama dama	Fallow deer	1		-20			3.9	
Erinaceus europaeus	Hedgehog	1		-20			5.2	

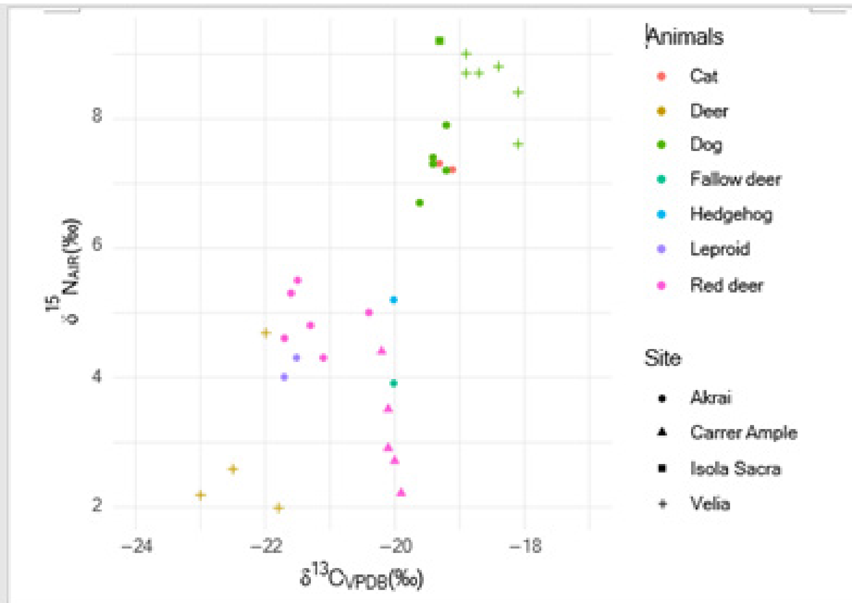

Figure 3: Distribution of δ13C and δ15N values of animals from Akrai/Acrae (present study), Carrer Ample [21], Isola Sacra [23], Velia [22].

Discussion

The present study confirms some previous observations [4]. Deer occupied the open wood-lands relying on the C_3 diet, however, the study failed to provide evidence of deer consuming the C_4 plants. Addition-ally, compared to the previous research [4], the spectrum of $\delta^{15}N$ values is narrower, indicating a smaller range of occupied settings. Compared to deer of Velia [22], specimens of Akrai/Acrae are enriched in both carbon and nitrogen heavier isotopes, probably due to more open habitat. Deer of Carrer Ample are enriched in the heavier carbon iso-topes, relative to specimen from Akrai/Acrae, but most of them are depleted in the heavier nitrogen isotopes. Nonetheless, deer of Carrer Ample exhibit great spectrum of values, similar to deer of Akrai/Acrae observed by Chowaniec et al. [4]. The enrichment in the heavier nitrogen isotopes was attributed to the moisture availability, which is unlikely. According to Pate & Anson [24], the $\delta^{15}N$ values significantly increase when the annual precipitation falls below 250mm, whereas Sicily receives more than 600mm.

Manuring is another important factor to take into account. The studied regions experienced intensive transformations aimed at boosting agricultural productivity. This could include manuring, which increases the $\delta^{15}N$ values of plants growing in fields and their vicinity [12]. Therefore, plants that are richer in the heavier nitrogen isotopes may be consumed by animals grazing fields in the vicinity. In this case, high values of both $\delta^{13}C$ and $\delta^{15}N$ may be an indicator of human-induced changes, such as deforestation and increased agricultural intensity. As opportunistic omnivores, dogs will depend on the food that is readily available, and usually supplied by people. Dogs can therefore serve as an excellent model, which is close to the human diet [25]. The fact that dogs express similar values as other carnivores, such as cats, suggests that their diet were abundance of animal proteins. Compared to other sites, dogs of Akrai/Acrae are depleted heavier isotopes of both carbon and nitrogen, probably as an effect of limited access to marine resources. Dogs do not appear to consume any C_4 plants in their diet. Assuming that diet of dogs and humans was similar, inhabitants of Akrai/Acrae most likely did not eat a significant number of marine proteins.

