Zooarchaeological evidence for resource intensification in Algarve, Southern Portugal

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Introduction

At least three dimensions of the later Paleolithic faunal record of the Mediterranean Basin indicate changes in human predator-prey interactions and, by extension, land use and the organization of human labor. The first of these dimensions concerns large game exploitation, not so much in the techniques of hunting as in the extent to which nutrition was squeezed from ungulate carcasses, specifically the addition of grease-rendering, a labor-intensive technique, to the long established practice of cold marrow extraction. The second dimension concerns changes in foragers' emphasis on certain classes of small game, and the third dimension is about differences in the resilience of small game populations to predator pressure. These shifts in human diet and predator-prey ecology do not occur everywhere or at all at once. The geography and chronology of their occurrence may relate to variation in demographic conditions, although competing explanations must also be explored.

The basic arguments developed here have been investigated most thoroughly in the northern and eastern Mediterranean Basin, where a great deal of zooarchaeologic and taphonomic information is available (e.g., Davis et al. 1994; Munro 2001; Stiner et al. 2000; Tchernov 1998). The Paleolithic of the Algarve region of southern Portugal, by contrast, has come under investigation only very recently (Bicho 1993, 1994, 2001; Stiner et al. 2003). The Algarve is ecologically distinctive on many counts, not least for its juxtaposition of rich Atlantic and Mediterranean marine communities and a declining terrestrial large mammal fauna after roughly 12,000 years ago (compare Antunes et al. 1989; Cardoso 1989, 1995; Davis 2002; Valente 2000) and well before the introduction of domestic livestock by Neolithic farmers (Arias 1997, 1999; Carvalho 2002; Davis 2002; Roche 1990). The Algarve's membership in the Mediterranean ecogeographic zone is obvious, in contrast to the Atlantic character of much of the rest of Portugal, and thus only Algarve is most suited for comparisons of local human dietary trends to those evidenced elsewhere on the Mediterranean Rim.

No comprehensive zooarchaeological review for Portugal will be attempted here. Rather, the focus is on new data and a few approaches that highlight both pan-Mediterranean affinities and anomalies peculiar to the Algarve. The observations are

based on recently excavated faunas from the Upper Paleolithic open site of Vale Boi (Bicho 2001) and a series of early Holocene shell middens located west of the modern city of Faro (Bicho et al. 2000; Stiner et al. 2003) (Figure 1). The faunal samples are limited as yet, but certain patterns are robust, making hypothesis refinement worthwhile. Specifically, the three zooarchaeological themes outlined above—briefly, grease-rendering, expanding dietary breadth, and differential prey population resilience under increased hunting pressure—are thought to be linked causally. They are developed here with attention to their theoretical underpinnings and whether they are supported across the Middle Paleolithic to Neolithic culture periods. All three phenomena may be expressions of resource intensification, potentially provoked by increasing in human population densities and the stress this places on food supplies. Southern Portugal presents a fascinating test case, with its extreme ecogeographic position and remoteness to the earliest centers of Middle-Upper Paleolithic and forager-farmer (Neolithic) cultural transition.

Grease rendering of bone

Two families of bone-processing techniques exist among foraging and other peoples for extracting nutrients from bone. Although both techniques emerged within the Paleolithic period, the first of these may have arisen in the time of the Australopithecines and is universal to the genus *Homo*. Here termed "cold" marrow extraction, it was the only technique in use for the bulk of prehistory and focuses almost exclusively on removing consolidated marrow from medullae (large central cavities) of major limb bones (Figure 2) and mandibles of large mammals, along with the brain. The procedure is purely mechanical and highly portable, requiring only a few simple, widely available tools. Cracking bones with the aid of stone hammers and anvils is remarkably efficient if compared to the energy and time that large-jawed carnivores must spend to open the same large bones (Stiner 1994:130-132). The procedure can be facilitated by heat but is easily accomplished without it. The peripheral elements of the body — legs and heads — are the main targets for cold marrow extraction. Paleolithic people rarely left good marrow untouched, and for this reason fragmented bone is characteristic of Paleolithic archaeofaunal assemblages.

The second family of bone processing techniques emerged during the Upper Paleolithic in some areas, but not in others. Carcass-processing routines became a good deal more complex, as heat-in-liquid rendering (*sensu* Binford 1978, 1993; Brink 1997; Lupo & Schmitt 1997; Delpech & Rigaud 1974; Wandsnider 1997) was added to the more basic method of cold marrow extraction. Often called "grease rendering" though a wider range of nutrients may be extracted this way, the technique is far more labor-intensive than cold processing methods. However, it allows humans

to squeeze more food out of any carcass they obtain. The advantages of the method are greatest where key resources are limited, whether due to conditions of high dispersion, unpredictable supplies, or constriction of hunting territories.

As implied by its name, heat is needed to mobilize the nutrients locked in small bone pores. First, large amounts of spongy bone tissues of vertebrae and softer limb ends are fragmented or pulverized (Figures 2 & 3), and then boiled in water by adding heated stones to the mixture. With heating, the fatty components float to the top of the mixture and form discrete, relatively pure layers of fat (and gelatin below) that can be skimmed off and stored. Heat-in-liquid techniques maximize both the protein and fat yields per carcass, well in excess of what is possible from cold extraction techniques alone (Binford 1978; Lupo & Schmitt 1997; Wandsnider 1997). The purified fatty components can be stored for months (Soffer 1989), and heat-rendered fats likely represent one of the earliest forms of food storage in the Upper Paleolithic, along with dried or smoked meat.

A grease-rendering operation may use containers composed of simple sheets of animal hide, sealed baskets or wooden vessels. Of course the organic components of grease rendering toolkits are seldom if ever preserved, but the *combination* of other debris is characteristic: (1) exceptional comminution of (fresh) bones; (2) large quantities of heat-fractured and heat-scarred stone, and (3) large, pitted stone anvils. Subterranean pits may also be found, but are less likely to be preserved. Grease rendering greatly affects the appearance and identifiability of skeletal elements in faunal assemblages, mainly by reducing spongy bone ends at a greater rate than is typical of cold marrow extraction (Binford 1978; Brink 1997; Delpech & Rigaud 1974). Thus, while the co-occurrence of the above phenomena in a site can indicate that bone grease rendering occurred, other potential explanations for the patterns of bone fragmentation, and especially the preferential destruction of spongy bone parts, must be excluded (*sensu* Binford & Bertram 1977; Brain 1981; Lyman 1984; Marean & Spencer 1991). Of particular concern is the possibility of density-dependent loss of spongy bone parts arising from non-human mechanical factors. This question normally is evaluated with the help of independent structural density standards for skeletal parts of the same or similar prey species, derived by photon densitometry technique (for a full review, see Lyman 1994; also Rogers 2000; Stiner 2002). If independence between prey body part representation in an archaeofauna and inherent bone density distributions can be demonstrated for the assemblage, and evidence of carnivore activity is minimal or absent, then the extreme patterns of comminution cannot be explained simply as post-cultural damage. Under these conditions, one may also observe good retention of fragile pore structures on fracture planes. Other sources of confusion for research on grease-

rendering are situations in which stone boiling and/or milling stones were likely applied to plant foods and/or stone-heated sweat lodges (saunas) were used.

