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RESEARCH ARTICLE

Living on the shores of the Alboran Sea. The Neolithic on the coast of Málaga (Spain) a multiproxy approach

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Abstract
Context The coast of Málaga is one of the core areas for the Neolithic in southern Iberia with the earliest occupations dating to the middle of the 8th millennium cal BP. From the outset, evidence shows a fully developed and highly diversified system of agriculture and animal husbandry. The palaeoenvironmental conditions during this period in the southern Iberian Peninsula reveal phases of aridity.

Objectives This study aims to understand how Neolithic communities adapted to these adverse environmental conditions. It also explores the role of wild resources and seasonal patterns in subsistence strategies.

Methods A multiproxy approach was applied, combining regional palaeoenvironmental data with archaeological, archaeofaunal, archaeobotanical and anthropological evidence. The analysis focuses on sites located near aquifer discharges.

Results Fully developed and highly diversified agriculture and herding practices are documented from the earliest Neolithic phases. The challenges posed by arid conditions appear to have been mitigated by settlement in areas linked to major aquifer outlets and by the cultivation of drought-resistant cereals. Multiple

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lines of evidence suggest a seasonal pattern of occupation, primarily from late autumn to early summer, when marine resources were likely exploited. Neolithic groups may have engaged in regular hunting and gathering activities or maintained interactions with local Epipalaeolithic–Mesolithic populations. Agricultural and pastoral management emerge as key factors for evaluating the contribution of wild resources to their subsistence.

Conclusions The integration of environmental, archaeological and biological records provides a more holistic perspective and better understanding of Neolithic economy and society along the Málaga coast between c. 7.6th—5th millennium cal BP, offering insights into subsistence strategies under arid conditions in a coastal setting.

Keywords Neolithic · Agriculture · Livestock · Palaeoenvironment · Marine resources · Seasonality

Introduction

The Neolithic expansion across Europe is one of the most fascinating research topics in human Prehistory. Within this context, the Neolithisation of the southern Iberian Peninsula is of particular interest due to its strategic location at the crossroads of Atlantic, African and Mediterranean Neolithic traditions (i.e., Manen et al. 2007, Faustino Carvalho 2008, Mercuri et al. , Cortés-Sánchez et al.,2012 Linstädler et al. 2012, Martín et al. 2018, Simões et al. 2023).

The Málaga coast, stretching over 161 km, is bordered inland by mountains over 1000masl (with highest peak surpassing 2000masl), forming a geographically sheltered strip. More than forty documented sites (Fig. 1) provide crucial information about the Neolithic period in the south of the Iberian Peninsula (see Cortés-Sánchez et al. 2012).

Available evidence suggests that the arrival and settlement of Neolithic communities in the region took place in parallel with neighbouring areas, beginning around 7.6 cal ka BP, despite certain idiosyncratic elements. These are expressed by singular features which collectively define the phenomenon known as the *Cultura de las Cuevas* (the Cave Culture, i.e. see Cortés-Sánchez et al. 2012; Aura-Tortosa et al. 2013; García Borja et al. 2014; Martín-Socas et al. 2018, Faustino Carvalho 2018). The Málaga coast incorporates natural along several river valleys that connect it with the hinterland. Its proximity to Africa suggests potential intercontinental connections and raises questions about specific strategies for the implementation of the Neolithic economy in the region, including the possible development of navigation (see reviews in Cortés-Sánchez et al. 2012, Fregel et al. 2017, Linstädter et al. 2012, Simões et al. 2023, among others). Europe and Africa are separated by the Alboran Sea, characterized by environmental conditions shaped by its latitudinal position and its role as a transition zone between the Atlantic Ocean and the Mediterranean Sea through the Strait of Gibraltar.

Archaeological evidence suggests that, from its earliest stages and throughout the Neolithic, the region displayed highly diversified agricultural and livestock practices. Neolithic assemblages also include evidence of hunting and gathering, which may indicate either supplementary subsistence strategies within an agricultural economy or connections with local Epipalaeolithic-Mesolithic populations (see discussion in Cortés-Sánchez et al. 2012). Previous research on the Neolithic of Málaga coast has addressed chronological, environmental, and

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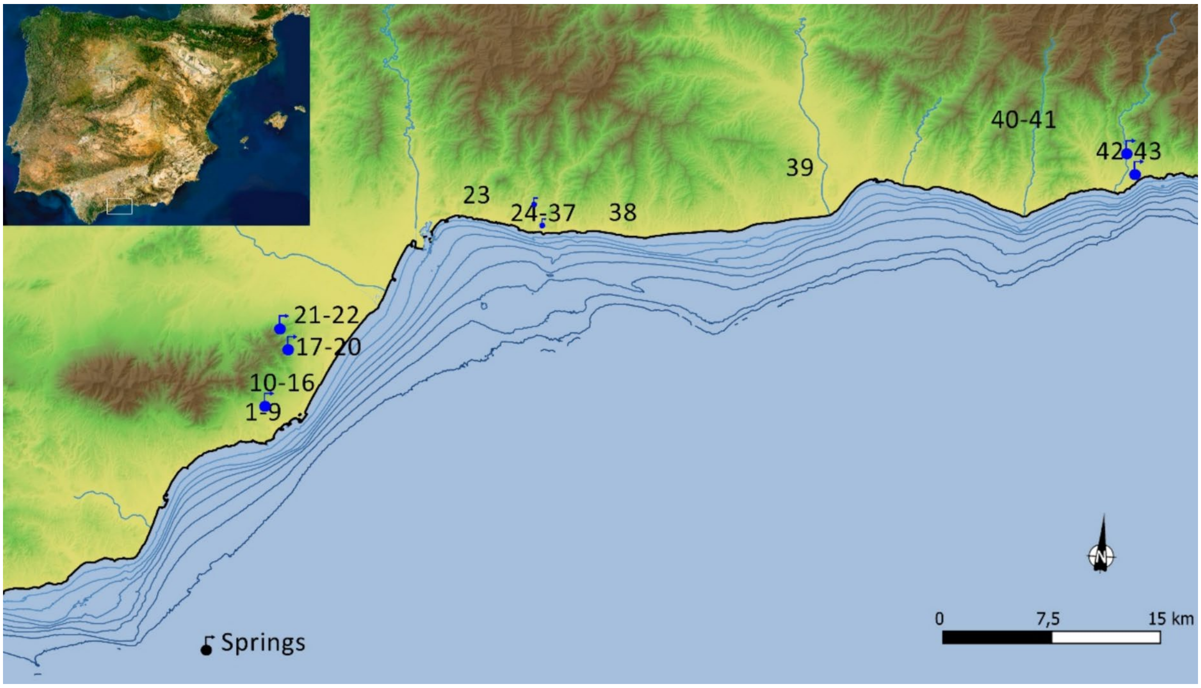


Fig. 1 Neolithic sites on the coast of Malaga: 1. Sahara, 2. Botijos, 3. Zorrera, 4. I/Sector I, 5. Alquibla 1, 6. Los Cangrejos, 7. Malas Pulgas, 8. La Mesa, 9. Caramelo, 10. Pellejera, 11. Tapada, 12. Roca Chica, 13. Hostal Guadalupe, 14. Bajondillo, 15. Bajondillo 2, 16. Tejones, 17. Tesoro, 18. Olivarillo, 19. Cortijuelo, 20. Lagarillo del Olmo, 21. María Vela, 22. Muñeco, 23. Cadenas, 24. Cabello, 25. Ángeles, 26. Piedras, 27. San Telmo, 28. Hoyo de la Mina, 29. Cuervo I, 30–32. Cantera I-III, 33. Abrigo 6, 34. Cuerda, 35. Dolmen Corona, 36. Victoria, 37. Higuerón, 38. Tapada-Torre de Benagalbón, 39. Cerca Niebla; 40. Frigiliana I; 41. Oscura; 42. Nerja; 43. Pintada. In bold letters, sites analyzed in this work

economic aspects (i.e. Pellicer Catalán and Morales-Muñiz 1995, Pellicer Catalán and Acosta Martínez 1997; Cortés-Sánchez et al. 2012; Aura-Tortosa et al. 2013, 2014). However, new data from key sites, unpublished materials (i.e. Nerja and Hoyo de la Mina), and a re-evaluation of existing studies have enabled us to adopt a novel multidisciplinary approach. This research focuses on crucial aspects of Neolithic societies, particularly economy strategies, with especial attention to resource exploitation and seasonal subsistence patterns.

The records used in this study derives from multiples excavations. Although dataset is uneven, it offers valuable qualitative insights, including information related to seasonality, which enables us to propose a comprehensive model of the Neolithic along the Málaga coast—a framework that will undoubtedly be refined as new contributions in the coming years.

In this paper, we examine a specific sector of the Alboran Sea—the Málaga coast—from a paleoecological perspective, focusing on the adaptive cultural systems developed by Neolithic communities. To this end, we have compiled and analysed all available evidence, including a substantial amount of unpublished material, and explored four main research themes:

(a) The Neolithic record of the region is approached from an integrated perspective that considers palaeoenvironmental conditions and their influence on human communities, as well as the chronological framework, settlement dynamics, and seasonal patterns of coastal occupations. Likewise, we will pay special attention to how these sites articulated subsistence strategies, especially in relation to the development of early agricultural practices and livestock management.
(b) Assessing the contribution of hunting, forestry, livestock, agriculture, and marine resources to subsistence strategies and cultural innovations.
(c) Investigating social structure and mobility patterns to determine the degree of population seg-

regation or integration, with a focus on funerary practices and demographic distribution of burials.
(d) Analysing the territorial distribution, functionality, and seasonality of Neolithic sites.

Material and methods

Archaeological sites

A total of 43 Neolithic sites have been identified along the Málaga coast. Of these, 40 are located between 100 and 250 m from the present-day coastline, whereas Nerja, Corona, and Frigiliana are situated 1.5–5 km inland (Fig. 1), (Tables 1, 2). Among

Table 1 Nerja Neolithic sequence and other sites discussed in the text

cal ka BP	Site/level Neolithic sequence	Nerja								**Hoyo Mina***	Other sites /level
		NV/59	NV/63–4* NV/82–87	NM	NT/82	NM/80A	NM/80B	NM/65–66*	NB/NC		
> 5.2/5 to < 5.7	Late N	IA-B	–	2	6	–	1–2	I-II	–	–	–
< 6.8 to 5.7	Middle N	IC	–	3 4 5	7 8	1	4–6	III	X	HM2 HM3	Tesoro Tapada H.Mina/2–3*
< 7.6 to 6.8	Early N	II III	1**-2–3	6–11	9 10	2–4	7–9 10A-B	IV	–	HM4	Bajondillo/2* Roca Chica* H. Guadalupe*
< 10.15	Mesolithic	–	3c?	12?	11	5	–	–	–	HM/5	–

Based on Simón-Vallejo 2003, Cortés-Sánchez 2012, Borja et al. 2014, Pellicer Catalán and Acosta Martínez 1997, Sanchidrián and Márquez 2005. Nerja: sector V (Vestíbulo), M (Mina), NB (Belén), NC (Cascada). NM-80A and NM-80B. N. (Neolithic). *(This paper), **(= V/59/III), X (Presence)

Table 2 Main characteristics of the sites analysed

Site	Use	Walling/ Closed	Burial (NMI)	Ceramics		Lithic industries	Seeds	Molluscs		Ref
				Full	Frag			Ornament	Consume	
1) Tesoro	Funerary	Yes	≥8	–	–	X	–	X	–	1
2) Tejones	Funerary	Yes	> 1	–	–	–	Yes	–	–	
3) Tapada	Funerary	Yes	?	–	–	X		X	–	
4) Bajondillo	Habitat (Funerary)	–	–	–	X	X	Yes	X	X	
5) Hostal Guadalupe	Funerary	¿?	1	X	–	X	Yes	X	–	
6) Roca Chica		¿?			–	X	Yes	–	X	
7) San Telmo	Funerary	Yes	Yes	X	–	X		–		
8) Hoyo de la Mina	Habitat (Funerary)	Yes	> 20	X	X	X	In study	X	X	
9) Abrigo 6	Funerary	–	≥3	X	–	X	–	–	–	
10) Victoria	Funerary	–	Yes	X	–	X	–	–	–	
11) Higuerón	Funerary	–	Yes	X	–	X	–	–	–	
12) Nerja	Habitat (Funerary)	–	≥65	X	–	X	Yes	X	X	2
13) Frigiliana I	Funerary	–	≥6	X	X	X	–	–	–	3

(Funerary): burials in diverticula or recondite chambers. X (Presence). Key information on the archaeological sites under investigation: (1. Simón-Vallejo et al. 2023, 2. Simón-Vallejo 2003, 3. Cortés-Sánchez et al. 2010 with references) these, only Nerja, Hoyo de la Mina and Bajondillo have yielded robust archaeological records and constitute the basis of our study:

a) Nerja is the most thoroughly excavated site and contains the richest archaeological deposits. Excavations at Nerja, conducted between 1959 and 1987 by various research teams using different analytical protocols, have resulted in heterogeneous datasets (Pellicer Catalán and Acosta Martínez 1997; Aura-Tortosa et al. 2005; Cortés-Sánchez et al. 2007, 2012; García Borja et al. 2014; Salazar-García et al. 2017).

b) Hoyo de la Mina was excavated at the beginning of the 21st century. Although only partial aspects of its technocultural sequence have been published, the site provides valuable insights into the early Holocene sequence of the Bay of Málaga. Its stratigraphic sequence includes Epipalaeolithic, Mesolithic and Neolithic levels, among others (Baldomero et al. 2005; Ferrer et al. 2006).

c) Bajondillo was excavated between 2000 and 2002. Its stratigraphic sequence (Fig. 2.2) has provided valuable palaeoecological data concerning the early Holocene and the transition from the Epipalaeolithic to the Neolithic in the Bay of Málaga (Cortés-Sánchez et al. 2007, 2012, 2020).

This paper is a synthesis of: a) unpublished data from Nerja, Room of Vestíbulo (NV) and Mina (NM) (NV63-64, NM65-66), and Hoyo de la Mina (HM1-HM3); b) published data generated by members of our research team from Nerja: Vestíbulo (NV), Mina (NM) and Torca (NT) (NV59, NV63-64, NT82, NM80A-B), Bajondillo, Roca Chica, Hostal Guadalupe, Tesoro, Tapada and Abrigo 6; c) information produced by others groups (NV82-87, NM83-86, Tapada and Sahara).

The analysed collections analysed are curated at the Museum of Málaga (Nerja, Hoyo de la Mina/Sect. 6, Bajondillo, Hostal Guadalupe and Tapada) and the Museo Nacional de Altamira (Tesoro).

Archaeozoology

The identification of vertebrate remains (Tables 3, 4, 5 and 6) was conducted using the reference collections from the Laboratory of Archaeozoology at the Autonomous University of Madrid and the Laboratory of Prehistory and the Faculty of Veterinary Medicine at the University of Córdoba. The number of identified specimens (NISP) and the total number of remains (NR), as defined by Reitz and Wing (2008), were used as quantifiers for faunal taxa. The minimum number of individuals (MNI) was determined following the criteria established by Grayson (1984) and Reitz and Wing (2008).

Given the difficulty of differentiating wild boar from domestic pig remains, a broader suid category (i.e., *Sus* sp.) was established. This category is not automatically assumed to represent either wild or domestic forms and is only considered once the frequencies of hunted and domesticated mammals have been determined based on remains that can be unambiguously assigned to one or the other. Moreover, it should be noted that pig/boar bone remains tend to belong to mostly young animals and osteometric data are often scarce because the bones are highly fragmented as a result of their practices.

The taphonomic criteria follow Lyman (1994), Fernández Jalvo and Andrews (2016) and Yravedra Sainz de los Terreros (2013), which, although focusing on macromammals provide clues to distinguish anthropogenic from biological alterations.

Avian skeletal remains have only been recovered from the site of Nerja. These remains have been the subject of several studies (Boessneck and Driesch 1980; Eastham 1986; Hernández-Carrasquilla 1995; Cortés-Sánchez et al. 2008). In no case have images or bibliographic descriptions been used for the final attribution of remains to the corresponding taxa. Previously identified birds have not been used as reference material to avoid repeated taxonomic identification errors. The final list and new additions are presented in (Table 7).

On the Málaga coast, fish remains represent the scarcest component of the archaeological record and are primarily confined to pre-Neolithic levels at the cave of Nerja (Boessneck and Driesch 1980, Morales-Muñiz et al. 1994, 1995, 1998, Roselló-Izquierdo et al. 1995, 1999, Aura-Tortosa 2002, Jordá Pardo et al. 2003, Morales-Muñiz and Roselló-Izquierdo 2008). To date, the only published Neolithic fish assemblages correspond to materials recovered from the so-called Room of Torca (NT, hereafter) and Room Mina (NM, hereafter) of Nerja. Together, these assemblages comprise a mere 85 identified specimens (NISP hereafter), representing 11 taxa: eight identified to species level, two to genus level, and one to family level (Table 8) (Boessneck and Driesch 1980; Morales-Muñiz et al. 1994; Roselló-Izquierdo et al.