Archaeological and archaeobotanical investigations should be added to the results described in connection with the discussion of deforestation and the intensification of agricultural production in the Akrai/Acrae region. According to archaeobotanical evidence, a wide range of plants were cultivated in this area between 3rd century BC and 8th century AD. The analysis shows the presence of deciduous wood species (such as Quercus type super as well as Ulmus and Fraxinus) and evergreen oak species. From the 3rd century BC until Late Antiquity, Olea europaea become-come less widespread. The cultivation of leguminous plants is also documented, while olive and grape agriculture only predominated between the 3rd century BC and the Roman Imperial period (1st-3rd century AD). The cultivation of olives, grapevines and grains in the Hellenistic period also seems to have been characteristic of the Roman Imperial period, during which the cultivation of fruit trees and other crops underwent additional advancements. There is also a noticeable increase in weed plants, such as Gallium, Malva, etc. throughout the Roman Imperial period, which could indicate the weeding and abandonment of the fields. The cultivation of cereals (Triticum aestivum/durum, Triticum docucam, Triticum monococcum, Hordeum vulgare), fruit trees (Maloideae and Prunoideae), and flax (Linum usitatissimum) increased in Late Antiquity. Furthermore, archeozoological research and stable isotope analysis contributed to understand that the Akrai/Acrae inhabitants were mostly dependent on terrestrial resources, with a minor amount coming from marine sources. In the data sets dated to the Late Hellenistic Early Imperial periods, the most prevalent of the four livestock species were pigs (47.0%), followed by sheep and goat (30.0%), and cattle (23.0%).

The proportion of animals in aforementioned varied in the archaeological strata dated to the Roman Imperial period. Estimates for the percentage of pig bones and teeth was 35.0%, for cattle - 34.0%, and for sheep and goats was nearly unchanged -32.0%. In the culture deposits dated between the end of 4th and the 8th century AD, the percentage for pigs decreased from 35% to 24%. At the same time, the percentage of cattle and sheep/goat has increased for cattle was 38.0%, for sheep and goats was 37.0%. In the Late Hellenistic – Early Imperial strata the highest number of wild animals, estimated at 10.0%, was recorded. At the more recent period, in the 4th century AD, the proportion of wild animals was lower, and it only amounted to 0.5%. The majority of wild animals were represented by red deer, fallow deer, wild boar and leporids. Among 450 bones identified as bird bones, approximately 81% were represented by domestic chicken. Wild or potentially domesticated animals, such as rock partridge, pigeon/dove, song thrushes, geese, quails, etc., were used to represent other species. Besides that also 200 fish bones were found, which was only 0.4% of all archeozoological set. A tiny number of the remains are bivalve, particularly oysters; 54 belong to turtles, and 202 to the land snail (predominantly Helix genus) [15].

Conclusion

Throughout the Greek and Roman periods, intense pastoralism and extensive farming caused a noticeable shift in the ecosystem. For instance, an increase in the proportion of ruminants bones found in strata dated to the Roman Imperial and Late Roman-Byzantine periods may indicate the spread of intensive pastoralism. In turn, the intensive breeding of sheep and cattle requires large grazing areas. Additionally, botanical research indicates that around the 3rd century BC, deforestation and degradation began to accelerate and worsen. This suggests that the natural environment was deteriorating due to deforestation in favor of ever-expanding cultivation of grains, grapevines, olive and fruit trees. These human-induced changes shaped the environment in a variety of ways, forcing animals to adapt to new conditions and surroundings. Those adaptations can be observed in their diet, which can become a good indicator of anthropogenic pressure. When compared to other Mediterranean regions, isotopic evidence from Akrai/Acrae revealed differences in the stable isotope values of deer occupying dense forests and open regions altered by agricultural activities. Dogs, on the other hand, can shed some light on the human diet, especially the food items that could be spared or leftovers.