No convincing cases of heat-in-liquid techniques has been reported for the Mousterian on the Mediterranean Rim or elsewhere in Eurasia. This is not surprising in light of other zooarchaeological evidence for narrow diets rich in highly ranked prey during the Middle Paleolithic period and low human population densities overall (Stiner et al. 2000, and below). Cold marrow extraction was pushed to its full potential in most Middle Paleolithic cases, but no further. More intensive processing of ungulate carcasses is apparent, however, in the Magdalenian of France and Germany (Audouze 1987; Audouze & Enloe 1991; David & Enloe 1993; Delpech & Rigaud 1974; Weniger 1987), and possibly as early as the Gravettian in Central Europe (see Svoboda et al. 1996 on Moravia). Similar evidence has come to light at Vale Boi in the Algarve, beginning in the Gravettian and continuing through the Magdalenian.

Vale Boi

The recently discovered site of Vale Boi today lies less than 2.5 km inland, just east of the town of Budens (Bicho 2001). The site presently is unique in the Algarve region in that it contains rich deposits of Gravettian, Solutrean, and early Magdalenian material, possibly underlain by late Mousterian deposits separated from the Upper Paleolithic by a depositional hiatus. Three excavation seasons at Vale Boi have essentially doubled the number of known Upper Paleolithic bone points in all of Portugal. Several ungulate species occur in the faunal assemblages (Table 1). Red deer is the dominant ungulate throughout, followed by one or more species of small equid. The remains of rabbits occur in significant numbers in all of the Upper Paleolithic levels, but especially in the Gravettian, when shellfish (mainly limpets) also are present. As climate cooled and sea level dropped with the approach of the Last Glacial Maximum, the site's position was farther inland. Gatherable marine shellfish would have been farther away from the encampment and perhaps less worthwhile to transport to it in the later Upper Paleolithic phases.

Young red deer and equid remains, almost all from fetuses or recently born fawns and foals, co-occur with roughly equal numbers of fully adult animals, most of which may be females. This result suggests that the mothers and their infants were hunted in the Vale Boi area during the spring. One sees close anatomical balance among the skull and limb regions of the body for the adult animals (*sensu* Stiner 1991, 2002), despite the intensively crushed state of the fauna, and the frequencies of bony parts of the cranium agree well with standardized MNE estimates derived for mature adult teeth. Countable vertebral elements of adult the ungulates are few, but fragments less specific to element are very common and delicate pore structures are

well preserved in many specimens. The axial elements were indeed carried to the site by humans and suffered extensive fragmentation on-site. Despite the great fragility of their partly formed bones and teeth, the fawns/foals are also represented by a full range of body parts.

Mild burning damage and cut marks on the Vale Boi bones occur in low but typical frequencies for Mediterranean Paleolithic faunas. The intensity of the burning damage seldom exceeded carbonization. Cone fractures indicative of marrow processing are prevalent (>15% of large mammal NISP), and the medullary cavity of every major element was opened by humans. The bones are also exceptionally fragmented, yet they often are recognizable despite the prevalence of neonate specimens. Extensive fragmentation of spongy bone parts is accompanied by large quantities of fire-cracked rock (Table 2) and well used anvil stones with large shallow depressions (Figure 4); no pit features have been found. Clearly the occupants of this site undertook extreme measures as early as the Gravettian to maximize the nutritional potential of ungulate carcasses, despite the additional labor required to do so. The relative quantities (kg) of bone and manuported stone vary through the G25 strata series for reasons not yet fully understood; small scale differences in colluvial action could account for some of this variation. However, the co-occurrences of fire-cracked rock and large, pitted stone anvils, and highly fragmented bone throughout the Upper Paleolithic is most important to the present discussion.

Trends in dietary breadth

Both the Middle to Upper Paleolithic transition and the "Broad Spectrum Revolution" of the late Epipaleolithic appear to have been times of expanding dietary breadth and demographic increase, albeit on a greater order in the latter period. Binford (1968) described substantial diversification of human diets in middle and high latitude Europe at the end of the Paleolithic, or Mesolithic, roughly 12,000-8,000 years ago. Expansion of the prey spectrum and innovations in food processing and food storage equipment generally accompanied the dietary shifts, suggesting intensified use of habitats and fuller exploitation of the potential foodstuffs they contained. Some of this behavior was directed to grinding and storing nuts but also involved small animals in many areas (e.g., Arias 1997, 1999; Clark & Straus 1983; Coles [ed] 1992; Jochim 1998; Keeley 1988; Price 1991; Roche 1990; Stiner et al. 2000; Straus 1991; Welinder 1978). Flannery pushed these observations further in 1969 with his "Broad Spectrum Revolution" (BSR) hypothesis, proposing that the emergence of the Neolithic in western Asia was prefaced by local increases in dietary breadth in the late Epipaleolithic. He argued that subsistence diversification, mainly by adding new species to the diet, raised the carrying capacity of an environment

increasingly constrained by climate instability at the end of the Pleistocene. For both authors, local imbalances between human population density and food availability were integral to the remarkable changes that took place in human societies just prior to the Paleolithic-Neolithic, or forager-farmer, transition.