Table 3 Mammals. Number of bone remains determined from the different species for Nerja Cave:

Taxa	EN	MN	EN	EN	EN	EN	EN	EN	EN	EN	EN	EN	EN	MN	LN	EN	EN	EN	EN	EN	EN	∑	∑	∑
Nerja	T79		T82			M79		M80A + B			M79-83					V82-87				M65-6	M67-8	**EN**	**MN**	**LN**
Bos primigenius?	–	1	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	-	2	1	-
B.taurus/primigenius	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	3	-	-
B. taurus	18	3	5	–	5	16	115	23	47	9	10	82	11	11	4	–	1	6	1	7	-	356	14	4
Ovis/Capra	111	28	153	9	19	127	630	183	261	88	139	785	302	143	38	-	142	340	78	58	161	3,586	171	38
Ovis aries	10	3	2	–	–	7	68	2	13	2	74	56	12	6	6	2	8	19	8	–	1	284	9	6
Capra hircus	9	2	–	1	–	12	36	6	7	7	7	13	6	8	5	–	–	3	1	–	-	108	10	5
Caprinae	–	–	–	–	–	–	–	–	–	–	19	4	–	–	–	–	–	–	–	–	38	61	-	-
Sus domesticus	36	8	–	–	–	37	112	–	–	–	46	90	35	27	10	2	7	26	4	–	2	397	35	10
Sus sp.	–	–	25	1	7	–	–	–	21	19	–	–	–	–	–	–	–	–	–	21	16	110	-	-
Canis familiaris	10	–	–	–	9	1	3	1	4	2	1	4	1	3		–	–	1	1	1	-	39	3	
Capra pyrenaica	3	–	2	–	–	9	59	3	4	3	39	43	15	3	3	–	103	62	23	–	29	397	3	3
Cervus elaphus	4	3	–	1	1	2	5	5	3	2	15	26	8	17	18	–	2	–	–	7	4	85	20	18
Capreolus capreolus	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–		–	–	–	-	2	-	-
Sus scrofa	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	1	–	–	–	-	3	-	-
Monachus monachus	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2	3	-	-
Lynx pardinus	1	–	–	–	–	–	–	1	–	–	5	1	–	1	2	–	–	–	–	–	6	14	1	2
Felis silvestris	3	–	–	–	–	1	4	–	–	–	–	2	–	–	–	–	–	1	–	1	3	15	-	-
Vulpes vulpes	2	–	–	–	–	1	–	–	–	–	8	2	–	1	–	–	–	–	–	–	-	13	1	-
Lepus sp.	2	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	-	2	1	-
O. cuniculus	142	9	55	2	10	7	20	5	9	4	87	50	55	68	85		107	67	30	19	655	1,324	77	85
Total	351	57	242	14	51	220	1058	229	369	136	451	1,158	445	289	171	4	371	525	146	114	920	6,804	346	171

Mina (M-79) and Torca (T-79), data collected from Boessneck and Driesch (1980), Mina (M-80A + M-80B) and Torca (T-82), data collected from Morales Muiz and Martín (1995), Mina (1979–1983) and Vestíbulo (V82–87), as Salazar-García et al. 2017; Mina 65/66 and Nerja/Vestíbulo 66–67 (this paper). *EN* early neolithic, *MN* middle neolithic and *LN* late neolithic

Table 4 Mammals. Number of remains found in the Neolithic sites on the coast of Málaga

	T	CS	HG	R. Chica	Hoyo de la Mina			Abrigo 6			Nerja		
Taxa	MN	MN	EN	EN	EN	MN	LN	EN	MN	LN	EN	MN	LN
Bos taurus/primigenius	–	–	–	–	–	–	–	–	–	–	3	–	–
Bos primigenius?	–	–	–	–	–	–	–	–	–	–	2	1	–
Bos taurus	–	–	–	2	–	5	5	1	1	–	356	14	4
Ovis aries	–	18	2	–	–	4	2	–	–	–	284	9	6
Ovis/Capra	–	–	2	17	12	136	108	–	1	1	,3586	171	38
Capra hircus	–	–	–	–	–	4	3	–	–	–	108	10	5
Caprinae	–	–	–	–	–	–	–	–	–	–	61	–	–
Sus sp.	–	–	–	–	–	–	–	–	–	-	110	–	–
Canis familiaris	–	–	–	–	–	2	1	–	–	–	39	3	–
Capra pyrenaica	–	–	–	–	5	–		1	1	–	397	3	3
Cervus elaphus	–	4	1	5	2	–	2	–	–	–	85	20	18
Capreolus capreolus	–	–	–	–	–	–	–	–	–	–	2	–	–
Sus scrofa	–	–	–	–	–	–	–	–	–	–	3	–	–
Sus domesticus	1	–	–	2	7	42	26	1	1	1	397	35	10
Monachus monachus	–	–	–	–	–	–	2	–	–	–	3	–	–
Lynx pardinus	–	2	–	–	–	–	–	–	–	–	14	1	2
Felis silvestris	–		–	–	–	–	2	–	–	–	15		–
Vulpes vulpes	–	3	–	–	–	–	3	–	–	–	13	1	–
Lepus granatensis	–		–	–	–	–	–	1	1	1	–	–	–
Lepus europaeus	–	1	–	–	–	–	–	–	–	–	–	–	–
Lepus sp.	–	–	–	–	–	–	–	–	–	–	2	1	–
Oryctolagus cuniculus	–	9	–	–	–	152	491	–	–	–	1324	77	85
Total	1	37	5	65	62	345	427	4	5	3	6804	346	171

T (Tesoro), HG (Hostal Guadalupe), RC (Roca Chica), EA (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic)

1995, 1999). Given the excavation and sampling methods employed at the time, it is reasonable to assume that the original assemblages were considerably richer, both in taxonomic diversity and specimen count.

In Nerja, fish remains have been identified across several stratigraphic levels. Early Neolithic contexts include NT82-10, NT79-4, NM (NM80A-4 and NM80B-10). Five Middle Neolithic levels yielded fish (i.e., NT82-8, NT79-3, NM80A-3, NM80B-9, and NM80B-8), along with three additional ones from the Late Neolithic (i.e., NT82-7, NM80A-2 and NM80B-7). The research methodology follows Roselló-Izquierdo (1989). However, given the small size of all fish samples, NISP was routinely used as the abundance estimator (Table 7). Most of the biological information derives from a local study of the fishes from the Sea of Alboran (Gil de Sola 1999).

Taxonomic identification of molluscs (Tables 8, 9, 10 and 11) was conducted using the criteria of several authors (Falkner et al. 2001, Giannuzzi-Savelli et al. 2001, Arrebola 2002, Ruíz Ruíz et al. 2006, Bouchet et al. 2005, Gofas et al. 2011a-b, Carter et al. 2011 and others). Species autoecology including habitats preferences and substrate types, was used to infer collection areas and environmental conditions, as well as to explore anthropic aspects related to food consumption and ornamental use. Archaeological specimens were distinguished from fossils. For the systematics and ecology of non-molluscan marine invertebrates, we follow Ocaña and Pérez-Ruzafa (2004). Taxonomic characteristics and biometrical parameters, facilitating species identification, were analysed following criteria provided by Vera-Peláez et al. (1993, 1999), Lozano-Francisco (1999), and Cortés-Sánchez et al. (2023).

Table 5 Mammals. Number of remains documented during the Neolithic period on the coast of Málaga

Taxa / Sequence	EN	MN	LN
Bos taurus/primigenius	3	–	–
Bos primigenius?	2	1	–
Bos taurus	359	20	9
Ovis aries	286	31	8
Ovis/Capra	3617	308	147
Capra hircus	108	14	8
Caprinae	61	–	–
Sus domesticus	407	79	37
Sus sp.	110	–	–
Canis familiaris	39	5	1
Capra pyrenaica	403	4	3
Cervus elaphus	93	24	20
Capreolus capreolus	2	–	–
Sus scrofa	3	–	–
Monachus monachus	3	–	2
Lynx pardinus	14	3	2
Felis silvestris	15	–	2
Vulpes vulpes	13	4	5
Lepus granatensis	1	1	1
Lepus europaeus	–	1	–
Lepus sp.	2	1	–
Oryctolagus cuniculus	1399	238	356
Total	6940	734	601

Table 6 Mammals from Nerja

Taxa	EP/M(1)	%	N	%
Bos taurus/primigenius	–	–	3	0.04
Bos primigenius?	–	–	3	0.04
Bos primigenius	1	0.0	–	–
Bos taurus	–	–	374	5.11
Ovis aries	–	–	299	4.08
Ovis/Capra	–	–	3,795	51.85
Capra hircus	–	–	123	1.68
Caprinae	–	–	61	0.83
Capra pyrenaica	344	16.7	403	5.50
Cervus elaphus	14	0.7	123	1.70
Capreolus capreolus	–	–	2	0.02
Sus scrofa	10	0.5	3	0.04
Sus sp.	–	–	110	1.50
Sus domesticus	–	–	442	6.04
Monachus monachus	43	2.1	3	0.04
Dephinus delphis	1	0.0	–	–
Canis familiaris	–	–	42	0.57
Lynx pardinus	9	0.4	17	0.23
Felis silvestris	5	0.2	15	0.20
Vulpes vulpes	3	0.1	14	0.19
Lepus sp.	–	–	3	0.04
Oryctolagus cuniculus	1632	79.1	1486	20.30
Total	2062	100	7321	100

(EP/M) Epipalaeolithic-Mesolithic (Cortés-Sánchez et al. 2008) vs. (N) Neolithic (this paper) levels

Archaeobotany

Regarding palaeovegetation data, the quantitative reconstruction of precipitation (in mm/yr) (Fig2.1) was obtained from Ramos-Román et al. (2018a-b) and Camuera et al. (2019, 2022). This reconstruction is based on transfer function techniques using the WAPLS method (Ter Braak CJF and Juggins 1993). It was derived from a modern pollen database (European Modern Pollen Database v2, Davis et al. 2020), combined with current meteorological data (WorldClim database; www.worldclim.org) and fossil pollen records from the Padul sequence (Ramos-Román et al. 2018a-b, Camuera et al. 2019).

All analysed charcoal samples (Table 12) were recovered during field excavations using the anthracological methodology established for the Iberian Peninsula (Uzquiano 1992; Badal et al. 2003; Théry et al. 2010). The charcoal remains were manually fractured along three anatomical planes: transversal, tangential, and radial sections. Identification was based on reference keys from both non-charred (Greguss 1959; Schweingruber 1990; Jacquiot et al. 1973) and charred wood atlases (Vernet et al. 2001). The analysis was conducted using a reflected light optical microscope (Olympus BX60M). Nomenclature follows the guidelines of *Flora Europaea* (Tutin et al. 1964) and Drew et al. 2017.

Regarding cultivated plants, we compiled all published evidence to date in the study area related to seeds (Table 13). None of these sites underwent systematic sampling.

Anthropology

Finally, anthropological data from the site of Nerja were compiled, including information on the sex and death for each individual. These data were used to

Table 7 Birds from Neolithic levels of the Nerja

	NV63*	NV82-87(c)			NM80A(b)		NM/80B(a)					NT82(b)				
Taxa / Level	EN	EN	EN	EN	LN	MN	MN	EN	LN	EN	LN	NM	LN	EN	MN	LN
cf. *Accipiter nisus*	–	1	–	–	–	–	–	–	–	–	–	–	–	1	–	–
Alca torda	–	–	1	–	1	–	–	–	–	–	–	–	–	1	–	1
Upupa epops	–	–	1	–	–	–	–	–	–	–	–	–	–	1	–	–
Buteo sp.	–	–	–	–		1	–	–	–	–	–	–	–	–	1	–
Anas crecca	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	
Branta bernicla	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Falco tinnuculus	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–
Alectoris rufa	–	–	–	–	–	–	–	–	1	–	1	–	–	2	–	–
Coturnix coturnix	–	–	–	–	–	–	–	1	–	1	–	–	–	1	1	–
Uria aalge	–	–	–	–	–	–	–	–	–	1	–	–	–	1		–
Columba livia/oenas	–	–	1	–	–	–	–	–	–	–	1	2	1	3	2	–
Galliformes indet.	–	–	1	–	–	–	–	–	–	–	–	–	–	1	–	–
Passeriformes indet.	–	7	5	22	–	–	–	–	–	–	–	–	–	33	–	–
Monticola solitarius	–	–	–	–	–	–	–	–	1	2	–	–	–	–	3	–
Oenanthe leucura	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–
Corvus corone	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–
Indeterminate	–	1	1	3	–	–	–	–	–	–	–	–	–	5	–	–
Total	2	9	10	25	1	1	1	1	2	6	3	2	1	52	8	3

(a) Eastham 1986, (b) Hernández-Carrasquilla 1995, (c) Morales Pérez et al. 2020. V (Vestíbulo) M (Mina), T (Torca), N (Neolithic), E (Early), M (Middle), L (Late). *This paper

Table 8 NISP of the Neolithic fish from Cueva de Nerja

TAXA	EN	MN	LN	TOTAL
Epinephelus marginatus *	12, 7	10, 1	14, (-)	44
Sparidae ○	(-), 4	(-), 5	4, 2	15
Dentex dentex ○	(-), (-)	(-), (-)	1, (-)	1
Dentex gibbosus ○	(-), (-)	4, (-)	1, (-)	5
Pagellus erythrinus ○	1, 2	(-), (-)	1, (-)	4
Pagrus auriga ○	(-), (-)	(-), (-)	1, (-)	1
Pagrus pagrus ○	1, 1	4, 3	(-), 2	11
Sparus aurata ○	(-), (-)	(-), (-)	1, (-)	1
Diplodus sp. ○	(-), (-)	1, (-)	(-), (-)	1
Chelon labrosus ●	1, (-)	(-), (-)	(-), (-)	1
Euthynnus alleteratus ●	(-), (-)	1, (-)	(-), (-)	1
Grand total (Totals of each column)	29 (15, 14)	29 (20, 9)	27 (23, 4)	85 (58, 27)

(*EN* early Neolithic, *MN* middle Neolithic, *LN* late neolithic) The numbers arranged into columns refer the NISPs provided by Roselló-Izquierdo et al. 1995 (left), and Boessneck and Driesch 1980 (right). The levels from which these assemblages derive are provided in the Material and Methods section (*Demersal, ●Pelagic, ○Mid-water)

Table 9 Estimated size ranges, expressed as standard lengths, of selected fish species from Nerja's Neolithic fish collections

Species	SL (cm)	Species	SL (cm)
Epinephelus marginatus	50–80	*Pagrus pagrus*	30–60
Dentex dentex	40–45	*Sparus aurata*	40–60
Dentex gibbosus	40–80	*Pagellus erythrinus*	45–50
Pagrus auriga	60–70	*Chelon labrosus*	45–55

explore demographic structures and usage site-use patterns (Table 14) with references).

Results

Of the more than forty archaeological sites with Neolithic evidence on the Málaga coast, thirteen contained records relevant to this study, including data

Table 10 Molluscs

	MNI		
Taxa	EN	MN	LN
Patella caerulea Linnaeus, 1758	1502	1101	698
Patella cf. *caerulea* Linnaeus, 1758	6	6	–
Patella rustica Linnaeus, 1758	332	230	165
Patella intermedia Murray, 1857	186	150	161
Patella ferruginea Gmelin, 1791	31	19	18
Patella ulyssiponensis Gmelin, 1791	340	295	325
Patella sp.	9	9	-
Cymbula safiana (Lamarck, 1819)	73	55	88
Phorcus richardi (Payraudeau, 1826)	29	17	1
Phorcus turbinatus (Born, 1778)	1467	948	193
Phorcus sp.	–	8	–
Tritia pellucida (Risso, 1826)	1	1	–
Cerithium vulgatum Bruguière, 1792	3	1	–
Luria lurida (Linnaeus, 1758)	–	–	1
Zonaria pyrum (Gmelin, 1791)	–	1	–
Charonia lampas (Linnaeus, 1758)	2	7	5
Stramonita haemastoma (Linnaeus, 1767)	402	379	155
Monoplex parthenopeus (S. Marschlins, 1793)	1	–	
Monoplex corrugatus (Lamarck, 1816)	1	–	1
Semicassis saburon (Bruguière, 1792)	–	1	–
Semicassis granulata (Born, 1778)	–	–	1
Nucella lapillus (Linnaeus, 1758)	70	22	8
Columbella rustica (Linnaeus, 1758)	33	6	–
Bolinus brandaris (Linnaeus, 1758)	–	1	–
Hexaplex trunculus (Linnaeus, 1758)	2	1	–
Conus ventricosus Gmelin, 1791	17	4	1
Siphonaria pectinata (Linnaeus, 1758)	42	34	31
Trimusculus mammillaris (Linnaeus, 1758)	1	1	
Gastropoda sp.	–	–	1
Theodoxus fluviatilis (Linnaeus, 1758)	4	–	–
Melanopsis laevigata Lamarck, 1816	3	2	1
Melanopsis praemorsa (Linnaeus, 1758)	1	–	–
Otala lactea (O.F. Müller, 1774)	2	1	4
Sphincterochila hispanica (Westerlund, 1886)	2	–	–
Iberus gualterianus (Linnaeus, 1758)	94	38	18
Iberus sp.	4	–	–
Grycymeris bimaculata (Poli, 1795)	2	1	–
Glycymeris nummaria (Linnaeus, 1758)	1	1	4
Glycymeris sp.	10	6	192
Mytilus galloprovincialis Lamarck, 1819	1153	480	2
Perna perna (Linnaeus, 1758)	–	4	–
Ostrea edulis Linnaeus, 1758	4	3	–
Chlamys sp.	1	–	3
Pecten maximus (Linnaeus, 1758)	27	12	-
Pecten jacobaeus (Linnaeus, 1758)	1	–	–
Pecten sp.	2	–	–
Spondylus gaederopus Linnaeus, 1758	1	2	–
Donax trunculus Linnaeus, 1758	–	–	1
Cerastoderma edule (Linnaeus, 1758)	16	6	–
Cerastoderma glaucum (Bruguière, 1789)	1	–	–
Anomia ephippium Linnaeus, 1758	1	–	1
Acantocardia tuberculata (Linnaeus, 1758)	2	1	–
Ensis cf. *ensis* (Linnaeus, 1758)	2	2	–
Ruditapes decussatus (Linnaeus, 1758)	–	1	–
Tapetinae sp.	4	–	1
Venus nux Gmelin, 1791	–	–	9
Callista chione (Linnaeus, 1758)	10	2	–
Chamelea gallina (Linnaeus, 1758)	–	–	1
NMI totals (12,316 individuals)	6367	3859	2090
NSP totals (103 species)	47	40	45

Minumin number of individuals (MNI) and Number of Species (NSP) for Nerja (Mina, Section NM80A, NM80B and 1966–68; Torca, Section NT-82, and Vestíbulo (1963–64). *EN* early neolithic, *MN* middle neolithic, *RN* recent neolithic. Data from the authors

on funerary practices (Table 2). These sites document the entire Neolithic sequence of the Málaga coast between ~ 7.5 ka and ~ 5 ka cal BP, structured within a three-phase chronocultural framework that integrates the proposals of various authors (Table 1).