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References

1. Thorp LJA (2008) On isotopes and old bones. Archaeometry 50(6): 925-950.
2. Fernandes R, Chowaniec R (2018) Interdisciplinary approaches to the study of ancient Roman foodways. Journal of Archaeological Science: Reports 19: 979-981.
3. Tanasi D, Tykot RH, Vianello A, Hassam S (2017) Stable isotope analysis of the dietary habits of a Greek community in archaic Syracuse (Sicily): A pilot study. STAR: Science & Technology of Archaeological Research 3(2)*:* 466-477.
4. Chowaniec R, Dotsika E, Gręzak A (2018) Late Hellenistic to later Roman/Byzantine periods faunal and flora assemblage in the ancient Akrai (Southeastern Sicily). Environment and Food Circulation Reconstruction. In: Chowaniec R (Ed.), Unveiling the past of an Ancient town. Akrai/Acrea in South-Eastern Sicily, Institute of Archeology University of Warsaw, Poland, pp.145-171.
5. Reitsema LJ, Kyle B, Vassallo S (2020) Food traditions and colonial interactions in the ancient Mediterranean: Stable isotope evidence from the Greek Sicilian colony Himera. Journal of Anthropological Archaeology 57: 101144.
6. Marshall JD, Brooks JR, Lajtha K (2007) Sources of variation in the stable isotopic composition of plants. In: Michener RH, K Lajtha (Eds.), Stable Isotopes in Ecology and Environmental Science, John Wiley & Sons, USA, pp: 22-60.
7. Leary OMH (1988) Carbon isotopes in photosynthesis: Fractionation techniques may reveal new aspects of carbon dynamics in plants. BioScience 38(5): 328-336.
8. Michener RH, Kaufman L (2007) Stable isotope ratios as tracers in marine food webs: An update. In: Michener RH, K Lajtha (Eds.), Stable Isotopes in Ecology and Environmental Science, John Wiley & Sons, USA, pp: 238-282.
9. Pyankov VI, Ziegler H, Akhani H, Deigele C, Lüttge U (2010) European plants with C_4 photosynthesis: Geographical and taxonomic distribution and relations to climate parameters. Botanical Journal of the Linnean Society 163(3): 283-304.
10. Bonafini M, Pellegrini M, Ditchfield P, Pollard AM (2013) Investigation of the 'canopy effect' in the isotope ecology of temperate woodlands. Journal of Archaeological Science 40(11): 3926-3935.
11. Amundson R, Austin AT, Schuur EAG, Yoo K, Matzek V, et al. (2003) Global patterns of the isotopic composition of soil and plant nitrogen. Global Biogeochemical Cycles 17(1).
12. Bogaard A, Heaton THE, Poulton P, Merbach I (2007) The impact of manuring on nitrogen isotope ratios in cereals: Archaeological implications for reconstruction of diet and crop management practices. Journal of Archaeological Science 34(3): 335-343.
13. Szpak P, Orchard TJ, McKechnie I, Gröcke DR (2012) Historical ecology of late Holocene sea otters (*Enhydra Lutris*) from northern British Columbia: Isotopic and zooarchaeological perspectives. Journal of Archaeological Science 39(5): 1553-1571.
14. Incarbona A, Zarcone G, Agate M, Bonomo S, Stefano E, et al. (2010) A multidisciplinary approach to reveal the Sicily climate and environment over the last 20 000 years. Open Geosciences 2(2): 71-82.
15. Chowaniec R, Fetner R, Fiorentino G, Gręzak A, Stella M (2021) Akrai, south–eastern Sicily. Multidisciplinary study on ancient human impact on the natural landscape. In: Prescott Ch, Karivieri A, Campbell P, Goransson K, Tusa S (Eds.), Trinacria, 'an island outside time'. International archaeology in Sicily, Oxbow Books, Oxford, Philadelphia, pp. 33-44.
16. Lentini F, Carbone S (2014) Geology of Sicily. Descriptive memoirs of the geological map of Italy 95: 31-98.
17. Chowaniec R (2015) Comments on the history and topography of Akrai/ Acrae in the light of new research. In: Chowaniec R (Ed.), unveiling the past of an ancient town. Akrai/Acrea in South-Eastern Sicily, Institute of Archeology University of Warsaw, Poland, pp. 43-78.
18. Chowaniec R (2017) The coming of Rome. Cultural landscape of South-Eastern Sicily, Institute of Archeology University of Warsaw, Poland.
19. Brown TA, Nelson DE, Vogel JS, Southon JR (1988) Improved collagen extraction by modified longin method. Radiocarbon 30(2): 171-177.
20. DeNiro MJ (1985) Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317: 806-809.
21. Rissech C, Pujol A, Christie N, Lloveras L, Richards MP, et al. (2016) Isotopic reconstruction of human diet at the roman site (1st-4th c. AD) of Carrer ample 1, Barcelona, Spain. Journal of Archaeological Science: Reports 9: 366-374.
22. Craig OE, Biazzo M, Connell OTC, Garnsey P, Labarga MC, et al. (2009) Stable isotopic evidence for diet at the imperial Roman coastal site of Velia (1st and 2nd Centuries AD) in Southern Italy. Am J Phys Anthropol 139(4): 572-583.
23. Prowse T, Schwarcz HP, Saunders S, Macchiarelli R, Bondioli L (2004) Isotopic paleodiet studies of skeletons from the imperial roman-age cemetery of Isola Sacra, Rome, Italy. Journal of Archaeological Science 31(3): 259-272.
24. Pate FD, Anson TJ (2008) Stable nitrogen isotope values in arid-land kangaroos correlated with mean annual rainfall: Potential as a palaeoclimatic indicator. International Journal of Osteoarchaeology 18(3): 317-326.
25. Guiry EJ (2012) Dogs as analogs in stable isotope-based human paleodietary reconstructions: A review and considerations for future use. Journal of Archaeological Method and Theory 19(3): 351-376.