Binford's and Flannery's ideas have stimulated much research and debate over three decades. The anthropological arguments were influenced by early works in population ecology, including what later came to be known as foraging theory and diet breadth models. Inspired particularly by Odum and Odum (1959), Emlen (1966), and MacArthur and Pianka (1966), Binford and Flannery proposed that economic change could have resulted from demographic crowding in certain regions of the world, which in turn may have altered the conditions of selection on human societies. Some archaeologists question the relevance of "population pressure" in human social evolution (e.g., Hayden 1995; Price & Gebauer 1995), but many continue to think of demographic factors as one of several ingredients necessary to the forager-farmer transition (e.g., Bar-Yosef & Meadow 1995; Binford 1999; Davis et al. 1994; Keeley 1988; Redding 1988; Watson 1995; Winterhalder & Goland 1993). Such a perspective is no longer limited by linear conceptions of cause and effect, for while population increase may provoke change by setting some new conditions for natural selection, it does not guarantee how the process of change will occur nor a particular outcome. Density-dependent effects nonetheless can play decisive roles in shaping the evolutionary histories of predator-prey systems (Boutin 1992; Pianka 1978; Sinclair 1991), and there is no reason to insist that humans are altogether immune to density-dependent effects (Binford 1999; Harpending & Bertram 1975; Winterhalder & Goland 1993). Changes in human population density certainly influence the rates at which people encounter one another, the feasibility of certain kinds of social networks, and the availability of critical foodstuffs. In times of scarcity and territorial circumscription, human populations may either undergo demographic decline or, in some cases, find new solutions for getting enough to eat throughout the year.

Theoretical expectations

Actually, evidence of increasing dietary breadth may take the form of more species in the diet *and/or* greater proportional evenness among high-ranked and low-ranked prey items. The latter is perhaps more diagnostic in general, since some environments simply do not support a high diversity of animal species. Either phenomenon may be provoked by declining availability of preferred food types. The idea is that a predator can afford to ignore lower quality prey at little cost if the chance of finding a superior type in the near future is high. An abundance of high quality prey fosters a narrower diet that centers upon just a few favorite foods, disproportionately to their relative availability in the environment (Figure 5). As the supply of preferred

prey dwindles, however, broadening the diet to include common but lower-yield alternatives maximizes a predator's returns per unit expenditure by reducing the search time (Pianka 1978). This second set of conditions encourages a more diverse diet in the sense that the predator's emphasis is spread more evenly among high- and low-yield prey types that occur naturally in the environment. So, under lean conditions people should become less selective about what animals to hunt rather than go hungry.

Broadening of late Paleolithic diets in Eurasia frequently involved both plants and animals, but energy-rich nuts and large seeds became particularly important in lower latitude environments. Because the nutritional benefits of these resources require considerable work and equipment to extract (Keeley 1988; Kelly 1995), the trend is most easily recognized from the proliferation of milling tools after the Last Glacial Maximum (Wright 1994), and, to a lesser extent, from increasing evidence of storage and preserved plant parts (e.g., Hillman et al. 1989; Miller 1992; and on Atlantic Europe, e.g., Rowley-Conwy 1986; Woodman 1981). The story from the faunal evidence was less clear, almost certainly because most analysts' measures of prey diversity have been based on Linnean taxonomic categories—counting species or genera. As such, taxonomic diversity approaches seem to register only one clear economic transition, that from foragers to farmers in the early Neolithic when there was gradual *decline* in dietary breadth (Davis 1982; Edwards 1989; Horwitz 1996; Neeley & Clark 1993; Munro n.d.). What little variation could be found by this method in the taxonomic diversity of archaeofaunas over the Middle, Upper, and Epipaleolithic periods was more easily explained by climate-driven environmental changes or geographic variation in animal and plant community composition (e.g., Bar-Oz et al. 1999; Simek & Snyder 1988; Stiner 1992). From the perspective of animal taxonomic diversity, there seemed to be no zooarchaeological support for the BSR hypotheses of expanding diet breadth in the later Paleolithic.

The discrepancies observed between the results on plant and animal exploitation stem from how zooarchaeologists tend to categorize prey animals (Stiner et al. 2000). Species and genera present the most obvious analytical categories available to zooarchaeologists, and thus diet variation normally is examined in terms of indexes of taxonomic richness (N-species or N-genera) and taxonomic evenness (proportionality in abundance) (e.g., Edwards 1989; Grayson & Delpech 1998; Neeley & Clark 1993; Simek & Snyder 1988). Consistent with the most literal expectations of Flannery's BSR hypothesis, such analyses employ either Kintigh's simulation-based technique (Kintigh 1984) or a more long-standing regression approach (Grayson 1984) that grew out of the work of Fisher, Corbet, and Williams (1943) for problems of sampling in modern community ecology. The main weakness of diversity approaches that rely on fine-grained Linnean taxonomic units is their

insensitivity to physical and behavioral differences among prey animals. The only qualification normally added to these analyses is prey body size, since all game animals are composed of similar tissues and large animals yield much more food than small ones. The logic of the latter practice is fine as far as it goes, but it potentially overlooks great differences in prey handling costs and the long-term price of heavy exploitation among animals that are broadly equivalent in food content and size. Some distantly related taxa are nearly equivalent from the viewpoint of handling costs because of their locomotor habits or ways of avoiding predators: tortoises and rock-dwelling marine shellfish, for example, are sluggish or immobile; hares and partridges, though similar in body weight to a Mediterranean tortoise or an arm-full of shellfish, are quick and maneuverable. Humans, because of their generalist dietary tendencies, will exploit a wider range of prey as the species diversity in ecosystems increases (usually at lower latitudes such as the Mediterranean area), which further increases the possibilities for prey type interchangeability.

Trends in Game Use in Mediterranean Italy, Turkey, and Israel

Differing prey type classification systems may greatly affect archaeologists' perceptions of change in prehistoric diet breadth. This point can be demonstrated by applying a simple measure of diversity to three faunal assemblage series from the Mediterranean Basin (Stiner 2001)—the Reciprocal of Simpson's Index, or $1/?(?_i)^2$, where $?$ represents the proportion of each prey type for array i in an assemblage (Simpson 1949; Levins 1968). The Mediterranean faunal series include a total of 32 assemblages from shelter sites in an inland valley of northern Israel (200-11 KYA), the western coast of Italy (110-9 KYA), and the south-central coast of Turkey (41-17 KYA) (Figure 6). Altogether these faunal assemblages span 200,000 to 9,000 years before present (for background information, see Kuhn et al. 1999, 2001; Kuhn & Stiner 1992, 1998; Munro 2001; Stiner 1994, 1999, 2001; Stiner et al. 2000). The faunal series from Italy, Israel, and Turkey represent distinct ecogeographic zones of the Mediterranean Basin (Figure 6), and thus the trends to be discussed below cannot be dismissed as local phenomena. (The Algarve of Portugal lies in a fourth quadrant, following Blondel & Aronson [1999].) Geographic context and site type are held generally constant for each of the Mediterranean series. The preferred counting unit is the number of faunal specimens (NISP) identified to the level of genus or a finer taxonomic distinction, as NISP is least subject to aggregation error (Grayson 1984). Fragment size is known to increase with prey body size in the data set, but the gradation in fragmentation is similar among assemblages, and prehistoric humans' emphasis on large versus small prey involved no apparent trends. The minimum number of individual animals (MNI) is used in the case of shellfish remains, however, to control for much greater fragmentation, substantially smaller body sizes, and the

fact that marine mollusks shells have exceptional identifiability quotients owing to their distinctive morphologies and surface textures.