The stratigraphy from multiple excavations at Nerja has been reorganised into a sequence of three phases (Early, Middle and Late Neolithic, (Table 1) based on criteria established by multiple authors (Pellicer Catalán and Acosta Martínez 1997; Aura-Tortosa et al. 2005; Simón-Vallejo 2003; García Borja et al. 2014; Salazar-García et al. 2017).

This framework allows for an integrated examination of palaeoenvironmental, economic, and seasonal aspects throughout the Neolithic sequence on the Málaga coast between ~ 7.5 ka and ~ 5 ka cal BP (Tables 1, 2).

Table 11 Mollusc

	Abrigo 6(a)			Abrigo 6(b)	Hoyo de la Mina(b)		Bajondillo(c)			Tesoro(d)	Hostal Guadalupe (e)	Tapada(f)	Sahara(g)
	(Ramos 2004)			(2002–4)									
	EN	MN	LN	NEO	EN	MN	EN	NEO	LN	NEO	NEO	NEO	NEO
Taxa	MNI			MNI	MNI		MNI			MNI	MNI	MNI	MNI
Patella caerulea Linnaeus, 1758	x	x	x	–	18	23	4	54	–	–	–	–	1
Patella rustica Linnaeus, 1758	–	–	–	–	–	3	–	1	–	–	2	–	–
Patella ferruginea Gmelin, 1791	–	–	–	–	–	–	–	–	–	–	–	–	1
Patella ulyssiponensis Gmelin, 1791	x	x	–	–	1	11	–	2	–	–	–	–	–
Patella sp.	–	x	–	–	1	5	4		–	–	–	–	1
Cymbula safiana (Lamarck, 1819)	–	–	–	–	–	–	–	1	–	–	–	–	–
Phorcus richardi (Payraudeau, 1826)	–	–	–	33	–	–	–	–	–	–	–	–	–
Phorcus sp.	–	–	–	–	–	1	–	–	–	–	–	–	–
Phorcus turbinatus (Born, 1778)	x	x	x	11	15	32	–	4	–	–	–	–	–
Phorcus sp.	–	–	–	–	–	2	–	–	–	–	–	–	–
Smaragdia viridis (Linnaeus, 1758)	–	–	–	8	–	2	–	–	–	–	–	–	–
Littorina obtusata (Linnaeus, 1758)	–	–	–	47	–	14	–	–	–	–	–	–	–
Melarhaphe neritoides (Linnaeus, 1758)	–	–	–	2	–	–	–	–	–	–	–	–	–
Natica sp.	–	–	–	1	–	–	–	–	–	–	–	–	–
Cerithium vulgatum Bruguière, 1792	–	–	–	1	–	–	–	–	–	–	–	–	–
Mesalia mesal (Deshayes, 1843)	–	–	–	1	–	–	–	–	–	–	–	–	–
Trivia monacha (da Costa, 1778)	x	–	–	16	–	–	–	–	–	–	–	–	–
Zonaria pyrum (Gmelin, 1791)	–	–	–	–	–	2	–	–	–	–	–	–	–
Bulla striata Bruguière, 1792	–	–	–	1	–	–	–	–	–	–	–	–	–
Stramonita haemastoma (Linnaeus, 1767)	x	x	–	26	3	16	4	7	1	–	–	–	6
Nucella lapillus (Linnaeus, 1758)	–	–	–	31	–	–	–	–	–	–	–	–	–
Columbella rustica (Linnaeus, 1758)	x	x	x	117	13	46	–	–	–	–	–	–	–
Bolinus brandaris (Linnaeus, 1758)	–	–	x	1	–	–	–	–	–	–	–	–	–
Hexaplex trunculus (Linnaeus, 1758)	–	–	–	1	–	–	–	–	–		–	–	–
Ocenebra erinaceus (Linnaeus, 1758)	–	–	–	4	–	–	–	–	–	–	–	–	–
Ocenebra edwardsii (Payraudeau, 1826)	–	–	–	5	–	–	–	–	–	–	–	–	–
Muricidae sp.	–	–	–	–	–	1	–	–	–	–	–	–	–
Pisania striata (Gmelin, 1791)	–	–	–	1	–	–	–	–	–	–	–	–	–
Tritia reticulata (Linnaeus, 1758)	–	–	–	5	1	3	–	–	–	–	–	–	–
Tritia corniculum (Olivi, 1792)	–	–	–	2	1	–	–	–	–	–	–	–	–

Table 11 (continued)

	Abrigo 6(a)			Abrigo 6(b)	Hoyo de la Mina(b)		Bajondillo(c)			Tesoro(d)	Hostal Guadalupe (e)	Tapada(f)	Sahara(g)
	(Ramos 2004)			(2002–4)									
	EN	MN	LN	NEO	EN	MN	EN	NEO	LN	NEO	NEO	NEO	NEO
Tritia gibbosula (Linnaeus, 1758)	–	–	–	3	–	–	–	–	–	–	–	–	–
Tritia pellucida (Risso, 1826)	–	–	–	11	–	–	–	–	–	–	–	–	–
Tritia sp1	–	–	–	1	–	–	–	–	–	–	–	–	–
Tritia sp2	–	–	–	1	–	–	–	–	–-	–	–	–	–
Conus ventricosus Gmelin, 1791	x	x	–	13	–	18	–	1	–	–	–	1	–
Isara nigra (Gmelin, 1791)	–	–	–	1	–	–	–	–	–	–	–	–	–
Siphonaria pectinata (Linnaeus, 1758)	–	–	–	–	7	39	–	2	–	–	–	–	–
Gastropoda sp.	–	–	–	–	–	1	–	–	–	–	–	–	–
Melanopsis laevigata Lamarck, 1816	–	–	–	–	–	1	1	6	1	–	–	–	–
Melanopsis praemorsa (Linnaeus, 1758)	–	–	–	–	–	–	16	19	–	–	–	–	–
Otala lactea (O.F. Müller, 1774)	–	–	–	–	–	–	2	2	–	–	–	–	–
Caracollina lenticula (Michaud, 1831)	–	–	–	2	–	2	–	1	–	–	–	–	–
Theba pisana (O.F. Müller, 1774)	–	–	–	3	–	5	4	13	–	–	–	–	–
Iberus gualterianus (Linnaeus, 1758)	–	–	–	–	18	104	2	5	–	–	–	–	–
Helicidae sp.	–	–	–	–	5	7	1	2	–	–	–	–	–
Cochlicella acuta (O.F. Müller, 1774)	–	–	–	1	–	–	–	–	–	–	–	–	–
Rumina decollata (Linnaeus, 1758)	–	–	–	1	4	3	–	1	–	–	–	–	–
Ferussacia follicula (Gmelin, 1791)	–	–	–	–	–	2	–	–	–	–	–	–	–
Cornu aspersa (O.F. Müller, 1774)	–	–	–	–	–	3	–	–	–	–	–	–	–
Grycymeris bimaculata (Poli, 1795)	–	–	–	–	–		–	1	–	–	–	–	–
Glycymeris nummaria (Linnaeus, 1758)	–	–	–	–	–	1	–	–	–	–	–	–	5
Glycymeris sp.	x	–	–	–	–	1	–	–	–	1	–	–	–
Mytilus galloprovincialis Lamarck, 1819	x	x	x	–	3	3	1	2	–	–	–	–	–
Perna perna (Linnaeus, 1758)	–	–	–	–	–	–	–	–	1	–	–	–	–
Ostrea edulis Linnaeus, 1758	x	x	x	–	–	–	–	–	–	–	–	–	–
Ostrea sp.	–	–	–	–	–	–	–	–	–	1	–	–	–
Pecten maximus (Linnaeus, 1758)	–	–	–	–	2	3	–	–	–	–	2	–	–
Pecten sp.	–	–	–	–	–	1	–	–	–	–	–	–	–
Spondylus gaederopus Linnaeus, 1758	–	x	–	–	–	–	–	–	–	–	–	–	–
Donacilla cornea (Poli, 1791)	–	–	–	–	–	–	–	13	–	–	–	–	–
Donax trunculus Linnaeus, 1758	–	–	–	–	–	-	–	1	–	–	–	–	–

Table 11 (continued)

	Abrigo 6(a) (Ramos 2004)			Abrigo 6(b) (2002–4)	Hoyo de la Mina(b)		Bajondillo(c)			Tesoro(d)	Hostal Guadalupe (e)	Tapada(f)	Sahara(g)
	EN	MN	LN	NEO	EN	MN	EN	NEO	LN	NEO	NEO	NEO	NEO
Cerastoderma edule (Linnaeus, 1758)	x	–	–	1	16	53	5	–	1	–	–	–	–
Cerastoderma glaucum (Bruguière, 1789)	–	–	–	–	2	28	–	6	–	–	–	–	–
Cerastoderma sp.	–	–	–	–	7	13	–	–	–	–	–	–	–
Cardiidae sp.	–	–	–	–	–	1	–	–	–	–	–	–	–
Ensis siliqua (Linnaeus, 1758)	–	–	–	–	–	2	–	–	–	–	–	–	–
Ruditapes decussatus (Linnaeus, 1758)	–	–	–	–	17	27	–	–	–	–	–	–	–
Polititapes aureus (Gmelin, 1791)	–	–	–	–	–	1	–	–	–	–	–	–	–
Venerupis corrugata (Gmelin, 1791)	x	–	x	–	42	265	–	–	–	–	–	–	–
Tapetinae sp.	–	–	–	–	26	1	–	–	–	–	–	–	–
Chamelea gallina (Linnaeus, 1758)	–	–	–	–	1	–	–	1	–	–	–	–	–
Bivalvia sp.	–	–	–	–	-	–	–	–	–	–	1	1	–
Antalis inaequicostata (Dautzenberg, 1891)	–	–	–	13	1	1	–	–	–	–	–	–	–
Antalis vulgare (Da Costa, 1778)	–	–	–	2	–	–	–	–	–	–	–	–	–
Antalis sp.	–	–	–	1	–	1	–	–	–	–	–	–	–
Paradentalium inaequale (Bronn, 1831)	–	–	–	–	–	–	–	–	–	2	–	–	–
Pseudantalis rubescens (Deshayes, 1832)	–	–	–	2	–	–	–	–	–	–	–	–	–
Paradentaliun sexangulum (Gmelin, 1791)	–	–	–	–	2	3	–	–	–	13	–	–	–
Mollusca sp.	–	–	–	–	–	–	–	1		–	–	–	–
Balanus sp.	–	–	–	–	1	–	–	–	–	–	–	–	–
Decapoda sp.	–	–	–	–	1	–	–	–	–	–	–	–	–
Paracentrotus lividus (Lamarck, 1816)	–	–	–	–	–	3	–	–	–	–	–	–	–
NMI Totals (1595 individuals)	13	11	7	370	208	754	44	146	4	17	5	2	14
NSP Totals (103 species)	13	11	7	35	25	43	11	23	4	4	3	3	5

Species and Minimum Number of Individuals (MNI), Number of Species (NSP). *EN* early neolithic, *MN* middle neolithic, *RN* recent neolithic, *NEO* neolithic. Data from the authors. When only presence (x) is recorded, MNI = 1 has been considered. (a) Ramos 2004, (b) this paper, (c-e) Cortés-Sánchez et al. 2012, 2020, (f) this paper, (g) Braun and Poulain (1963)

Table 12 Molluscs. Total minimum number of individuals (MNI) and total number of species (NSP) and by site

	Nerja			Abrigo 6			Hoyo de la Mina		Bajondillo			Tesoro	Tapada	Sahara	Nerja		
	Vestíbulo + Mina + Torca			Ramos 2004											Vest	Mina	
	EN	MN	LN	EN	MN	LN	EN	EN	EN	MN	LN	Neo	Neo	Neo	EN	MN	LN
MNI = 13,911	6367	3859	2090	13	11	7	208	102	44	146	4	17	2	14	367	705	598
NSP = 103	47	40	45	13	11	7	25	6	11	23	4	4	3	3	12	14	13

EN early Neolithic, *MN* middle Neolithic, *RN* recent Neolithic, *NEO* neolithic, *Vest* Vestíbulo. Data from the authors

Archaeozoology

Mammals

Five domestic taxa have been identified in the Neolithic levels: sheep, goat, pig, cow, and dog (Tables 3, 4 and 5). Direct dating of sheep remains confirms the presence of this species in the regional Early Neolithic. On the Málaga coast, sites such as Nerja, Roca Chica, and Hostal Guadalupe attest to their presence from approximately 7.6 cal ka BP (Tables 3, 4, 5), (Figs. 3–8). A marked decline in wild mammal remains is observed, with rabbits being the primary species still present unpublished data from Nerja (NM65-66 and NM67-68) indicate that rabbit remains, predominantly from adult individuals, exhibit cut marks, fractures, and traces of fire, suggesting their consumption by human groups. When excluding rabbits, domestic livestock accounts for approximately 90% of the assemblage, compared to 10% for wild animals (Tables 3, 4 and 5). This suggests that, during the Neolithic period, meat consumption depended primarily on livestock.

Birds

The bird remains from Nerja have been extensively studied (Boessneck and Driesch 1980; Eastham 1986; Hernández-Carrasquilla 1995; Cortés-Sánchez et al. 2008). A total of 18 species have been identified, 13 from the Early Neolithic, five from Middle Neolithic, and two from Late Neolithic (Table 7).

Four wintering species have been identified in the Neolithic levels (Table 7): a) *Branta bernicla*. This species has a North Palearctic distribution, breeding primarily on Arctic islands and wintering along the northern European coasts. Currently, on the Iberian Peninsula, this species is an irregular and scarce winter visitor (Huntley et al. 2007). Most records come from the Cantabrian coast, although this species reaches the coasts of Cádiz annually, with most sightings occurring between December and February (Díaz et al. 1996, SEO Bird Life Database: https://seo.org/ave/barnacla-carinegra/); b) *Anas crecca* is another species that primarily winters in Iberia, although occasional breeding individuals have been observed. It prefers inland wetlands. Arrival to the Mediterranean coast is linked to harsh winters in Europe (Asensio and Carrascal 1992); c) *Uria aalge* breeds along the Atlantic coasts, from northern Europe to Portugal. In winter, some individuals occasionally reach the eastern Mediterranean (Huntley et al. 2007). On the Iberian Mediterranean coast, sightings are extremely rare, occurring between October and April, with a maximum in February (Díaz et al. 1996); d) *Alca torda* breeds on the coasts of northern Europe. In winter, its populations disperse along European coasts, reaching as far as the eastern Mediterranean (Huntley et al. 2007). It is present from November to March, with peak occurrences in December and January (Díaz et al. 1996).

None of these species enter caves during their wintering period. During the breeding season (which also occurs in winter), only *Uria aalge* nests in sea cliff hollows. Thus, the presence of these bird remains in the archaeological layers of Nerja suggests that the site was occupied by human groups during at least part of the winter.