In the first analysis, diversity is examined on a single taxonomic plane, counts by genus. Application of the Reciprocal of Simpson's Index to assemblages which potentially contain about 20 genera yields consistently low levels of evenness in dietary breadth in the three faunal series over a 200,000 year span (Figure 7). There is only a very weak correlation with time (*r* 0.386, r^2=.15, p=.05, n=32), and there is no correspondence to the 6-7 climatic oscillations indicated by oxygen isotope data from deep sea cores (following Shackleton & Opdyke 1973). While sample size varies among the assemblages, this fact does not explain the pattern in Figure 7. In fact this approach yields no support for the BSR hypothesis within the Paleolithic, just as Edwards (1989), Neeley and Clark (1993), and Horwitz (1996) observed from their studies of other Old World faunas. For better or for worse, most investigations of Paleolithic diet breadth changes have stopped here.

But Binford and Flannery expected to see the greatest changes in foragers' use of small animals. We know that small game animals were important to human diets in the Mediterranean Basin from at least the early Middle Paleolithic onward (Klein & Scott 1986; Stiner 1994; Stiner & Tchernov 1998), although the proportional contribution of small game to total meat intake varied from staple to supplement. The spectrum of animal taxa eaten by Paleolithic peoples in the Mediterranean Basin did not vary much (Stiner 1994; Tchernov 1994), and included, where available, tortoises (*Testudo*), marine shellfish (e.g., *Patella*, *Mytilus, Monodonta*), large legless lizards (*Ophisaurus*), ostrich eggs, game birds such as partridges (*Alectoris, Perdix*), hares (*Lepus*), and rabbits (*Oryctolagus*), in addition to ungulates such as deer (*Cervus, Dama, Capreolus*), gazelles (*Gazella*), wild goat (*Capra*), and wild cattle (*Bos*).

Interestingly, the relative emphasis that humans placed on three general types of small animals changed dramatically with time. It seems that Middle Paleolithic foragers seldom bothered with small prey unless they were easily obtained, namely collectable small prey such as tortoises, shellfish, large lizards and/or ostrich eggs. This was not the case in many areas from the early Upper Paleolithic onward.

Prey-ranking systems cannot be inferred from watching people make decisions, but the relative values (pay-offs) of prey can be evaluated from knowledge of modern variants of the animals whose bones occur in archaeological deposits. Observations built from modern wildlife data on predator avoidance strategies, productivity, and other characteristics provide a logically independent basis for ranking prey values to foragers, ignoring for the moment the advantages of some later technologies (Kuhn & Stiner 2001; Stiner et al. 2000). Variation within the small game fraction of each Mediterranean faunal series (Figure 8) reveals a clear trend

toward more even dependence on high-ranked and low-ranked small prey, confirmation of expanding dietary breadth during the later part of the Mediterranean Paleolithic. This way of grouping the data distinguishes only between slow-moving, easily collected small animals (tortoises & shellfish), fast-running mammals (mostly lagomorphs), and quick flying game birds such as partridges. Only 18 assemblages in the Mediterranean series contain small game components large enough to be compared, with four from the early Middle Paleolithic of Italy collapsed into one to increase sample size. Removing large game from the comparison allows clear expression of expanding diet breadth in small game exploitation *(r 0.606, r^2=.37, p=.01, n=18)*. It also shows that most of the expansion took place during a cold climate stage (OIS 2). This is the opposite of what is expected to result from climate-driven changes in animal community composition, since the number of small animal species tends to be greater in warmer environments (Blondel & Aronson 1999; Pianka 1978). The evidence indicates a categorical or step-wise change in how humans interacted with small animal populations beginning after about 40,000 years ago.

Foragers' perceptions of prey cannot be expected to follow the rules of biological systematics. Indeed they did not in the case of Paleolithic humans in the Mediterranean areas considered. Prey body size should be a valuable non-taxonomic criterion for ranking the potential returns of prey, but it too has its limits because of the additional complications of capture costs and, in some cases, processing costs as well (e.g., Jochim 1976; Madsen & Schmitt 1998; Stiner et al. 2000; Welinder 1978). The large-to-small body size contrast in the three Mediterranean series, expressed as the percentage of ungulates in the total count for each assemblage in Figure 9, is largely trendless (*r* 0.276, p=1, n=18), whereas the proportion of slow animals within the small game fraction of each assemblage clearly declines with time (*r* 0.572, .02>p>.01, n=18); the converse of the latter pattern is of course an increasing reliance on small quick animals. Prey body size must have had some economic significance, but it seems that absolute differences in prey size often were recalibrated from the foragers' point of view by the differing capture costs among small prey animals. These results are compatible with optimal foraging theory, which ranks prey in terms of costs of pursuit and handling vs. energetic returns (Pianka 1978; Stephens & Krebs 1986).

The surge in bird exploitation is among the earliest symptoms of new pressure on traditional resources and, by extension, Upper Paleolithic demographic expansion. Lagomorph exploitation also increases by about 40,000 years ago in some areas, but it associates most conspicuously with the later stages of diet breadth expansion in the eastern and northern Mediterranean areas. Surges in lagomorph hunting are also eventually seen in Epipaleolithic or Mesolithic sites in a wider range

of environments, including parts of Iberia, northern and eastern Europe, and even North Africa (reviewed in Kuhn & Stiner 2001; see also Jochim 1998). Middle Paleolithic people rarely hunted lagomorphs in the ecosystems where other predators, such as denning wolves, frequently did (Stiner 1994:166-170, 211-212). Upper Paleolithic people exploited lagomorphs in modest quantities, but Epipaleolithic and Mesolithic people hunted them most of all.

Western Algarve, Portugal

It is unreasonable to expect that all other Mediterranean faunal series will match the patterns found in the eastern and northern rim. Animal communities vary in their composition, as do the choices of prey species available to foragers, and symptoms of resource intensification may take many forms. Portugal already is suspected to be an outlier to the pan-Mediterranean trend in some respects (Hockett & Bicho 2000; Hockett & Haws 2002), although it is wise on ecological grounds to separate study areas bordering the Mediterranean Sea (Algarve) from those characterized by an Atlantic climate.

Presently we only have data for the Gravettian to early Magdalenian in western Algarve, but there clearly was fairly heavy use of quick small game—rabbits—throughout the Upper Paleolithic phases represented there. Greatest use of rabbits occurs in the Gravettian, probably the warmest phase in the Vale Boi sequence and coincident with shellfish collecting (Table 1), presumably when the shoreline was very close by. Overall, one might conclude that the evidence on dietary breadth, in combination with that for grease rendering from bone, points to much intensification in western Algarve as early as the Gravettian, perhaps 25-26,000 years ago. This is coeval or only slightly prior to when lagomorphs became very important on the northern Mediterranean Rim at Riparo Mochi (ca. 25,000 years ago, Stiner et al. 2000). However, Vale Boi is also among the earliest documented cases of grease rendering of ungulate prey in Europe. The challenge in future work at Vale Boi will be distinguishing larger trends in subsistence organization from local (site-to-site) differences in subsistence strategies. It is possible that early signs of resource intensification were provoked by early impoverishment of large mammal communities in this southernmost edge of Iberia (see also Hockett & Haws 2002). Extreme reliance on marine resources follows in the Mesolithic of western Algarve.

Predator pressure and the differential resilience of prey populations

The fact that small prey animals differ tremendously in their development rates permits an unusually clear view of how increases in Paleolithic diet breadth shifted with local demographic growth. This is not a matter of how much small game

animals contributed to total game intake so much as how certain very sensitive species can serve as symptoms of threshold effects in predator-prey systems. Independent standards for prey classification from wildlife data can be linked to predator pressure and demographic increase with the help of predator-prey simulation modeling (Stiner et al. 2000).

In the Mediterranean Basin, a simple distinction in the "catchability" of small animals happens to correspond to great differences in prey population resilience, the latter governed mainly by individual maturation rate (Stiner et al. 2000). Slow-moving Mediterranean tortoises (*Testudo*, maturing at 8-12 years) and some shellfish such as limpets (*Patella*) and large predatory gastropods such as *Thais* (large drills, 1-5 years) are especially susceptible to over-harvesting because of their slow maturation rates (Blasco et al. 1986-87; Dye et al. 1994; Hailey et al. 1988; Hockey 1994; Siegfried et al. 1994). Slow growth translates to lowered availability of that prey type in succeeding generations if exploitation by the predator exceeds the inherent capacity of the prey population to recover. It is unlikely that Paleolithic foragers viewed prey in terms of their potentials for population recovery, but they certainly would have been aware of declining availability of prey and thus declining returns for the same level of foraging effort.

There is evidence of harvesting pressure on "low turnover" prey populations in the later Mediterranean Paleolithic, and a corresponding increase in the exploitation of agile, warm-blooded small animals, mainly birds such as partridges and lagomorphs. These quick small animals mature in ?1 year, and their populations rebound easily from heavy hunting by humans. Predator-prey simulation modeling indicates that hare (*Lepus*) and partridge (*Alectoris* & *Perdix*) populations can support seven to ten times the annual off-take that tortoise (*Testudo*) populations can support (Stiner et al. 2000) (Figure 10). A similar result was obtained from simulation modeling of rabbits (*Oryctolagus* & *Sylvilagus*) (N. D. Munro, personal communication, 2001). Although not modeled in the same manner, limpets and large predatory marine mollusks, such as *Thais*, are only somewhat more resilient than tortoises.

Because tortoises and shellfish grow throughout much of their life span, over-harvesting potentially also causes *diminution* or a reduction in the mean size of individuals subsequently available to foragers (Blasco et al. 1986-87; Dye et al. 1994). Slow-growing, slow-moving tortoises and certain marine mollusks dominate the small game fractions of the Mediterranean Middle Paleolithic record, constituting up to half of all identified specimens in several of the assemblages (Stiner et al. 2000). What is more, the individuals taken by early Paleolithic foragers were larger on average than those collected by later Paleolithic foragers. Body size diminution occurred for tortoises in Israel (?44 KYA) by the late Middle Paleolithic or earliest

Upper Paleolithic, and this effect was sustained over multiple climate cycles thereafter. Limpet diminution began by 23 KYA in Italy (Stiner et al. 2000), but considerably later to the west in Cantabrian Spain (Clark & Straus 1983). The timing and duration of the diminution effects discussed here are largely independent of global climate trends—the other potential cause of diminution—and thus point to a human cause. Greater dependence on slow-growing animals during the Middle Paleolithic, and on larger individuals on average implies that these early human populations were very small and dispersed. Paleolithic foragers' more "even" emphasis on slow (highly ranked) and quick (lower ranked) small prey with time is the predicted outcome of hunting pressure and demographic increase in the absence of a correlation to climate warming.

Marine exploitation from the Mesolithic to Early Neolithic in Algarve

New data from shell middens in western Algarve bear on the question of whether the so-called early Neolithic was a continuation of a hunting and gathering existence in this area. The appearance of ceramics in stratigraphic series of the region ca. 5,500 B.C. could represent the addition of just a few utilitarian ceramic vessels to local tool kits, or, alternatively, the adoption of low-level agriculture or livestock herding.

Gravitation of human settlements towards coastlines during the Mesolithic has been noted in several areas of Atlantic Europe (Arias 1997; Arnaud 1990; Lubell et al. 1985; Roche 1990; Straus et al. 1990) and is explained at least in part by widespread formation of coastal embayments and other rich aquatic habitats during this time (Bicho 1994; on other Atlantic regions, see Price 1991; Lewthwaite 1986; Rowley-Conwy 1986; Troels-Smith 1967; Jensen 1982; Welinder 1978). In southern Portugal, considerable impoverishment of large herbivores seems to have begun roughly 12,000 years ago or earlier. It is likely that the once extensive steppes of Iberia became fragmented and isolated, and those remaining in southern Portugal soon cut-off by forests from the north (e.g., Madeyska 1999) and perhaps no longer able to support major herbivore populations. On the other hand, some Holocene marine and brackish water habitats of Atlantic Europe were extraordinarily productive. Many archaeologists believe that the rich aquatic resources of Atlantic Europe supported high forager population densities, fostering greater demographic and social "resistance" of Mesolithic groups to Neolithic expansion (Arias 1997; Carvalho 2002; Roche 1990; Rowley-Conwy 1986; Straus et al. 1990; Zvelebil 1986).