Fishes

Table 8 provides an overview of the Neolithic fish assemblages in terms of NISP, categorized by chronological phases, along with relevant studies (Boessneck and Driesch 1980; Morales-Muñiz et al. 1994;

Table 13 Mollusc. Number of species (NSP) and percentages with respect to the NSP of those represented in each site according to their palaeoenvironment, autoecology and use

		Nerja						Abrigo 6		Hoyo de la Mina				Bajondillo						Tesoro		H. Guada-lupe		Tapada		Sahara	
		EN		MN		LN		NEO		EN		NEO		EN		MN		LN		NEO		NEO		NEO		NEO	
		NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%	NSP	%
Paleoenv	IR	10	21.5	14	35,0	8	17,8	–	–	5	20	17	38,6	3	27,3	5	21,7	–	–	1	25	1	33,3	-	-	2	40
	MR	6	12,8	7	17,5	3	6,7	21	60	2	8	4	9,1	1	9,1	3	13,5	1	25	–	–	–	–	1	50	1	20
	LR	3	6,4	4	10,0	2	4,44	–	–	2	8	3	6,2	–	–	7	30,4	1	25	–	–	–	–	–	–	–	–
	IAF	15	31,9	13	32,5	8	17,8	8	22,8	11	44	17	38,6	1	9,1	6	26,1	1	25	3	75	1	33,3	1	50	2	40
	LN	3	6,4	1	2,5	–	–	–	–	2	8	2	4,5	–	–	–	–	–	–	–	–	1	33,3	–	–	–	–
	IAlg	1	2,1	–	–	1	2,2	1	2,8	–	–	3	6,8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	MAF/IAF	–	–	–	–	1	2,2	1	2,8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	PT	4	8,5	2	5,0	2	4,4	4	11,4	3	–	7	15,9	4	36,4	6	26,1	–	–	–	–	–	–	–	–	–	–
	DA	4	8,5	1	2,5	1	2,2	–	–	–	–	1	2,3	2	18,2	2	8,7	1	25	–	–	–	–	–	–	–	–
Autoecology	EP	32	68,1	29	72,5	36	80	26	74,3	13	52	21	47,7	4	36,4	9	39,1	2	50	1	25	2	66,7	1	50	5	100
	IN	9	19,1	9	22,5	6	13,3	5	14,3	9	36	12	27,3	1	9,1	4	17,4	1	25	3	75	1	33,3	1	50		
	CO	7	14,9	3	7,5	3	6,7	4	11,4	3	12	8	18,2	6	54,5	8	34,8	1	25								
Use	Con-sume	37	78,7	36	90	20	44,4	6	17,1	18	72	26	59,1	4	36,4	13	56,5	3	75			2	66,7			4	80
	Orna-ment	14	29,8	14	35	5	11,1	35	100	9	36	9	20,4	–	–	–	–	–	–	4	100	1	33,3	2	100	1	20
	Other	–	–	–	–	–	–	–	–	1	4			–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Natural Hab	5	10,6	3	7,5	4	8,9	4	11,4	4	16	6	13,6	6	54,5	8	34,8	1	25	–	–	–	–	–	–	–	–
	?	2	4,3	2	5,0	1	2,2	–	–	2	8	–	–	–	–	1	4,3			–	–	–	–	–	–	–	–
	MNI	6367		3859		2090		370		208		754		44		146		4		17		5		2		14	
	NSP	47		40		45		35		25		44		11		23		4		4		3		3		5	

The total minimum number of individuals (MNI) per site and the total NSP are also provided. *IR* rocky infra-littoral, *MR* rocky mesolittoral, *IAF* sandy-muddy infra-littoral, *LN* swimming libred, *IAlg* algal infra-littoral, *MAF* sandy-muddy mesolittoral, *PT* terrestrial pulmonate, *DA* freshwater, *EP* epifaunal, *IN* infaunal, *CO* continental

Table 14 Wood charcoal for Hoyo de la Mina

	MN-HM/3		EN-HM/4	
Taxa	N	%	N	%
Deciduous *Quercus*	1	1	9	9
Salix-Populus	–	–	1	1
Quercus ilex-coccifera	1	1	7	7
Olea europaea	66	66	19	19
Rhamnus-Phillyrea	–	–	3	3
Arbutus unedo	–	–	1	1
Pistacia lentiscus	–	–	2	2
Cistus sp.	2	2	6	6
Salvia rosmarinus	3	3	6	6
Fabaceae	3	3	12	12
Amaranthaceae		–	5	5
t. *Viscum*	4	4	5	5
Undeterminables	20	20	24	24
TOTAL	100	100	100	100

EN (Early Neolithic), MN (Middle Neolithic)

Roselló-Izquierdo et al. 1995, 1999; Morales-Muñiz and Roselló-Izquierdo 2003).

The fish assemblages exhibit relative "stasis" in terms of NISP (EN:29; MN:29; LN:27), with only a slight increase in taxonomic diversity over time (EN:4, MN:5, LN:7). This pattern suggests that fish remained a minor resource at Nerja throughout the Neolithic (Table 8). This hypothesis should be interpreted with caution, as it may reflect the relatively large mesh sizes used for sieving samples from NT and NM (Table 9) and it must be contrasted in future archaeological work.

The variety of fish species at Nerja suggest that multiple habitats were exploited Seabreams (Sparidae), a mid-water, neritic group, together with the common grouper (*Epinephelus marginatus*), a demersal species (i.e., living near the seafloor but not strictly benthic), together represent the bulk of the catch across all periods (Table 8). However, despite their anecdotic representation, pelagic fish (open water/oceanic species), such as the little tunny (*Euthynus alleteratus*), and grey mullets (*Chelon labrosus*) represent *ca.* 3.5% of the Early and Middle Neolithic assemblages. Seabreams include more open water species, such as all *Dentex* sp. and *Pagellus erythrinus*, and more demersal taxa such as species of the genus *Diplodus.* All these species are present today in the Mediterranean and Alboran Sea (Whitehead et al. 1984, Gil de Sola, 1999). Most mid-water and benthonic fish tend to be sedentary whereas most pelagic taxa are migratory. Grey mullets being movements along littoral (inshore) waters with seasonal upstream runs into rivers. In terms of NISP, roughly 96% of the taxa correspond to sedentary species.

Only the migratory species, which are absent from Late Neolithic collections, serve as seasonal indicators. Middle Neolithic assemblage includes a late summer/early autumn taxon (i.e., the little tunny). Depending on the spawning period in the Alboran Sea, the *Chelon labrosus* from the Early Neolithic phase could be either a winter or summer spawner, suggesting its capture in spring or autumn.

Another issue of interest concerning fishes refers to the size of those elements on which this parameter could be estimated. The thus far published standard lengths (SL) of the majority of the species are set within a rather narrow range of 40–60cm, with the largest specimens reaching to 80cm correspond with the largest species (i.e., the grouper and *Dentex gibbosus*), and only the porgy ranges down to 30 cm (Table 9). The weights that roughly correspond to the first group would range between 500–1,000 g, whereas 30cm would correspond fishes of *ca*. 250g, and the 80cm specimens reflect animals over 4–5 kg depending on the species (Roselló-Izquierdo et al. 1995). Fishes of these sizes could be taken through a variety of methods including hooks, arrows, traps and weirs (Morales-Muñiz 2010).

Molluscs

The analysis of the marine molluscs fauna from seven Neolithic sites along the coast of Málaga has identified a total of 13,911 individuals (MNI) and 103 different taxa (Table 10), (Fig. 9). Of these, only sixteen were identified at the genus level, four at the family level, two at the class level. Seventy-seven taxa were at the species level (two of them as *confer*). This indicates both the great diversity and abundance of molluscs collection.

Nerja stands out as the richest site, with a total of 12,316 individuals representing 58 different taxa (Table 11) with the highest MNI during the Early Neolithic with 50% of the total number of individuals (Fig. 9). Rocky shore species predominate (> 40%), which is consistent with the nearby marine environment. All published studies indicate that most

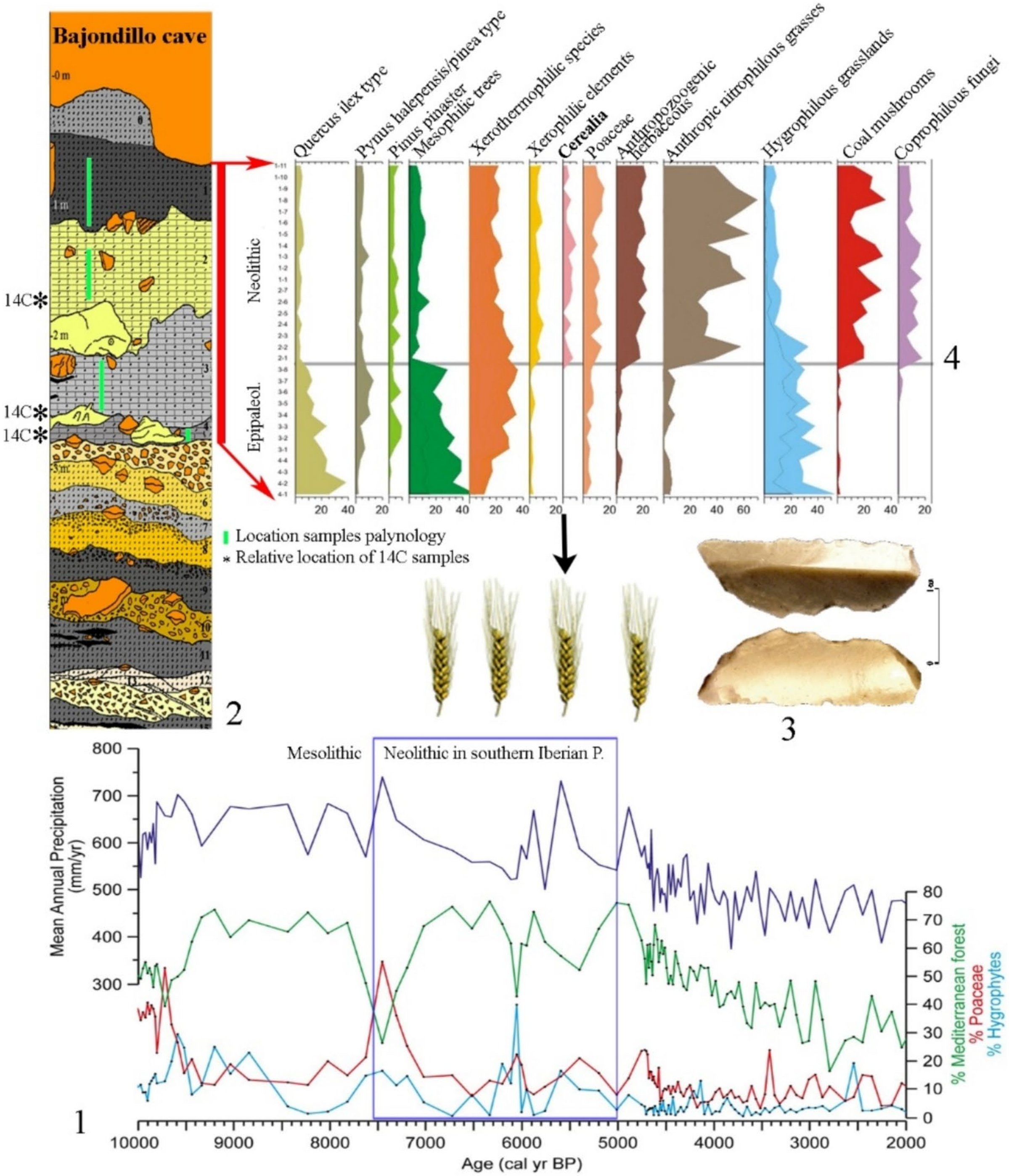


Fig. 2. 1) Quantitative reconstruction of precipitation (mm/year) (dark blue) based on the Padul pollen record (Camuera et al. 2022), along with the percentages of Mediterranean forest (green), Poaceae (red) and hygrophytes (light blue) (Ramos-Román et al. 2018a-b, Camuera et al. 2019). 2) Bajondillo cave sequence. 3) Sickle element from Bj/2. 4) Schematized pollen composition of the Bajondillo record (López et al. 2007, Cortés-Sánchez et al. 2008)

Fig. 3 Unpublished data from Nerja and Hoyo de la Mina (EN, MN, LN). Reinterpretation of data from Nerja (MN, LN) (Morales and Martín 1995). Age at death/slaughter. MNI (minimum number of individuals), EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic)

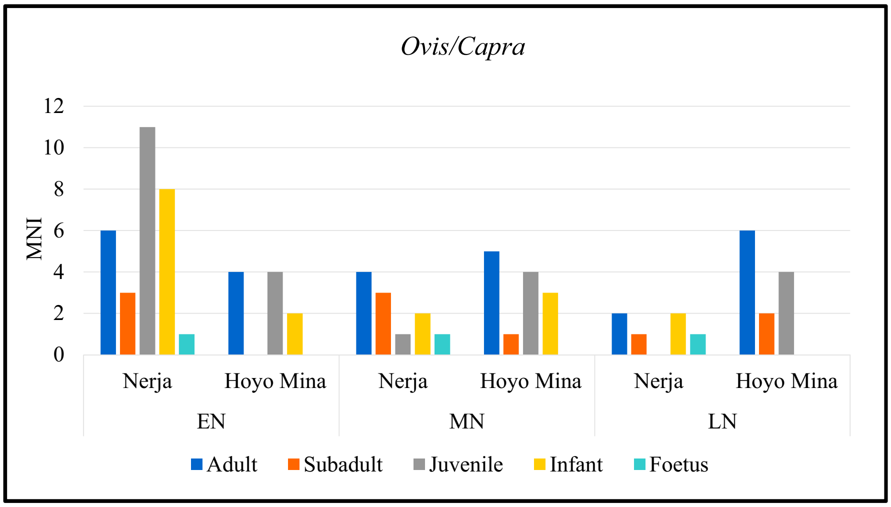
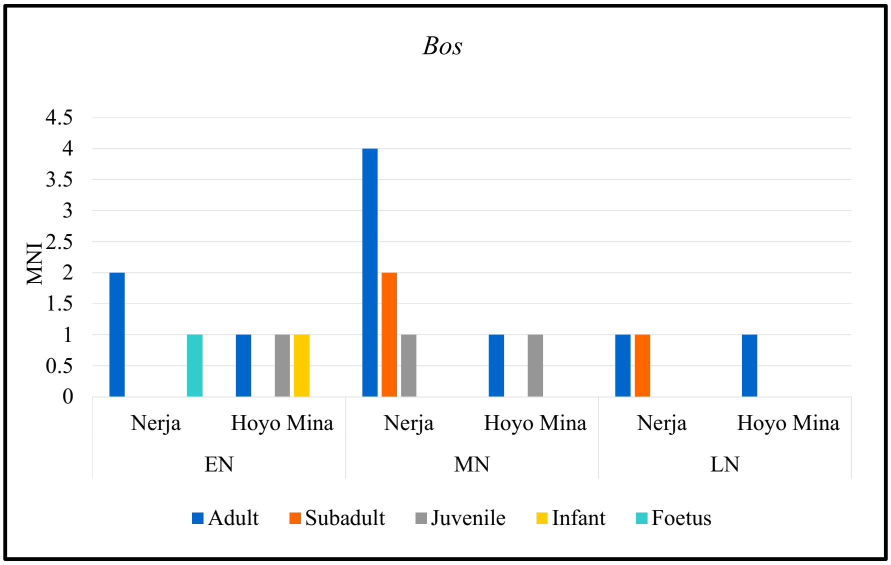


Fig. 4 Unpublished data from Nerja and Hoyo de la Mina (EN, MN, LN) (this paper). Reinterpretation of data from Nerja (MN, LN) (Morales and Martín 1995). Age at death/slaughter. MNI (minimum number of individuals), EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic)



individuals appear to have been collected for consumption and show clear signs of exposure to fire. Thus, for example, out of a sample of just over 2000 specimens, about half (e.g. 46.5% in NV) showed signs of thermo-alteration. Epifaunal species are the most common, with limpets (MNI = 5583) and mussels (MNI = 1639) comprising almost 70% of the total. The trochid *Phorcus turbinatus* is also abundant, with 2,608 individuals.

At Abrigo 6, molluscs appear to have been primarily used for symbolic purposes, featuring perforations and other modifications, although 17% of the 45 identified taxa may have been consumed. Rocky shore species predominate (60%), and 74.3% of the taxa are epifaunal (i.e. living on the sediment surface (tabs. 6.1–6.3). *C. rustica* is the most represented species (117 individuals). Four different species of scaphopods have also been identified, all contemporary to the site, unlike at Hoyo de la Mina, where fossil scaphopods from the Lower Pliocene are also present (Lozano-Francisco et al. 2025). In the material corresponding to the 2001/2003–2004 campaigns, 100% of the molluscs were ornamental featuring perforations and other modifications. However, six species may have been consumed (Table 11).

At Hoyo de la Mina, more than 70% of the molluscs have been collected primarily for consumption, as many show signs of thermal alteration. A total of 48 taxa has been identified: 25 taxa from the Early Neolithic and 43 from the Middle Neolithic, with a total of 962 individuals (Early Neolithic: 208 and Middle Neolithic: 754). More than 50% of the individuals are infaunal species from sandy-muddy infralittoral habitats, primarily used for consumption. Among these, 294 are clams from the subfamily Tapetinae (mostly from the genus *Venerupis*) (Tables 10, 11 and 12). Among the elements of symbolic use, the collection of fossil scaphopods species is particularly noteworthy, likely gathered from Pliocene outcrops near the site.

At Bajondillo, a total of 194 individuals (Late Neolithic: 4, Middle Neolithic: 146 and Early Neolithic: 44) representing 25 taxa have been retrieved (Table 11). Approximately 50% of the species are from rocky shore environments, with 68% of them likely representing food items (Table 12).