The Neolithic arrives earlier and more intrusively to northern and central Portugal (Carvalho 2002), but later and more sporadically to the south. The introduction of Neolithic farming systems to Europe generally associates with population increase (Ammerman & Cavalli-Sforza 1984; Binford 1999; Jensen 1982;

Winterhalder & Goland 1993), so the consequences of colonization and low-level cultural diffusion can be very different. At least two scenarios for the Mesolithic-Neolithic transition in the Algarve have been proposed: (1) maritime pioneer colonization from the north/northwest, marked by the abrupt arrival of a full-blown farming and herding adaptation at a few coastal localities (Zilhão 2001); and (2) gradual acculturation of or at least exchange with indigenous Mesolithic foragers (e.g., Arias 1999; Silva & Soares 1987). These are not necessarily conflicting viewpoints, as an extended period of forager-farmer coexistence is considered likely in southern Portugal (Carvalho 2002); the area may have supported a heterogeneous patchwork of human populations and economic systems for five centuries or longer.

      Presence of ceramics is the main means for detecting earliest Neolithic contact in a region, but, as noted above, these artifacts may indicate either colonizing populations or much simpler technology transfers. Mesolithic foragers of Europe were container-dependent long before there were ceramic vessels to be had (e.g., Troels-Smith 1967), and thus an interest in ceramic vessels could arise quite independently of other facets of Neolithic existence. Discussions of what early ceramics imply in central and southern Portugal are stimulating if contentious (reviewed by Carvalho 2002; cf. Arnaud 1990; Zilhão 2001). Resolution has been out of reach because of limited stratigraphic control at some sites, specifically the possibility of downward mixing of younger material into older sediments, not to mention the small number of cases available for consideration. Zooarchaeological criteria for a Neolithic economic transition would be the relatively abrupt appearance of domestic ungulates in relation to wild prey (e.g., Davis 1982, 2002), but the exclusive reference to shell midden samples here could limit the visibility of domesticates due to specialized use of coastal sites.

      Another set of faunal criteria focuses on possible signals of demographic increase in the details of shellfish exploitation itself. Shellfish were but one aspect of Mesolithic and early Neolithic subsistence in the Algarve. However, the perennial importance of marine resources in Algarve suggests that the malacofaunas can register important shifts in subsistence organization, regardless of whether shellfish were primary or "fall-back" sources of animal protein, fats, and other nutrients.

      Several shell middens were identified during survey of western Algarve by N. Bicho, R. Ferring, and J. Lindly (Bicho et al. 2000); those tested between 1997 and 1999 yielded the collections discussed here. All of the sites lie west of Faro (see Figure 1), most within a few hundred meters of the modern Atlantic shore, perched on limestone coastal cliffs 10 to 60 m above sea level with access to rocky collection areas below. The Algarve shell middens span roughly 9,500 to 6,500 years before present and the late Mesolithic-early Neolithic culture periods (Table 3). Rocha das

Gaivotas (Mesolithic) and Vale Santo I (early Neolithic) represent one consecutive faunal series, and Barranco das Quebradas 1 and 3 represent a second, older series. Ceramic sherds are present in the stratigraphically younger deposits of each faunal series, and all of the middens contain fire-cracked rock, suggesting that stone-boiling or related heating techniques were used. These shell midden sites seem to support the idea of foragers' singular, early adoption of ceramics; that is, the presence of ceramics in the upper portions of each series does not seem to be explained by downward mixing from Neolithic farmer components, as has been proposed for other sites (Zilhão 2000). All other classes of materials in the Rocha das Gaivotas-Vale Santo I and Barranco das Quebradas 1-3 series appear more or less constant.

The middens contain marine mollusk shells almost exclusively. The sediment chemistry of the middens would seem suitable for bone preservation, as the shells are abundant and in good condition, leaving us with the conclusion that bones seldom were deposited (Stiner et al. 2003). The genera commonly exploited (Table 4) have similar adult soft tissue weight ranges and most inhabit the rocky intertidal zone: mussels (*Mytilus*), limpets (various *Patella* species and, rarely, *Siphonaria*), turbans (*Monodonta*), and a large drill known as *Thais haemastoma. Thais* occurs on a wide range of substrates but is most common on rocky shores. All of these shellfish represent significant sources of fat and carbohydrates in autumn, winter, and especially in spring (Fernandez-Reirez et al. 1996; Hove 1992), and the energetic returns of some shellfish are considerably more complete than those of terrestrial wild animals such as rabbits. Well-fed mussels may convert 4-5% of the algal protein they consume into lipids, 33-64% to carbohydrates, and 44-47% to body protein prior to the spawning season (Fidalgo et al. 1994). Comparable information is not available for *Thais haemastoma,* but the closely related subtropical species, *T. cattifera,* can yield as much as 56% protein dry weight; 6.5% crude fat, 12% ash, and 24% carbohydrates prior to spawning (Udoh et al. 1995).

There is much repetition among the assemblages in the molluskan genera collected from hard substrates. A possible trend is seen for the combined faunal series (Figure 11) in that turbans are most abundant, sometimes in combination with mussels, in the lower cuts but decrease with time (15 time-ordered calculable ratio values*, r_s = 0.75, p = .001); limpet frequencies vary essentially randomly. More significant, the proportion of drills appears relatively stable throughout the time-ordered assemblages (Figure 11). Intersite differences could explain some of the variation in shellfish species representation overall. Although the rocky shore sites share similar settings, it is difficult to exclude the possibility that natural, stochastic variation in intertidal community structure is responsible for the trends in the species exploited. Such variation occurs naturally over very short time intervals of a decade

or less (on various marine provinces, compare Buss 1986; Dayton 1971; Dethier 1984; Hartnoll & Hawkins 1985; Lubchenko & Menge 1978; Petraitis 1995).

Turbans, limpets, mussels, and *Thais* differ in the rates of individual development in the wild, properties that translate to significant differences in population growth and turnover rates. Mussels are extraordinarily productive, often maturing within 1-2 years of age, and turbans in about 1-3 years, so their populations replenish rapidly. Many limpet species, and especially large drills, take longer to mature on average (usually 2-5+ years), making population replacement slower (cf. Ardizzone et al. 1996; Bombace 1995; Branch 1981; Gardner et al. 1993; Hockey & Bosman 1986; Kendall 1987; Koch & Wolff 1996; McLachlin & Lombard 1981; Moreno et al. 1984; Oliva & Castilla 1986; Paine et al. 1985; Pombo & Escofet 1996; Richardson et al. 1990; Southward & Southward 1978; Sukhotin & Kulakowski 1992). Because the latter two genera are more vulnerable to over-harvesting by humans, they also are more likely to experience body size diminution (e.g., Branch 1975; Dye et al. 1994) and/or declining abundance relative to high-turnover mollusk species. The large-bodied bivalve predator, *Thais* falls at the least resilient end of the population turnover continuum and is the most sensitive to population decline as predation increases.