A total of 17 individuals from four species have been recovered at Tesoro, five individuals from three species at Hostal Guadalupe, two individuals from two species at Tapada, and 14 individuals from five species at Sahara Cave (Table 13). Tesoro, Hostal Guadalupe, Tapada and Sahara have similar proportions of species from both rocky shore and sandy-muddy infralittoral habitats. All specimens were used as ornaments, except at Sahara, where ornaments represented only 20% of the total assemblage (Table 13). Tesoro, Hostal Guadalupe, and Tapada also yielded a small number of shell ornaments. Both Tesoro and Hoyo de la Mina contained fossil scaphopods (Cortés-Sánchez et al. 2019).

Archaeobotany

Wood charcoal

Wood charcoal analyses from Hoyo de la Mina (Table 14) are consistent with the landscape defined by the Bajondillo pollen column (Fig.2.4). In the two oldest levels, the dominant taxon is the wild olive (*Olea europaea* var. *sylvestris*). Among arboreal taxa, both deciduous oaks (*Quercus*) and evergreen oaks (*Quercus ilex-coccifera*) appear, but in low frequency at HM/4 and marginally in HM/3. Shrub diversity and abundance are higher in the oldest Neolithic occupation, indicating a Mediterranean scrubland dominated by rockroses (*Cistus* sp.), rosemary (*Salvia rosmarinus*), and, most notably, Fabaceae.

In the earliest Neolithic at Nerja, the anthracological diagram indicates a decline in Fabaceae in favor of *Olea*, which becomes the dominant taxon. However, Fabaceae values remain significant. Conifers (*Pinus nigra, P. halepensis, Juniperus*) are present at very low amounts, almost negligible levels, a trend that persists in the later Neolithic layer. In the most recent Neolithic layer, *Olea* shows a gradual decline, though it remains the dominant taxon. Scrub formations are represented by a diverse floral assemblage, particularly *Salvia rosmarinus*, which reaches nearly 20% (Badal 1990: 151). According to the author, these scrub formations correspond to well-established thermo-Mediterranean communities (Badal 1990: 160).

Evidence of wild fruit collection has been documented at Nerja, including olives, pine nuts, and acorns from various oak species (Table 15). The presence of *Arbutus unedo* wood at Hoyo de la Mina may indicate the consumption of its fruits at the site. Additionally, a fragment of *Pistacia* was found in HM4 (see Table 14).

Domestic plants

Remains of domestic plants have been identified at several sites along the Málaga coast, including Nerja, Bajondillo, Roca Chica, and Hostal Guadalupe (Table 15). Two large cereal deposits, one exceeding 12 kg at Roca Chica and another in a grain silo at Nerja, constitute most of this remains. The remaining samples from Nerja, Bajondillo, and Hostal Guadalupe were manually collected. All the material is homogeneous in terms of crop diversity and appears charred. The main cereals represented are naked barley (*Hordeum vulgare* var. *nudum*), naked wheat (*Triticum aestivum/durum),* and emmer wheat (*T. dicoccum*). Of these, naked barley is by far the dominant species. There is no evidence of einkorn (*T. monococcum*), which appears to have been a marginal crop in much of Andalusia, a pattern also observed in this study area. Pollen record from Bajondillo indicates agricultural activity (Fig2.3). Here, a direct AMS date on a wheat (*Triticum* sp.) caryopsis yields a date of 7154–6792 cal BP, closely matching those from Hostal Guadalupe and Roca Chica (Table 15),

Table 15 Seed and lithic industries linked to harvesting

	Early Neolithic (~5570–5000 BC)					Midddle Neolithic (~5000–4000 BC)			
Taxa)	NM/3	HG	RC	Bj/2	Total	NM/2	NV/IC(a)	NB/NC	Total
Hordeum vulgare	–	1	6	–	7	1001	–	–	1001
cf. *Hordeum vulgare*	–	2	–	–	2	–	–	–	–
Hordeum vulgare var. *nudum*	31	45	2,103	–	2,179	11(2)+48	3,213	31	3,303
Hordeum vulgare rachis (two-row)	–	–	7	–	7	–	–	–	–
Hordeum/Triticum	–	–	106	–	106	–	688	–	688
Triticum dicoccum	–	–	211	–	211	–	–	–	–
Triticum dicoccum (spikelet)	–	–	5	–	5	–	–	–	–
cf. *Triticum dicoccum*	–	–	1	–	1	–	–	–	–
Triticum aestivum/durum	24	–	211	1	236	874	1738	24	2636
Triticum sp.	–	2	26	–	28	11	–	–	11
Triticum sp. (rachis)	–	–	3	–	3	-	–	–	–
Triticum sp. (rachilla)	–	–	1	–	1	–	–	–	–
Lathyrus sativus/cicera	–	–	–	–	–	4	2	–	6
Pisum sativum	–	-	-	-	–	5	23	–	28
cf. *Pisum sativum*	–	–	–	–	–	2	–	–	2
Cereal indet. frag	–	41	–	–	41	–	–	–	–
Vicia / Lathyrus	–	–	–	–	–	2(2)	–	–	2
Vicia faba	–	–	–	–	–	46	–	–	46
Fabaceae	–	–	–	–	–	1	–	–	1
Cultivated plants: TOTAL	55	91	2680	1	2827	2005	5664	55	7724
Olea europaea	–	–	–	–	–	23	–	–	23
Olea europaea frag	7	–	–	–	7	14+2(2)	–	–	16
Pinus pinea	18	–	–	–	18	–	–	–	–
Pinus sp. bractea	523(1)	–	–	–	523	376(1)+39(2)	–	–	415
Pinus sp. shell	49(1)	–	–	–	49	39(1)	–	–	39
Quercus sp.	1(2)	–	–	–	1	4	–	1	5
Quercus sp. cotyledons	5	–	–	–	5	–	–	9	9
Quercus sp. frag	–	–	–	–	–	7	8	65	80
Quercus sp. pericarp	–	–	–	–	–	–	9	>1(3)	10
Quercus sp. base	–	–	–	–	–	–	10	7	17
Wild plants: TOTAL	603	–	–	–	603	504	27	83	614
Sickle element		Nerja, Tesoro							
Use wear lihic industries(c)		Cereal harvesting: 18.2% Cereal harvesting ground level/near the ground: 1.8%							

Elaborated from (a) Hopf and Pellicer 1970: silo of 30 l, 340 g, (b) Peña-Chocarro et al. 2015, (c) Gibaja et al. 2017. Sequence as Simón-Vallejo 2003. (1)Badal 1990, (2)Aura-Tortosa et al. 2005, (3)Pellicer Catalán and Acosta Martínez 1997. Several thousand fragments have not been computed

(Fig2.4). At latter site, has documented the remains of the threshing as *"spikelet forks and rachises*" (Peña-Chocarro et al. 2015: 41).

Among the legumes, three species have been identified at Nerja: pea (*Pisum sativum*), broad bean (*Vicia faba),* and grass/red pea (*Lathyrus sativus/cicera*). No evidence of pulses has been found at the other sites. To date, lentils have not been documented in the archaeobotanical record of the Málaga coast, nor have flax (*Linum usitatissimum*) or poppy (*Papaver somniferum*), both of which are known from other Neolithic sites in Andalusia (Rovira 2007; Peña-Chocarro et al. 2015, 2018). Some studies on lithic industries also provide indirect information on the management of agricultural products (see Sect. 4.4.)

Human record

In Nerja, a total of 67 individuals have been identified (see Table 16, with references). From the Epipaleolithic period, one adult individual (41–59 years), one adult female (21–40 years), one infant, and one foetus were determined. In the Early Neolithic phase, five adults aged 41–59 years (two males, one female, and two undetermined individuals), three adults aged 21–40 years, one juvenile, one infant, and two foetuses were documented. For the Middle Neolithic, one senile individual (> 60 years), six adults aged 21–40 years, seven juveniles, ten infants, and one foetus was recorded. In the Late Neolithic stage, one adult aged 41–59 years, three individuals aged 21–40 years (one male and two females), an individual aged 13- 20 years and four infants were identified. Finally, for the Chalcolithic period, one adult aged 41–59 years, six individuals aged 21–40 years (two females), three juveniles, and seven infants were documented (Table 16), (Fig. 10).

Discussion

Data supporting archaeological research on this subject derive both from our own analyses and from previously published studies. These data encompass multiple sources, including carpology, archaeometry, material culture, and technocultural elements such as ceramics, lithic industries, and ornaments, as well as functional analysis. This combination reflects the diversity of methodologies employed and helps to contextualise some of the limitations observed in certain proxies.

Table 16 Anthropological remains documented in the Epipalaeolithic and Neolithic of Nerja

MNI /Age (1)	Epip	Early Neolithic	Middle Neolithic	Late Neolithic	Chalcolithic
Foetus	1	2*	1	–	–
0–12 years	1	1	10	4	7
13–20 years	–	1	7	1	3
21–40 years	1 (W)	3	6	3 (2W, 1 M)	6 (1W, 1 M, 4?)
41–59 years	1	5 (2 M, 1W, 2?)	–	1	1
> 60 years	–	–	1	–	–
MNI = 67	4	12	25	9	17
NR/Age/Period	Epip	Early Neolithic	Middle Neolithic	Late Neolithic	Chalcolithic
Years	3000	800	900	900	900
NMI	4	12	25	9	17
Years/NMI	750	~ 67	36	100	~ 53
Nerja/Room/Levels	Epip	Early Neolithic	Middle Neolithic	Late Neolithic	Chalcolithic
Mina(3)	–	NR = 115			–
Mina/Jordá-7,5 and 4(2)	–	2	–	–	–
Mina/80B/3, 8–9-10(4)	–	2	13	–	4
Mina/80A/(4)	–	–	3	–	–
Vestíbulo (5)	2	8 (3*)	–	–	–
Torca/82/4–5, 8(4)	–	–	11	–	8
Mina/65–6/IV(6)	XX (> 1)	–	–	–	–
Mina/67		–	-	–	3
NR = 57 + 115 = 172	3	12	27	–	15

Data from (1) Pellicer Catalán and Acosta Martínez 1997, Simón-Vallejo et al. 2003, (2) Salazar et al. 2017; (3) Ribs from a cut adjacent to another probed by M. Pellicer, so we cannot rule out that they correspond to one of the individuals computed, (4) Pérez Ripoll et al. 1986: 448, (5) Morales-Muñiz and Martín 1995, Epip. (Epipalaeolithic), (*) archaeological excavations carried out in 1965/1966. This paper

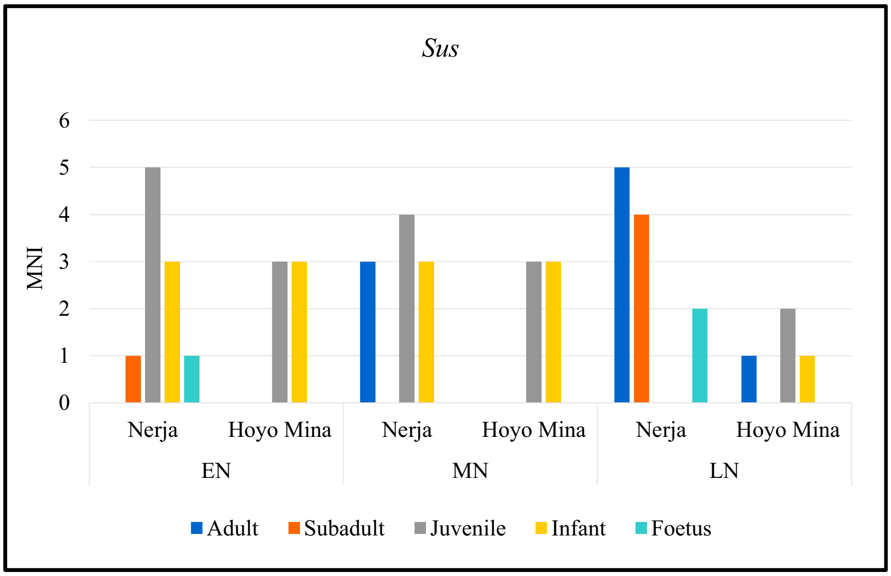


Fig. 5 Unpublished data from Nerja and Hoyo de la Mina (EN, MN, LN). Reinterpretation of data from Nerja (MN, LN) (Morales and Martín 1995). Age at death/slaughter. MNI (minimum number of individuals), EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic)

Palaeoenvironment

The recent palynological studies from Padul Lake (Granada) have provided new data on regional palaeovegetation over the past 200 ka in southern Iberia (Camuera et al. 2018, 2019, 2021, 2022; Ramos-Román et al. 2018a-b). This record, near the Málaga coast and 75 km north of Nerja, documents the high-resolution palaeoenvironmental and palaeoclimatic conditions throughout the Holocene (Fig. 2) (Ramos-Román et al. 2018a-b).

According to long-term climatic oscillations recorded in the Padul pollen sequence, Mediterranean forest cover remained above 50%, reaching up to 75% during the Early and Middle Holocene. However, exceptions occurred during specific arid and cold phases at ~ 10–9.5, 7.5, 6.1, and 5.4 cal ka BP (Fig2.1). A quantitative reconstruction of mean annual precipitation, using transfer function methods, suggests an average of ~ 550 mm/year between 8 and 4 cal ka BP—approximately 100–150 mm/year higher than present-day conditions. Currently, the mean precipitation in Padul (2001–2024) is ~ 426 mm/year (*Red de Información Agroclimática de Andalucía*) (Fig2.1). This suggests that precipitation values during the middle Holocene in the southern Iberian Peninsula were around 20–25% higher than present-day averages (Camuera et al. 2022). For the Málaga region this would imply a shift from the nowadays values of ~ 485 mm/year to some > 650 mm/year.

The beginning of the Neolithic in the region appears to coincide with this arid event at

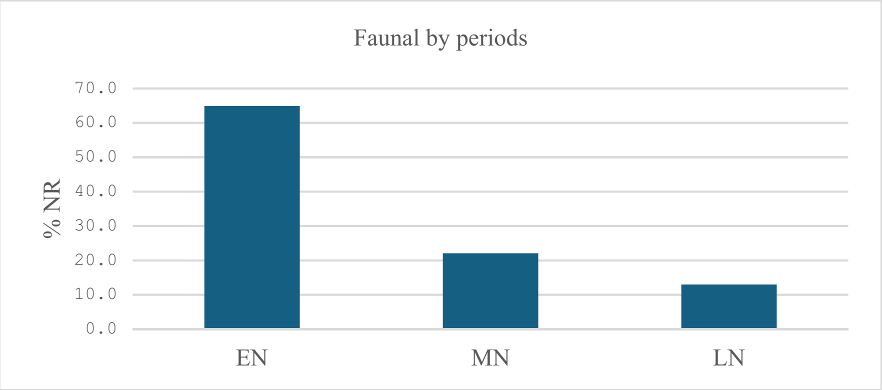


Fig. 6 Evolution of the presence of remains (percentage) during the Neolithic: EN (Early Neolithic), MN (Middle Neolithic), LN (LateNeolithic). % NR by periods (percentage of the number of total remains [NR] per period), *(Without Molluscs)

7.4 ± 0.2 cal ka BP (Cortés-Sánchez et al. 2012). This episode could be associated with the establishment of the present thermohaline circulation over the Western Mediterranean (Jiménez-Espejo et al. 2008) and the summer insolation decrease in the Northern Hemisphere (Laskar et al. 2004; Kaufman et al. 2020) among others likely mechanisms, such as changes in the North Atlantic subtropical gyre position (Pinho et al. 2025). Recent studies recognize intense arid episodes around 7.4 ± 0.2 cal ka BP on the Western Mediterranean margins, as in Morocco (Depreux et al. 2022), and in marine records of pollen in the Alboran Sea (Fletcher et al. 2013), which could have had global impacts (Hou et al. 2023). In parallel, in other North Africans region by 7.3 ka, northeast African summer rain began to retreat southward and hunter-gatherer groups began to leave areas far from permanent water availability (Kuper et al. 2006, Traut et al. 2018). Two additional arid periods (i.e., at 6.1 and 5.4 cal ka BP) also occurred during the Neolithic in the studied region (Fig. 2.1). The contraction of the Mediterranean forest during these periods was also interpreted as being caused by these alternating cold and arid climatic conditions (Ramos-Román et al. 2018b). However, our pollen data did not reveal a significant increase of arid-adapted taxa (i.e., xerophyte values always below 4%), and the Padul pollen-based quantitative reconstruction did not show marked precipitation declines during these periods (Camuera et al. 2022) (Fig. 2.1). In addition, the reduction of the Mediterranean forest at ~ 7.5, 6.1, and 5.4 cal ka BP are coeval with rising percentages of Poaceae and hygrophytes (i.e., the sum of *Typha* sp. and Cyperaceae), the latter suggesting increasing lake levels at Padul. Also, the decline of deciduous oak (*Quercus* sp.) and the increase of the lake level between ~ 7.6 and 4.7 cal ka BP could reflect a reduction in the seasonality, with a decrease in summer insolation that favored less evaporation and an increase in lake level (Ramos-Román et al. 2018b). It has been estimated that around 5.4–5.3 cal ka BP the Mediterranean climate became established in Málaga region (Jalut et al. 2000; Walczak et al. 2015) when a major decline occurs in the percentages of *Quercus* sp. pollen in Southern Iberian records that might reflect burning during the Neolithic (Carrión et al. 2024). The major change in the precipitation regime in South Iberia margin took place ~ 4.5 cal ka BP during the Copper-Bronze Age transition (Català et al. 2019; Jiménez-Espejo et al. 2024). This event signals the moment when the current climatic dynamics became established, with a greater influence of the North Atlantic Oscillation on the Iberian climate and smaller-scale wet-dry cyclicities (~ 1.4 ka), compared to previous cycles (~ 2.1 ka) of the early and middle Holocene (Ramos-Román et al. 2018b). In southwestern Portugal, the increase in aridity documented between 7.8 and 7.3 ka cal BP (Davis and Detry 2013, Mateus and Queirós 1997, Fletcher et al. 2007) suggests that these climatic shifts may have acted as a catalytic factor in the cultural transformations of Mesolithic communities. Within a context of demographic–ecological imbalance, such environmental pressures could have accelerated the onset of neolithisation processes in the region (Soares 2020).