Extensive shell fragmentation prohibits a classic diminution analysis of *Thais* (drills) in the midden series. However, the question of harvesting pressure on shellfish at western Algarve sites can be examined by comparing the relative frequencies of the drills to the mollusks upon which they normally prey. While MNI counts are not perfectly equivalent to mollusk biomass, MNI is suitable for this comparison because the edible mollusks eaten by humans in the Algarve have similar mean adult body masses, except for the carnivorous drill, which can be somewhat larger. If human exploitation intensified with time, as might be expected to result from increased human population density with a transition to farming in the area, productive intertidal mollusk species are unlikely to be affected much, but *Thais* would be adversely affected due to its substantially lower potential for population recovery. Thus the question is whether the ratio of *Thais* is independent of or diminishes significantly with time.

The observed ratio of predatory *Thais* to herbivorous and suspension-feeding mollusks in the time-ordered rocky shore sites in Table 5 is independent of time (r_s = 0.17; r^2 = 0.0345, N = 15, p = .51). The close relation between the relative frequencies of *Thais* and productive mollusks likely reflects normal saturation in the balance between this large drill and its prey—the number of adult *Thais* an intertidal community can support—and secondarily, humans' opportunistic collection of these predatory gastropods in the context of mussel exploitation on rocky shores. Apparently exploitation was not sufficiently intense to reduce the relative abundance

of *Thais* between ca. 7,800 and 4,800 years B.C. in western Algarve. The lack of evidence of *Thais* decline in the context of prehistoric shellfish harvesting may indicate no change in human population densities across the Mesolithic to early Neolithic boundary, even though ceramics came into use in the later part of the sequence.

It is probable that our study area is biased to the representation of locally persistent foragers in the region. Nonetheless, any general loss of habitat to invading farming populations could suppress the food supplies of resident foragers more generally, causing them to intensify use of the resources that remained accessible to them. There is no evidence of such intensification between the Mesolithic and earliest Neolithic period at the localities we have studied. Questions for the future include whether other shell middens in western Algarve display comparable patterns, and fuller elucidation of the cultural and economic geography of the Algarve during this volatile transition period.

Discussion

The Upper Paleolithic faunas of Vale Boi in western Algarve display an emphasis on ungulate hunting, supplemented to variable degrees by marine shellfish and small mammals. There also is evidence of grease rendering of large game carcasses from the Gravettian onward, based on the co-occurrence of abundant fire-cracked rock, stone anvils, and highly fragmented spongy bone. Grease rendering methods are most likely to gain importance in forager systems when and where encounter rates for large mammal prey and mobility options are in decline. Few if any other examples dating to the Gravettian are known, a fact explained either by a lack of recognition of carcass processing techniques in in general or because there was special incentive for this behavior in southern Portugal. The possibilities for out-migration would have been limited by the cul-de-sac nature of the Algarve, and perhaps territorial circumscription may have been experienced there quite early despite its geographic isolation.

The second question asked in this review concerns how the zooarchaeological record of the Algarve compares to pan-Mediterranean trends in small game use and expanding dietary breadth. Most of the shifts in predator-prey dynamics outlined here concern small animals rather than big ones. Greater proportionality in the representation of slow- versus quick-maturing species in faunal series in the eastern and northern Mediterranean areas suggests increasing harvesting pressure over time, with earliest evidence of dietary expansion and demographic pulses relating to the spread of early Upper Paleolithic cultures from Asia into Europe; additional, intense demographic pulses occur during the

Epipaleolithic. These signals spread mainly along east to west axis of the Mediterranean Basin. Available information for the western Algarve indicates heavy use of rabbits as early as the Gravettian, in conjunction with labor-intensive grease rendering of ungulate carcasses at the site of Vale Boi. The timing of such resource intensification and dietary expansion is in temporal agreement with the patterns observed for the northern Mediterranean Rim. However, the coupling of heavy rabbit exploitation and grease-rendering of ungulate prey with the Gravettian of Algarve is intriguing and not altogether anticipated.

The third question raised in this review concerns the nature of the Mesolithic-Neolithic transition in Algarve. Marine shellfish were major sources of animal protein and food energy in the region prehistorically. The lack of change in the relative abundance of productive grazing and suspension-feeding intertidal mollusks to slow-growing large drills in the archaeofaunal assemblages suggests, however, that no additional pressure was placed on marine resources from the late Mesolithic to the time when ceramics first appear (early Neolithic) in the study area. All of the middens contain fire-cracked rock, confirming that stone-boiling and related heating techniques were widely used through the Mesolithic period. Under these circumstances, the benefits of adopting a few ceramic containers may have been considerable, without concomitant alteration of other aspects of Neolithic subsistence or technology (Bicho et al. 2000). The full Neolithic subsistence package may have coalesced considerably later in this area.

The demographic cant of this presentation does not treat population pressure as the engine of culture change. The data simply show us that demographic processes formed part of the substrate upon which selective factors operated on foraging cultures. In most periods, human populations adjusted to environmental and demographic stresses through straightforward population decline, without substantive changes in behavioral adaptations. In fewer instances, there is evidence of behavioral adjustment and even cultural evolution. In other words, people's responses to spatial constraints were not strictly determined by population pressure or territorial circumscription: solutions were as diverse as the inception of bone grease rendering and food storage, reorganization of cooperative networks, and expanded use of animal resources. With regard to the latter, some prey populations proved to be more resilient and reliable in the face of heavy exploitation once the capture costs were be reduced artificially with technology, so much so that the resulting technological radiations are a defining feature of many late Pleistocene and early Holocene foraging cultures.

The zooarchaeological data on diet breadth do not reveal all of the causes of demographic growth in Mediterranean regions, but they may prove essential for identifying the places and periods of economic change, including cases that do not fit

expectations. In the case of the Algarve, much more remains to be done on the Middle Paleolithic through early Neolithic periods. It already is clear, however, that some ideas based on predator-prey dynamics and the reproductive ecology of prey species are worth pursuing.