The pollen record from Bajondillo depicts a landscape during the Epipalaeolithic (Bj/3, ^{14}C of the second half of the 8th millennium cal BP) dominated by significant arboreal vegetation and a dense forest landscape primarily composed of oak species under humid climatic conditions (Fig. 2.3, López-Sáez et al. 2007, Cortés-Sánchez et al. 2008). Evergreen and deciduous oak forests would be the dominant vegetation, with the former thriving in more xeric and sunny areas and more edaphically restrictive environments, whereas the latter would dominate the upper vegetation belts or even the moist valleys facing northwards. The coastal location of Bajondillo allowed for the presence of pine forests and a rich xerothermophilous maquis without any indication of agricultural or livestock activities. From Bj/2 onwards, significant deforestation can be observed, limiting to pockets deciduous and evergreen oak formations, as well as pine forests. A significant xerothermophilous maquis, characterizing the nowadays thermomediterranean vegetation of this area, and the development of nitrophilous grasslands fostered by an anthropisation linked to agriculture and livestock practices can also be observed during the Early Neolithic.

Neolithic communities inhabiting Nerja and Hoyo de la Mina intensively exploited local wild olive tree formations. The pollen records from eastern Andalusia record high frequencies of *Olea europaea* var. *sylvestris* since the end of the last glacial cycle but, in particular, since the beginning of the Holocene, coinciding with the early-mid Holocene humid phase (Fig. 2) (Langgut et al. 2019). Wild olive became the most characteristic plant formation of the Málaga coastal area, as reported by these records (Yll et al. 1995, 1996, 2003; Pantaleón-Cano et al. 1999, 2003; Pérez-Obiol et al. 2011). Anthracological data are consistent with the pollen records which not only attest to its presence but also an intensive exploitation in the Mesomediterranean stage from the Middle Neolithic onwards, in both Andalusia and the southeast of the Iberian Peninsula (Rodríguez-Ariza 1996; Rodríguez-Ariza and Montes 2005; Carrión-Marco et al. 2010; Uzquiano et al. 2021). At Hoyo de la Mina, the wild olive is already the most exploited taxon at the beginning of this cultural phase, its use being almost monopolistic in level 3 (Table 14), during the Early Neolithic. These differences are most likely related to the economic practices and logistical mobility associated with the exploitation of the territory around Hoyo de la Mina.

Another noteworthy aspect of these pollen records is the presence of diverse scrub formations, bioindicators of open landscapes and dry conditions, whose values increased throughout the Neolithic period. If one considers each taxon in isolation, their values at Hoyo de la Mina are low; however, when combined, they present a greater floristic variety than the tree stratum.

Chronology and settlement pattern of the Neolithic

Chronological data derived from short-lived taxa associated with agriculture and livestock farming indicate that the food production system was established between the mid-7th and late 7th millennium cal BP (Fig. 1), (Table 1), (Fig. S1).

The characteristics of the Neolithic in the region allow for the delimitation of a core area that developed contemporaneously with the expansion of Cardial ceramics in the Iberian Levant (Pellicer Catalán and Acosta Martínez 1997; Cortés-Sánchez et al. 2012; Martín-Socas et al. 2018; García Borja et al. 2014).

Based on the available data, the model of Neolithic implantation on the Málaga coast may be interpreted as a phenomenon of “coexistence” that was conducive to the absorption of Neolithic innovations (which would explain the speed with which these economies spread throughout southern Iberia). Specifically, the data from Nerja and Bajondillo point to the persistence of hunter-gatherer populations on the coastal strip at pericontemporaneous times to the arrival of the Neolithic even though on both sites erosive processes dismantled the deposits corresponding to c. 8–7.6 cal ka BP (see Cortés-Sánchez et al. 2012 with references).

Although early genomic studies initially suggested an absence of genetic contribution from local hunter-gatherers to early Neolithic populations, more recent data indicate: (a) the survival of two Late Pleistocene lineages in Holocene western Europe, particularly in the Iberian Peninsula; (b) interbreeding between early farmers in southern Iberia and local Mesolithic populations (Villalba-Mouco 2019, Olalde et al. 2019, Faustino Carvalho et al. 2023); and (c) a genomic transformation resulting from admixture between Mesolithic hunter-gatherers and Neolithic farmers of Western Anatolian or Aegean ancestry (Parasayan et al. 2024 with references). This phenomenon, which took place during the Middle Neolithic, is traceable both in Iberia and other European regions and defines a hodgepodge of migrant and autochthonous populations (Lipson et al. 2017; Martiniano et al. 2017; Olalde et al. 2019). From this standpoint, the marked signal of hunter-gatherer ancestry observed in other parts of Europe during the Middle Neolithic has been explained as a result of sustained gene flow after the initial contact between hunter-gatherers and farmers, suggesting that this type of genetic ancestry was conserved in different regions (Lipson et al. 2017; Villalba-Mouco et al. 2019). Long-distance networks, in this case with North Africa, could also be deduced, both from the presence of some characteristic cultural traces and, perhaps, from the genetic data of one individual in Nerja (see Cortés-Sánchez et al. 2012).

Livestock and hunting

At Nerja, from the Early Neolithic to the Late Neolithic there is a notable decrease both in the number of faunal remains (NR) (Fig. 6) and in the diversity of species consumed in all the taxonomic groups identified.

In all of the Neolithic sequences analysed, the importance of livestock seems clear, although there is a decline in the number of remains at Late Neolithic (Figs. 7–8). A similar trend is observed in wild herbivores and omnivores, whose presence is more significant at the beginning of the sequence and gradually decreases in the Late Neolithic. This pattern may be related to a more stable open-air

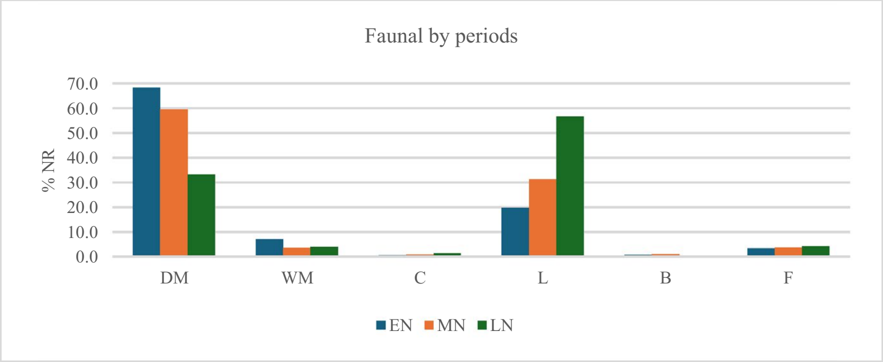


Fig. 7 Evolution of the presence of the different groups during the Neolithic (in percentage). DM (Domestic mammals), WM (Wild mammals), C (Carnivores), L (Lagomorphs), B (Birds), F (Fishes), EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic), NR (number of total remains)

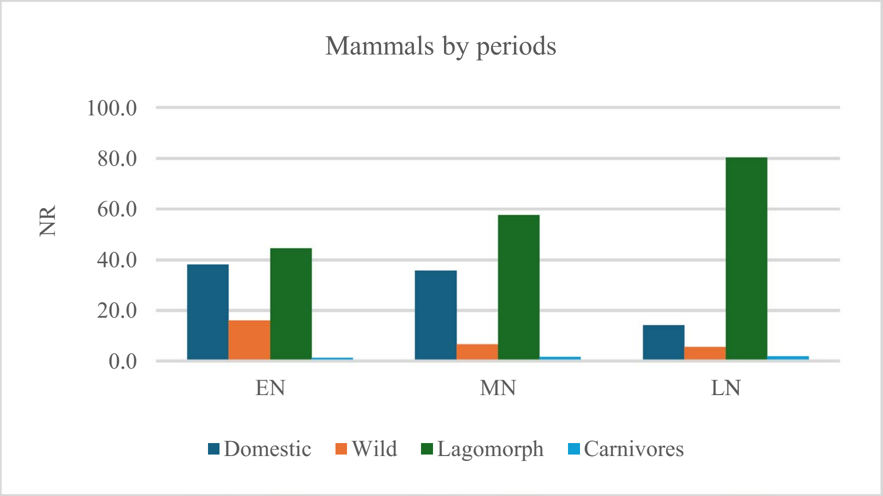


Fig. 8 Change in the representation of different groups (in percentages) by period. EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic), NR (number of total remains)

settlement and a more restricted use of the caves as sheepfolds and/or burial sites (Table 2).

Only small carnivores are represented, remains scarce throughout the sequence without significant variation. The only animal species following a distinct diachronic pattern is the rabbit, which was initially abundant and increased in number throughout the sequence. It should be considered that the rabbit bone material basically belongs to adult individuals and there are numerous traces of fire and cuts. The observed fracture pattern can only be attributed to human activity. Furthermore, anatomically connected juvenile remains have been documented within the burrow themselves.

The impoverishment in NR and species is also seen in the birds and with data available only for Nerja, a group that consistently makes only marginal contributions (Fig. 7). The number of species (and remains) is reduced from the Early Neolithic to the Late Neolithic, as can be seen in the results provided.

In the case of fish (Fig. 7), their presence is proportionally maintained throughout the sequence, although with at low values and a significant loss of species diversity. In the Early Neolithic, fish account for 80.5% of the total of fish (24 taxa, 232 remains), in the Middle Neolithic the 10,1% of the total (6 taxa, 29 remains), and Late Neolithic the 9.4% (8 taxa, 27 remains).

The trend continues for molluscs (Fig. 9). Thus, in Nerja, of the 12,316 individuals (MNI) counted, 6367 were identified in the Early Neolithic, 3859 in the Middle Neolithic and 2090 in the Late Neolithic (Table 10). These data can, so more extent, be extrapolated to a greater or lesser extent to the other sites (Table 11). Although the number of molluscs identified is not as high as in Nerja, the total for each period of the individuals identified in these sites clearly shows this trend (Fig. 6), (Table 12). The data from Nerja indicate a gradual shift in site functionality and the exploitation of marine resources.

During the Neolithic, the analysed sites indicate that meat consumption primarily derived from livestock, with hunting playing a secondary role. Husbandry practices focused on the exploitation of caprines, with a lower presence of cattle and pigs.

Additionally, rabbits were abundant, along with other wild species such as deer, wild goats, seals, and small carnivores. Since most of the bone material corresponds to adult individuals, it is unlikely that these were intrusive animals. The fractures observed in rabbit bones, along with fire marks, indicate human intervention.

The presence of livestock is indirectly reflected in the pollen column from Bajondillo (Fig. 2.4) through the increased presence of anthropozoogenic taxa and coprophilous fungi (i.e. *Chaetomium* and *Coniochaeta)* (López-Sáez et al. 2007). *Chaetomium* also serves as an indicator and its frequently recorded in burned wood horizons.

Regarding the Neolithic faunal spectrum and husbandry practices, in the Early Neolithic of Nerja, wild fauna remained an important food source, but the first domestic animals, primarily caprines, began to appear. These later become the basis of food consumption, although rabbits and wild goats continued to be significantly to the diet (Table 3). The presence of sheep is documented in Early Neolithic levels (the earliest direct date, 7430–7172 cal BP, Aura-Tortosa et al. 2005, (Table S1). Additionally, the presence of monk seals indicates an occasional utilization of marine resources during this period (Fig. 3.3–3.4).

At Hoyo de la Mina, a similar pattern is observed, with caprine husbandry dominating, while bovids and suids are less prevalent. In the case of suids, the limited material—mainly from infant and juvenile animals—makes it difficult to distinguish between domesticated pigs and wild boars. Rabbits remain a significant resource, and their bones frequently show cut marks and fire damage.

Age distribution analysis of caprine remains, based on dental wear and epiphyseal fusion, indicates the presence of all age cohorts, with a predominance of infantile and juvenile individuals over subadults and adults. This suggests a management strategy focused on herd replacement and control, particularly in the case of sheep and goats. At Hoyo de la Mina, during the Late Neolithic, there is evidence of a shift in mortality patterns towards a higher incidence of adult and subadult deaths or sacrifices, which may reflect an intensified exploitation of secondary products (see Fig. 3).

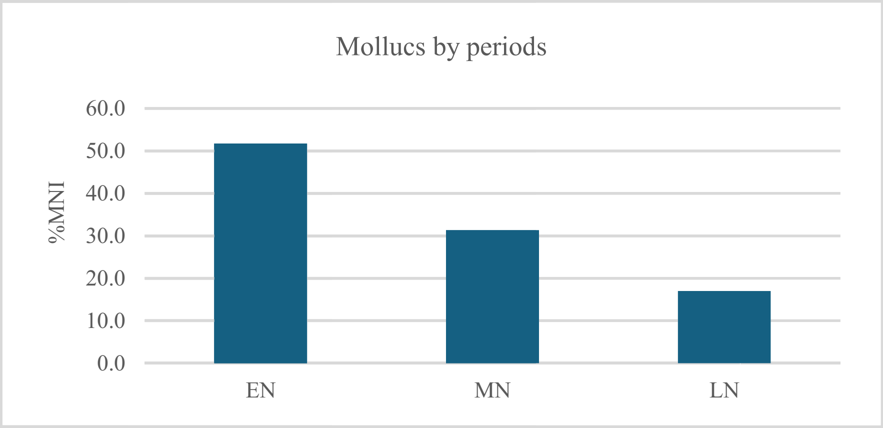
At Neolithic coastal sites in Málaga, ovicaprines were the primary source of animal protein. Their prevalence increased over time, although rabbit remains were more abundant during certain phases. The age-at-slaughter patterns of ovicaprines suggest greater meat utilization during the Early Neolithic, similar to trends observed in other European regions (Serjeantson 2011). In the Late Neolithic there was a preferential slaughter of adult animals (see Fig. 3), which could indicate a greater exploitation of secondary products, as suggested by a recent study on southern Iberia (Anaya et al. 2024). Lastly, regarding the presence of sheep and goats in herd composition, there is no clear predominance of either species throughout the analysed sequence.

For bovids, the slaughter of young individuals in the Early Neolithic indicates a focus on meat production. In contrast, the Middle and Late Neolithic saw an increase in the slaughter of adults and subadults, suggesting secondary uses such as traction and load bearing (Fig. 4).

A similar pattern is observed in suids: during the Early Neolithic, infant and juvenile individuals were slaughtered, likely for rapid food production. In the Middle Neolithic, this trend continued, though some adults were kept for herd replenishment. By the Late Neolithic, suids were increasingly kept until adulthood or subadulthood, maximizing meat yield (see Fig. 5). Consistent with these trends (see Table 6), the contribution of marine mammals decreased significantly (2.1% vs. 0.2%), as did hunting activity, reflected in a decline in rabbit remains (79.1% vs. 63.2%). However, this reduction is not necessarily due to a lower presence of carnivores (0.7% to 1.19% [wolf, lynx, wildcat and fox], (Table 6), suggesting that changes in subsistence strategies were the primary factor.

A clear differentiation in subsistence strategies is observed in the archaeological record (Table 6). The Epipalaeolithic/Mesolithic economy was based on hunting wild ungulates and rabbits, while the Early Neolithic saw the introduction of domestic species such as sheep and goats, signalling a shift toward husbandry. An analysis of the data on domestic

Fig. 9 Percentage of the number of individuals during the Neolithic at Nerja. MNI (minimum number of individuals), EN (Early Neolithic), MN (Middle Neolithic), LN (Late Neolithic)



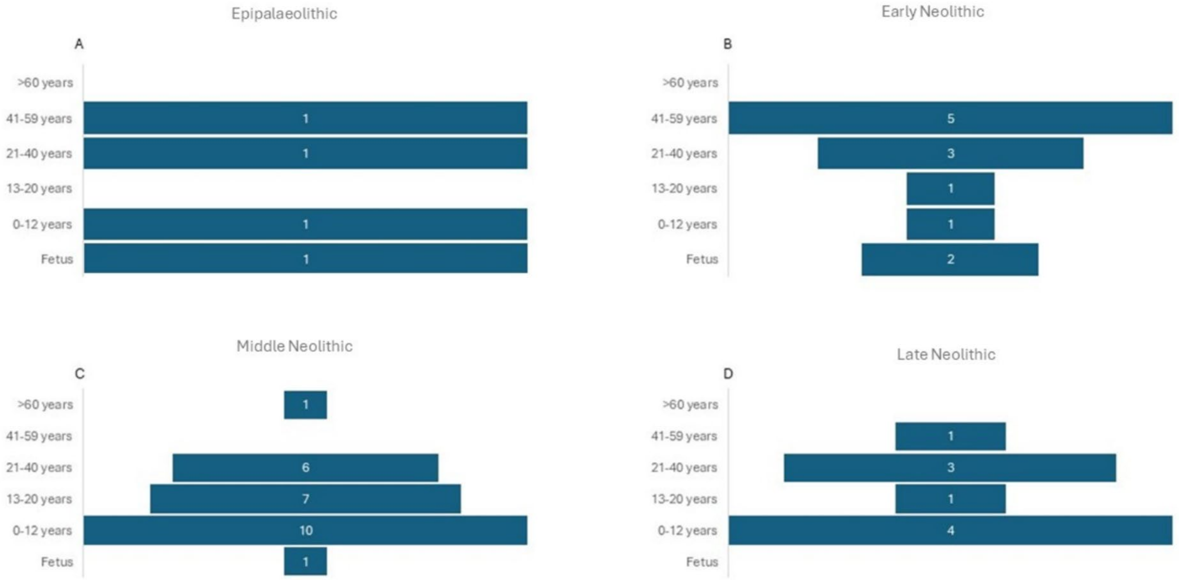


Fig. 10 Nerja human record. Bar diagrams showing the frequency of ages in absolute values of the individuals identified for the Epipalaeolithic, Early Neolithic (EN), Middle Neolithic (MN) and Late Neolithic (LN)

versus wild taxa (with lagomorphs and carnivores considered separately from the latter) reveals an increase in domestic species at the expense of wild taxa throughout the different stages of the Neolithic (Fig. 8).

Even in the Neolithic, wild species—especially wild goats and rabbits—remained part of the diet, but their relative abundance declined as domestic taxa increased. Ovicaprines became the dominant livestock, likely due to the environmental and topographic characteristics of this coastal area. However, domestic pigs and cattle were also present.

Furthermore, the reproductive cycles of the main domestic species were closely tied to seasonal changes. Sheep and goats typically enter oestrus during decreasing daylight hours in autumn and winter, with oestrous cycles occurring approximately every 17 ± 3 days in sheep and every 21 ± 3 days in goats. Most births took place between March and August, coinciding with favorable environmental conditions for the survival of newborns.

Data from other Iberian Neolithic sites, such as Toro (Sierra et al. 2024), suggest that herders may have extended the birthing season to different times of the year, indicating a level of herd management. However, in the absence of isotopic studies from Nerja, it is difficult to determine whether the same strategy was applied there.

The available data suggest a slaughter pattern focused on juveniles (Fig. 3), which aligns with an economy based on meat production. For domestic cattle, it is worth noting that even in non-industrial modern livestock systems, births tend to coincide with those of their wild ancestors, occurring mainly in spring and early summer.

If we apply the standard palaeontological assumption that the most frequently documented specimens represent the most common individuals in the population, the presence of foetal remains (sheep/goat, cattle, and pig, see Figs. 3–5) likely corresponds to this seasonal birthing period.

Agriculture

All human populations exhibit some type of subsistence seasonality. For hunter-gatherers, this is strongly influenced by the availability of resources and their accessibility throughout the year in the different subsistence territories. In the case of farmers, the "reduction" of mobility and the establishment of settlements for extended periods are primarily driven by the need to protect fields between sowing and harvesting.

The onset and progressive impact of agriculture on the Málaga coast are documented in the only available palaeoenvironmental record for the region: Bajondillo pollen sequence (López-Sáez et al. 2007) (see Fig2.4). In the Mesolithic stratum (Bj/3, ~ 8th millennium cal BP), arboreal vegetation accounts for approximately 50%, with evergreen oak (c. 20% in Bj/3) and deciduous trees (c. 15%) as dominant components, accompanied by a significant presence of pine forests. Mesophilic and riparian forest elements are more prominent than in previous strata, particularly alder, ash, elm, and hazel, likely reflecting more humid environmental conditions. Supporting this interpretation are the notably high percentages of *Lonicera* and *Hedera*.

Shrub vegetation (15–35% during the Mesolithic period) indicates a significant presence of a xerothermophilous vegetation, typical of the thermomediterranean bioclimatic floor (laburnum, mastic, wild olive, aladern, and myrtle). Herbaceous vegetation also suggests humid conditions. Thus, among the hygrophilous pastures, it is worth mentioning the abundance of reeds (Cyperaceae), which exceed 20%. The maximum percentages for distinct types of pteridophytes identified (Filicales monoletes and triletes) can be interpreted in the same way. The shrub vegetation represents almost 20% of the S.B.P., being especially noteworthy for the floristic list of species characteristic of a xerothermophilous maquis, such as laburnum (*Phillyrea*), mastic (*Pistacia*), aladern (*Rhamnus*), wild olive (*Olea*), and even myrtle (*Myrtus*). These species are the best indicators of typical thermomediterranean vegetation around the cave. There is no pollen evidence of anthropization of the environment in the deposits prior (Bj/4 and Bj/3, last hunters and gatherers) to the arrival of the Neolithic technological and economic innovations, which occur in Bj/2, anthropogenic pollen appears in this level, and in Bj/1, in percentages "*…. enough (> 3%) to allow us to admit its local cultivation in the vicinity of the cave*" (López-Sáez et al. 2007: 151).

During the Early and Middle Neolithic periods in Bajondillo (Bj/2-Bj/1), associated with cereals, palynomorphs indicative of nitrophilic ecology were identified in the pollen spectra of Bajondillo, suggesting anthropogenic environmental alteration (Cichorioideae, *Plantago lanceolata* type, Boraginaceae, Amaranthaceae, *Aster* type, Cardueae, *Convolvulus arvensis* type, and species of *Rumex*). Some of these taxa, such as *Plantago lanceolata* type*, Urtica dioica* type, and *Polygonum aviculare* type, are bioindicators of livestock management, suggesting the presence of domesticated animals in the cave. Additionally, fungal ascospores of types 55 and 112, non-pollen palynomorphs associated with coprophilic ecology, were identified at Bajondillo. These spores are commonly found in animal dung, further reinforcing evidence of domesticated animals in the cave.

Indirect bioindicators of environmental anthropization include non-pollen palynomorphs associated with erosive processes, such as *Glomus* cf. *fasciculatum*, as well as evidence of fire activity, possibly including too *Chaetomium* sp. and *Coniochaeta* cf. *ligniaria* (although the latter are also associated with faecal ecology). These findings suggest the anthropogenic use of fire for forest clearance, likely to create grazing areas or agricultural fields. In parallel with these processes—and as a consequence of them—successive degradative forest taxa appear in the region, including *Cistus ladanifer* and heath

(*Eric*a type), both of which are pyrophilous, as well as *Asphodelus albus*, a species of herbaceous biotype.

These data suggest that the establishment of agriculture and livestock, at Bajondillo, which took place during the second half of the 6th millennium cal BP (Bj/2), was the result of intentional burning activities to clear the dense Mediterranean forest that had established itself in the area.

Agricultural production appears to be fully developed with a significant variety of species (Cortés-Sánchez et al. 2010; Peña-Chocarro et al. 2013, 2015; Peña-Chocarro and Zapata 2010; Pérez Jordà et al. 2011; Zapata et al. 2004). Cereals provided carbohydrates, complemented by the proteins supplied by legumes. Barley is a crop particularly tolerant to a variety of environmental conditions, including aridity and salinity (Zohary et al. 2012), which may explain its success in many Mediterranean areas (Schirrmacher et al. 2024), whereas free-threshing wheats are more demanding in terms of environmental conditions. The three cereals are classified as winter crops, although evidence also suggests the presence of spring varieties. However, in the absence of arable weed flora, which has not been identified in any of the samples studied, exploring sowing seasons is challenging. Barley, wheat, and emmer were probably grown in the vicinity of the sites. The distribution of Neolithic sites along the Málaga coast coincides with the coastal aquifer discharge areas (Fig. 1). These aquifers must have provided water throughout the year and on an inter-annual basis, sustaining the development of a reliable agriculture. However, archaeobotanical data are insufficient to confirm whether crops were cultivated locally. Indeed, the absence of cereal chaff and weeds does not allow one to explore the issue. Some items of the material culture, in particular sickles (F ig. 2.3), support the idea of cereal harvesting, and functional studies on lithic industries from Bajondillo and Nerja reveal the use of sickles by the Early Neolithic (see Gibaja et al. 2010).

Roca Chica is one of the few sites in southern Iberia where evidence of threshing activities (spikelet forks and rachises) has been documented (Peña-Chocarro et al. 2015: 41), which points to the proximity of the site to the cereal harvesting area.

Recent δ^{13}C and δ^{15}N isotopic data (Table S2) of 20 cereal seeds from Roca Chica and Hostal Guadalupe, suggest that, rather than the cultivation of small orchards, more extensive agriculture was practiced, provided there was water availability and moderate manure use (Araus et al. 2024). Not surprisingly, the Torremolinos area has one of the most important aquifers of the Málaga coast (Fig. 1). As for livestock, up until today, sheep and goat feed on the remains of wheat and barley once harvested, a strategy known as the '*agostadero*'. This practice of fertilising fields with livestock manure ensures fertilisation for subsequent crops and could explain the isotopic values of the cereal seeds analysed at both sites.

Regarding legumes, it can be assumed that sowing of peas, broad beans, and grass peas in Mediterranean areas occurred in autumn, with harvests spanning a prolonged period depending on environmental conditions. These crops could be consumed either dried or immature (i.e., in a fresh state). In the latter case, pulses would have been sown during the early spring (Table 17).

Although focused on agriculture, Neolithic subsistence practices were complemented with the wild resources of the area, including shellfish, fish, wild plants and game (Cortés-Sánchez et al. 2012). A limited number of wild fruits were present in Nerja. The most abundant one was the acorn (*Quercus* sp.), from which cotyledons, shells, and cupules were retrieved. In addition, wild olives, pine shells, and bracts from unidentified taxa were also identified. Acorns and pine nuts, as items for long-term/delayed consumption, likely played important roles during winter or lean periods, while wild olives could also be a significant food source, possibly processed for storage (Table 17). These items are likely grossly underestimated in archaeological records, as evidenced by the remarkable and unpublished samples of these fruits in the Early Neolithic deposits at Nerja (e.g., NM-84 A/5 and NT-89/9–11) (Pellicer Catalán and Acosta Martínez 1997: 360).

Foodstuffs exhibited strong seasonality. During the cereal growing season (from late autumn to late spring/early summer, depending on the species and environmental conditions), availability decreased, and the resulting food shortages must have been overcome by resorting to alternative strategies including food storage, game hunting, fishing, wild plant gathering, etc. Cereal surpluses influenced the selection of alternative subsistence strategies depending on seasonal and annual conditions. In fact, the ceramic container from Roca Chica with many cereal grains, and the silo from Nerja, suggest that storage was an

Table 17 Neolithic of coast of Málaga. Products from hunter, gathering and livestock, and their seasonality

Activity/Species	Early Neolithic				Middle Neolithic		Seasonality	
Hunter and fishing	Nerja							
Alca torda	NM80A/7						Mediterranean coast: end October►end April	
Aria aalge	NM80B/9						End October ► end April	
Anas crecca						N80B/4	Winter?	
Branta bernicla	NV2						December-February	
Euthynnus alleteratus	NV2					NT82- 8	End summer-start autumn	
Sardine, anchovy and mackerel	NV2						End Spring -Summer	
Acipenser sturio	NV2						January. Star Spring	
Pollachius pollachius	NV2						Winter	
Gathering	H. Mina	Nerja	Bajondillo		H.Mina	Nerja	Seasonality	
Olea europaea / olive	HM/4	X			HM/3		October	
Quercus sp./ acorns		X					September ► November	
Pinus pinecone brac / pinion		NV2 NM-84 A/5 NT-89/9–11				NB/NC NM-84 A/5 NT-89/9–11	November ►April	
Pistacia	X						October ► December	
Agriculture	R. Chica	H. Guadalupe	Bajondillo	Nerja			Sowing ► Harvesting	
Triticum aestivum/durum			X	X			Cereal	Legumes
T. dicoccum	X			X			End Autumn/ beginning of winter ▼ ▼ Beginning of summer	Autumn ▼ ▼ ▼ ▼ ▼ Spring
Hordeum vulgare/nudum	X	X		X				
Lathyrus sativus/cicera				X				
Pisum sativum				X				
Vicia faba				X				
Livestock/ neonate foetus	Nerja					Nerja	Births (NV)	
Sheep/Goat						1/NT82-8	Autumn ▼ ▼ ▼ April	
Cow	1/NM80B-9					1/NT82-7		
Pig	1/NT82-6							

	Early Neolithic				Middle Neolithic				Late Neolithic			
Activity/Seasons	A	W	S	Su	A	W	S	Su	A	W	S	Su
Hunter of birds	1	2	1	–	–	1	–	–		1	–	–
Fishing		2	3	3	1	–	–	1	–	–	–	–
Agriculture/Crop harvesting	–	–	4	–	–	–	2	–	–	–	6	–
Collection of wild products	5	–	–	–	3	–	–	–	–	–	–	–
Livestock/ neonate foetus		–	2	–	–	–	2	–	–	–	2	–

Table 17 (continued)

	Early Neolithic				Middle Neolithic				Late Neolithic			
Activity/Seasons	A	W	S	Su	A	W	S	Su	A	W	S	Su
Total	6	4	10	3	4	1	4	1	–	1	8	–

A autumn, *W* winter, *S* spring, *Su* Summer

agricultural practice used to overcome seasonal lows in food availability.

At present, all the sites analysed in this paper fall within an agroclimatic zone that forces wheat and barley to be grown in winter under restricted rainfall conditions, which traditionally leads to low yields (León Llamazares 1989).

Wild plants, including many fruits and seeds for which no archaeobotanical evidence has yet been recovered, represented a valuable resource at all times, particularly during periods of scarcity. The scarce amount of evidence found at our sites focused on the most nutritious taxa (acorns, pine nuts, and wild olives), which not only provided immediate food but also allowed for easier storage. In addition to plant resources, Neolithic communities also took advantage of the many resources available in the coastal area (Cortés-Sánchez et al. 2012), which were essentially exploited between the end of autumn and the beginning of summer, following the seasonal calendar of foods (Table 17). During summer, we find no evidence of occupation, and this suggests that these groups, or at least part of them moved inland to areas of richer pastures at higher altitude. In any case, our research brings together all kinds of seasonality signatures from terrestrial biotopes (game, collection of wild fruits), the agricultural economy (crops), and husbandry plus fishing practices. The food of continental origin shows a clear trend outlined in the text (autumn-early summer). The presence of fish would point to one of these extremes of temporal range (late summer/early autumn) but does not contradict the signal of the remaining bioindicators.

If Neolithic communities did not practice agriculture when settling along the coastal strip, this would have broader implications. In those circumstances, when the groups moved, they would have had limited seeds to sow, meaning their economy would have relied primarily on livestock or a mixed strategy combining production with hunter-gatherer activities. Recovering the sowing-harvesting cycle would have required the existence of established exchange networks or alternatives strategies of livestock management or wild resource consumption that have not yet been documented in southern Iberia.

In summary, the available archaeobotanical record suggests the existence of a fully developed agriculture characterized by a significant variety of species, including cereals and legumes. This crop diversity indicates that farmers were not only aware of the different requirements of crops but also conscious of alternative crop management strategies. In addition, the plant food calendar of the coastal inhabitants of this region took advantage of this combination of crops and wild resources, which in both cases followed seasonal cycles. Cereals would have been available since late spring/early summer and later when stored; pulses were accessible from spring but could also be stocked for later consumption; and wild fruits were only consumed at specific times, mainly spring, summer, and early autumn. Within this context of seasonal exploitation of resources, marine resource gathering and hunting activities appear to have been closely linked to agricultural cycles, with particular emphasis on late autumn and early summer (Table 17). The seasonal agricultural cycle played a fundamental role in shaping the lives of Neolithic communities along the Málaga coast.

Harvesting of marine resources

Available data from the Málaga coast suggests that, during the first half of the Holocene, human populations relied on coastal resource exploitation as a key component of their economy (Aura-Tortosa et al. 2002; Ferrer et al. 2006; Ramos Fernández 2004; Cortés-Sánchez et al. 2012). Similar patterns have been documented for other Mediterranean regions, Epipalaeolithic-Mesolithic coastal sites along the Alboran Sea were likely occupied seasonally, primarily from autumn to spring. However, fishing activities may have extended beyond this period (Colonese et al. 2009).

During the Neolithic, marine and coastal ecosystem species are well represented in the archaeological record. As already shown (Table 12), (Fig. 9), the species identified correspond to those expected along the local coastline. This is evident if we analyse the autoecology of the molluscs and non-molluscs taxa that predominate in each of the sites. This pattern is particularly evident when analysing the ecological preferences of both. At Nerja, more than 40% of the identified species are associated with rocky coastal habitats, with limpets and clams comprising over 70% of the total individuals. On the contrary, in Hoyo de la Mina we found a high percentage of species from the muddy-sandy infralittoral (~60%) (mainly *Venerupis* and *Cerastoderma*). The autoecology of these species indicates that the collection area included sandy-muddy beaches near estuaries with abundant detritus and variable salinity (Gofas et al. 2011b). The presence of species from the nearby rocky coast can be explained by the site's proximity—Hoyo de la Mina is only about 700 m from Abrigo 6. At Bajondillo, more than 45% of the collected species were intended for consumption. These species are typically found on sandy beaches near rocky areas influenced by freshwater inputs (Table 13). At Abrigo 6, among the total number of species identified (Table 12), only six are edible (Table 13). The large number of Helicidae, specifically of the genera *Iberus* and *Otala* represented at Nerja (MNI = 222) and Hoyo de la Mina (MNI = 122), suggests that this is an intentional collection for consumption, only large adult specimens are represented (23.3 mm average diameter) which would indicate an increase in the diversification of these resources (Table 10, 0.11).

The relevance of the Neolithic fish from Nerja must be assessed in terms of their ability to shed light upon the consistency of the evidence within the long-term fishing sequence.

The fish assemblages from Nerja have been the subject of a number of studies that range from the Solutrean to the Chalcolithic period (Boessneck and Driesch 1980, Morales-Muñiz et al. 1994, 1995, 1998, Roselló-Izquierdo et al. 1995, 1999, Aura-Tortosa et al. 2001, 2002, Jordá Pardo et al. 2003, Morales-Muñiz and Roselló-Izquierdo 2008, 2016, Álvarez-Fernández et al. 2022). Although this long-term sequence exhibits discontinuities of up to 5000 years, the evidence suggests that fishing was consistently practiced at the site. Moreover, when the NISPs from the different analyses are pooled together, the nearly 11,000 identified remains reveal a clear trend of numbers rising from the Solutrean to the Magdalenian decreasing afterwards, gradually at first (i.e., during the Epipaleolithic/Mesolithic) and drastically later (Solutrean (NISP): 1,454 [13%], Magdalenian: 5,456 [50%], Epipaleolithic/Mesolithic: 3,645 [33%], Neolithic: 85 [0.5%] and Chalcolithic: 71 [0.6%]). From this perspective, the reported stability in Neolithic fish frequencies at Nerja appears to contrast with the overall trend observed at the site (Table 8).

The dominance of seabreams (Sparidae) has been a persistent feature at Nerja for over 20 millennia (Table. S3). We pattern is observed not only along the coast of Málaga and the Strait of Gibraltar area, but also in the central and eastern Mediterranean (Morales-Muñiz and Roselló-Izquirdo, 2008 with references). From this perspective, continuity rather than disruption characterizes fishing at Nerja during the transition from the Epipaleolithic/Mesolithic to the Neolithic. Most Neolithic fish assemblages at Nerja are consistent with earlier periods, being mostly composed of resident species with a pronounced Mediterranean affinity (Gil de Sola 1999, Cortés-Sánchez et al. 2012).

The only factor that disrupts this pattern of continuity at the onset of the Neolithic is the Epipaleolithic/Mesolithic fish assemblage from NV (Table S3). These remains are not only distinct from Early Neolithic samples but also from most other assemblages at Nerja, as they show an abundance of cold-water gadids, particularly Pollock (Pollachius pollachius) and Haddock (Melanogrammus aeglefinus) (Rodrigo García 1994; Aura-Tortosa et al. 2001, 2002; Jordá Pardo et al. 2003). The chronology of this assemblage coincides with the Younger Dryas cold event (c. 12.9–11.7 cal ka BP) and, due to the high presence of wrasses (Labridae), differs from the typical Mediterranean character of the Nerja fish collections. These NV assemblages suggest a shift towards fishing a more productive—though perhaps seasonally limited—resource (Gadidae). They may also indicate rougher sea conditions in the Alboran Sea at the time, as suggested by the abundance of Labridae, which are typically caught inshore under turbulent sea conditions (Rodrigo 1994, Aura-Tortosa et al. 2001, 2002; Jordá Pardo et al. 2003; Leach 2006).

The Epipaleolithic/Mesolithic fish assemblages from the other two areas of Nerja, however, are consistent with Early Neolithic assemblage presented in this paper (Table S3). For such reasons, one might tentatively assume that at Nerja, except for the Epipaleolithic/Mesolithic at NV, there existed continuity in the nature of the fishing prior to and after the onset of the Neolithic period as seems to have been the case on the northern Alboran coast. Lastly, notwithstanding retrieval biases, no hint of a fishing down the food web shift has been detected at Nerja during the transition into the Neolithic or on the long-term (Morales-Muñiz and Roselló-Izquierdo 2004).

Some tentative inferences can be made regarding the fishing tackle used to catch the fish species found in the Early Neolithic (EN) levels and the biotopes where these fish could have been obtained:

a) The presence of medium-sized mid-water fish, such as most Sparidae, suggests the use of conventional hooks (i.e., hook-and-line, fishing rods, etc.) and fishing from beaches or cliffs overlooking the sea.

b) The straight hooks (Aura-Tortosa et al. 2001, 2002) could be used for medium-sized, bottom-dwelling species such as wrasses and gurnards for which no evidence exists in the examined collections.

c) The presence of grey mullets and giltheads could be taken to indicate the use of fish leisters in calm, shallow waters (e.g., estuaries, river mouths).

d) These same species could also indicate fishing in very shallow waters (e.g., coastal lagoons) using various traps (e.g., palisades, baskets, cast nets).

Isotopic data obtained from the three human individuals -two from the Early Neolithic and one from the Middle Neolithic- indicate a diet based mainly on C3 plants and continental resources. However, the oldest individual (NM7) did provide a detectable signal of the consumption of marine resources, although it is not detected again in the most recent specimen, and the possibility that the early farmers interacted significantly with the later hunter-gatherers and could have adopted or shared some of their economic practices, i.e., marine exploitation (Salazar-García et al. 2017), is an issue already proposed by other authors (Cortés-Sánchez et al. 2012).

Additionally, isotopic analysis of some caprines indicates δ^{13}C values higher than those of a typical terrestrial environment of C3 plants (-17.7‰ during the Middle Neolithic, -17.6‰ and -15.9‰ during the recent stages of the Early Neolithic, and -11.4‰ during the middle stages of the Early Neolithic) (Salazar-García et al. 2017 with references therein). The Mediterranean coast, including Málaga, harbors a significant number of C4 plants such as Amaranthaceae, Juncaceae, Asteraceae, and grasses traditionally consumed by domestic livestock (Barroso et al. 2005; Santana et al. 2010; Pyankov et al. 2010; Taiz and Zeiger 2010). This could justify that variable C3-C4 signal throughout the year in some of the caprines from Nerja and inland areas. Similarly, isotopic analyses from hinterland of Toro Cave (< 30 km in a straight line to the coast) indicate a comparable pattern (Sierra et al. 2024). Thus, Neolithic human groups in the Alboran Sea region likely frequented areas with abundant C4 plants, which may have contributed significantly to livestock diets. Moreover, the marine influence on dune vegetation must be considered as a factor shaping local plant resources. Indeed, Zunzunegui et al. (2024) show how the different plant species of the dune ecosystem incorporate different strategies for the absorption of Nitrogen from seawater spray.

The diversified economic model, combining agricultural and hunter-gatherer activities, which includes important contributions molluscs and marine fish, deduced for the coast of Málaga is analogous to that established for other Iberian coastal areas (i.e. Faustino Carvalho 2008; Antolín and Saña 2022, etc.).

Human record

The human remains documented at archaeological sites along the Málaga coast offer valuable insights into the demographic patterns of Neolithic populations and offer clues about site usage. In addition to 177 skeletal remains recovered from different Neolithic levels in Nerja, a total of sixty-seven individuals have been identified (Table 16), 46 of whom date to the Neolithic period (García Sánchez and Jiménez Brobeil 1995; Pellicer Catalán and Acosta Martínez 1997). Human remains from the Epipalaeolithic-Mesolithic period are scarce, with a minimum of four individuals, all associated with shell middens. This contrasts with the Neolithic period, when cave sites were systematically used for burial, becoming a distinctive cultural practice. In fact, the systematic deposition of the deceased in caves—documented at 12 of the 13 analysed sites (Table 2)—represents a key innovation, likely tied to identity and symbolic appropriation of sites and territories.

At Nerja, demographic data (Table 16), (Fig. 10) suggest an increase in the individuals-to-year ratio during the Middle Neolithic (1 individual per 40 years) compared to the Early Neolithic (~ 1 per 72 years), followed by a significant decline during the Late Neolithic (~ 1 per 100 years). This trend may be linked to the widespread practice of polyphasic collective burials in caves and rock shelters (Table 2), located outside of the habitat zones. In Nerja, these burial sites have been less excavated than the external chambers where habitation was concentrated (Mina, Torca, and, more sporadically, Vestíbulo).

Notably, burials found within the habitat zone, whether in pits or protected by stone blocks, consistently lack associated grave goods. However, adjacent contexts contain abundant technological artifacts and evidence of consumption practices (Pellicer Catalán and Acosta Martínez 1997, Pellicer Catalán and Morales-Muñiz 1995). In strictly funerary areas (caves or shelters used exclusively for burial, or hidden recesses within inhabited caves), successive burials are accompanied by a selection of technological artifacts (ceramics, lithic tools), ornamental items, and subsistence-related remains, including domestic livestock, certain wild mammals, and a few marine shells (Tables 2, 13). Interestingly, birds and fish are absent, a pattern also observed at Tesoro, possibly reflecting a symbolic representation of the relative importance of different subsistence resources in these communities.

The mortality pattern indicates a high percentage of infant individuals (~ 40%), a parameter which remains stable from the Middle Neolithic to the Chalcolithic. This proportion, together with the distribution of the remaining cohorts, is compatible with a use of the cave by all members of a group between the Middle Neolithic and the Chalcolithic, whereas during the Early Neolithic, the high proportion of adults and low proportion of infants are surprising, although only two foetuses are currently documented. Population pyramids obtained (allowing us to approximate a static representation of the structure of the population at a given time) thus show an age distribution where mortality was higher in younger individuals (infant mortality is 44.4% of the total), mainly from the Middle Neolithic and the Chalcolithic onwards; all this trend may suggest that the entire group settled in the area. However, the fact that in the EN, percentage of infants is only 15.4% the disproportion may illustrate the population profile of the pioneer Neolithic groups in the southern Iberian Peninsula, an aspect that should be further investigated. In the case of a pioneer group, it can be speculated that it is mainly made up of adults, while the number of child individuals is initially lower. When the Neolithic production system was consolidated, these groups would grow significantly.

Determining the precise seasonality of deaths in Nerja remains challenging at this stage. Interestingly, modern demographic data show a higher mortality rate during winter. Between 1975 and 2015, winter deaths in the study area were nearly 24% higher than in other seasons, with peaks reaching 48.9% in 2005 (http://cort.as/sAE5). This trend is linked to seasonal increases in viral and bacterial diseases, such as pneumonia, which disproportionately affect vulnerable populations, particularly children.

Territorial occupation, site functionality, and seasonality

Ethnographic studies of present-day populations indicate that marine resources are typically exploited within a coastal strip of approximately 5 km, where marine resources are typically exploited within a coastal strip of approximately 5 km (Bigalke 1973; Erlandson 2001). A similar pattern can be identified on the Málaga coast during the Neolithic. However, this model does not apply to ornamental items, which were transported far inland through exchange networks that became more structured during the Middle to Late Neolithic and the Chalcolithic (see, e.g., Cortés-Sánchez 2023).

Our understanding of Mesolithic groups along the Iberian coast of the Alboran Sea remains incomplete, particularly for the period between 8000 and 7600 cal BP. The absence of evidence is determined by the erosive phases documented in key sequences such as that at Nerja (i.e., Aura-Tortosa et al. 2009). In contrast, data from Bajondillo suggest continuous occupation along the coast. However, the limited archaeological record does not allow for a detailed analysis of key aspects of the 400 years preceding the arrival of the Neolithic (see Cortés-Sánchez et al. 2012, 2020 with references).

During the Neolithic and until the final phases (Carinated Bowls phase), there is no evidence of permanent settlements in southern Iberia (García Borja et al. 2014). The same applies to the Málaga coast, where all occupations are documented in caves, as well as their sepulchral use (i.e., 12 out of the 13 analysed sites), a deeply rooted use which will last until the Bronze Age (3rd millennium BC, see Cortés-Sánchez et al. 2023 with references). Data from nearby coastal areas, such as the Atlantic strip of Cadiz, shows instead that, at least during the 4th millennium BC, open-air necropolis such as Campo de Hockey (Middle Neolithic) appear. The collection pattern of the *Phorcus lineatus* species in this site focuses on winter, although its collection is documented throughout the year in a more punctual manner (García-Escárzaga et al. 2024).

The presence of wild fruits and cultivated crops suggests that human occupation in the coastal area of Málaga occurred primarily between autumn and spring. Marine resources probably correspond to this period, when human populations would resort to livestock management, with hunting and gathering, with hunting, gathering, and aquatic resources serving as complementary strategies.

Functionality sets apart habitat from funerary sites (Table 2). Among the former, however, burials in secluded places are also found (e.g., Bajondillo, Hoyo de la Mina, and Nerja). Within the cavities used primarily as burial areas, we find anthropological remains associated with diverse types of grave goods, including complete and profusely decorated ceramics, with impressions and incisions, as well as polished and carved stone artifacts along with a remarkable set of ornaments made mainly from marine molluscs, alongside seeds and animal remains.

The dating of cultivated seeds (Table S1) falls between two arid periods of the Holocene, yet rather than being part of these dry phases, they correspond to a relatively favourable climatic interval around 7.5 cal ka BP. The choice of areas such as Torremolinos or Nerja, with their springs and well-drained soils, reflects the need to ensure successful crop cultivation.

Another indication of seasonality at Nerja is the presence of four species of wintering birds in the Early, Middle and Late Neolithic levels (*Anas crecca, Branta bernicla, Uria aalge,* and *Alca torda*), as well as sturgeons and possibly pollock as well during the Early Neolithic (see Table 7, 8 and below). The presence of six caprine, cattle and suid neonates/foetuses (Table 17) at Nerja could also suggest seasonality, albeit with more caution, as it coincides with the typical birth period of these animals, centred in early spring (Morales-Muñiz and Martín 1995).

Conclusions

Our analysis of the Neolithic period along the northern coast of the Alboran Sea does not definitively resolve several key aspects, including settlement model, as well as demographic, genetic, economic, and seasonal dynamics, which still require further investigation through new fieldwork and specific analyses. Nevertheless, the available data allow allow us to propose an initial coherent model, based on some economic practices, population and seasonality.

Regarding wood use, the variety of shrubs and bushes identified in Hoyo de la Mina, known for their high flammability, likely provided an essential source of firewood for domestic use during the Neolithic. This pattern is consistent with Mediterranean landscapes in prehistoric times, as confirmed by anthracological analyses conducted across the Iberian Peninsula.

The arrival of Neolithic innovations on the Málaga coast is documented in the middle of the 8th millennium cal BP, contemporaneous with other areas of the Iberian Mediterranean and probably associated with an arid pulse around 7.4 ± 0.2 ka cal BP. In the case of the study area, the main sites are located near areas associated with the discharge of the region's principal aquifers. These areas of occupation along the Malaga coast had been established, the territories and sites remained in use for most of the Neolithic period. These areas of occupation appear to have been maintained throughout much of the Neolithic period, a pattern that should be further tested in future research. The presence of coastal aquifers would have provided reliable water availability, supporting the development of agriculture in the region.

During the Neolithic, the human communities that frequented the Málaga coast developed a fully-fledged food-producing economy. The highly diversified cultivation of cereals and leguminous plants articulated the seasonality, between autumn (as revealed by some wild fruits) and spring-early summer for harvesting.

Additionally, during this period, the gathering of forestry and marine resources, along with hunting, played a fundamental role in subsistence, though to a lesser extent than in previous stages. These resources are taken from the Epipalaeolithic-Mesolithic tradition of the region. Similarly, domestic animals are present (5 species), with the control of sheep and goats being the main focus of meat production, while hunting, although important, is experiencing a clear decline compared to previous times. The reproductive cycles of livestock management are also linked to this seasonal pattern.

With the available data, it is very difficult to differentiate the degree of determinism exercised by the seasonal cycles in the organization of activities or the mobility of the communities. Establishing a fine definition will require further efforts, in the form of projects and studies on the subject and the area. Despite the limitations and the fact that only Nerja has a sufficiently diversified repertoire to address the subject, while the other of the sites provide more specific information, it can be argued that, during the Neolithic period, the economy in the coastal area of Málaga was mainly based on agriculture and livestock, in a time period between autumn and early summer (a period during which it was expected that the greatest part of the agricultural harvest). Hunting, fishing, shellfishing, and gathering wild plants, on the other hand, played a secondary and complementary role in supplying essential nutrients during this period.

The available data on seasonality suggest that Neolithic occupations were concentrated mainly between autumn and early spring. However, further research is needed to consider regional factors such as the presence of C4 plants, seasonal algal accumulations on beaches, and other ecological variables. Finally, based on mortality pattern, the human groups occupying Nerja included all age groups, with men, women, and a high number of children.This suggests that entire communities resided in or near the site during its periods of occupation, at least from the Middle Neolithic to the Chalcolithic.

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Data availability The unpublished data described correspond to archaeological materials deposited in the Museum of Málaga. These data are not in open access, as the museum does not have a database of these materials. However, all the materials are available for consultation and analysis in the repository of this institution.

Declarations

Conflict of interest The authors declare no competing interests. During the preparation of this work, the authors used https://www.deepl.com/write and ChatGPT to improve language and readability. Subsequently, they carefully reviewed and refined the content, assuming full responsibility for the final version of the publication.

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