Acknowledgments

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Table 1. Preliminary faunal distributions in the Upper Paleolithic Vale Boi cultural sequence as fractions of the total sample from square G25 (2000-2001 excavation)

Vertical Units (cuts)*	sample size**	MNI shellfish	NISP rabbit	NISP equid	NISP red deer	NISP MU	NISP aurochs	NISP wild goat
1-3 (early Magdalenian)	101	.00	.04	.24	.41	.32	.00	.00
4-7 (Solutrean)	254	.07	.17	.09	.39	.28	.00	.00
8-9 (Proto-Solutrean)	380	.13	.21	.04	.32	.30	.00	.00
10 (late Gravettian)	226	.13	.28	.03	.30	.25	<.01	.00
11-15 (Gravettian)	489	.12	.36	.05	.24	.22	.00	.01
16-25 (Gravettian)	906	.16	.55	.01	.10	.15	.01	<.01

* Culture assignments are preliminary.
** Sample size in the number of identified specimens (NISP) for vertebrates, but minimum number of individuals (MNI) is used for shellfish to correct to significant differences in fragment sizes of identifiable invertebrate versus vertebrate remains.

Table 2. Weight (kg) percentage distributions for manuported stone, bones, and food shells by time-ordered, culturally defined units in square G25 of the 2000-2001 Vale Boi excavations.

Unit & Cut	Culture*	% stone	% bone	% shell	Total kg
1-3	early Magdalenian	84	16	0	1.690
4-7	Solutrean	82	18	<1	10.622
8-9	Proto-Solutrean?	68	30	2	10.429
10	late Gravettian	73	25	2	6.595
11-15	Gravettian	80	19	1	22.631
16-25	Gravettian	59	37	4	19.284

* Culture assignments are preliminary. The majority of heavy stone material is fire-cracked rock and/or stone anvils.

Table 3. Shell midden sites, radiocarbon dates, and presence/absence of ceramics studied in western Algarve, Portugal (from Stiner et al. 2003).

Site name	Cut (cm bd)	Date ybp*	Laboratory code	Calibrated date B.C.	Ceramics
R.ª de Alcantarilha**	—	6,120±70	Wk-6672	5,207-4,859	In all units
	—	6,160±60	Wk-6851	5,227-4,999	In all units
Vale Santo***	—	6,340±120	Wk-6673	5,470-5,145	In all units
Rocha das Gaivotas***	—	6,890±70	Wk-6075	5,839-5,671	None****
Bco. das Quebradas 1***	0-22	7,980±80	Wk-8940	7,053-6,771	On surface only
	60-70	8,400±60	Wk-8951	7,569-7,377	None
Bco. das Quebradas 3***	40-50	8,580±70	Wk-8939	7,707-7,543	None
	110-120	8,640±70	Wk-8950	7,731-7,587	None

* Because all dates were obtained on marine shell, it is expected that the true ages of these sites are somewhat younger, with a correction factor of 360 ± 35 years subtracted from the initial value, after Soares (1993). Calibration of the radiocarbon dates (B.C., 1 sigma) was carried out using CALIB 25. Fire-cracked rock is abundant in every assemblage.
** Estuarine site associated with soft-substrate shellfish habitats.
*** Coastal sites associated with rocky shore shellfish habitats.
**** None in units studied.

Table 4. Edible marine mollusk species common in the rocky shore shell middens of western Algarve, along with information on diet, preferred substrate, and approximate adult shell length.

Family	Genus, species	Name source	Common name	Diet	Sub-strate	Adult size (mm)
GASTROPODA						
Patellidae	*Patella caerulea*	Linne	limpet	H	r	30-45
	Patella vulgata	Linne	limpet	H	r	30-45
	Patella depressa=intermedia	Pennant	limpet	H	r	30-45
	Patella aspera	Lamarck	limpet	H	r	30-45
	Patella rustica=lusitanica	Gmelin	limpet	H	r	25-30
Siphonariidae	*Siphonaria* sp.	—	false limpet	H	r	20-30
Trochidae	*Monodonta lineata*	da Costa	turban	H	r	20-35
Thaididae	*Thais haemastoma*	Linne	dog winkle*	C	r	60-75
BIVALVIA						
Mytilidae	*Mytilus galloprovincialis*	Lamarck	mussel	F	r	20-100
	Mytilus edulis	Linne	mussel	F	r	20-100
Ostreidae	*Ostrea edulus*	Linne	flat oyster	F	r,s,m	100+

Sources: Hayward and Ryland 1995; Saldanha 1995; Tornaritis 1987. Mollusk diet codes are (H) herbivore; (F) filter or suspension feeder; (C) carnivore. Substrate codes are (r) rock and other firm surfaces; (m) mud; (s) sand.
* Or drill.

Table 5. Ratio* of *Thais haemastoma*, a large carnivorous drill, to the total number of herbivorous and filter-feeding mollusks (MNI) in rocky shore sites in chronological order (from Stiner et al. 2003).

Site	*Thais* MNI	herbivore & filter-feeder MNI	Predator ratio[a]
Vale Santo I	22	118	.16
Rocha das Gaivotas	59	498	.11
Barranco das Quebradas 1	72	471	.13
Barranco das Quebradas 3	84	540	.13

* Predator ratio is calculated as *Thais* MNI, divided by the sum of *Thais* MNI and herbivore (grazing limpet & turban) and filter-feeder (mussel, clam & cockle) MNI.

Figure 1. Distribution of western Algarve sites discussed in text: (1) Barranco das Quebradas 1 and 3, (2) Rocha das Gaivotas, (3) Vale Santo I, (4) Vale Boi; (5) Ribeira de Alcantarilha. Localities 1-3 are rocky shore shell middens, locality 5 was an estuary site characterized by soft substrate shellfish habitats, all of Mesolithic and/or early Neolithic age. Locality 4 is mainly Upper Paleolithic but may also contain Neolithic and possibly Mousterian components. All sites occur in open settings, although three are backed by low rock outcrops that may have reduced wind exposure.

Figure 2. Distribution of bone marrow source types in two examples of major ungulate limb elements—humerus and femur. Concentrated medullary marrow is easily removed using a "cold" extraction technique; trabecular marrow stores in spongy bone normally require labor intensive smashing and heat-in-liquid procedures to extract. Black lines represent typical fracture planes and fragment sizes of grease-rendered bone.

Figure 3. Foci of grease-rendering methods in the ungulate skeletal anatomy.

Figure 4. Stone anvil, probably used for intensive bone smashing at Vale Boi. Arrows indicate the central, pitted depression resulting from repeated use (photo by N. F. Bicho).

Figure 5. Predicted differences in the degree of evenness among prey types (A-C) taken by predators under two distinct foraging conditions: Condition 1 represents high availability of the highest-ranked prey types; and, Condition 2 represents declining availability of the highest-ranked types such that the predator's choices must diversify to include more lower-ranked items. Prey types are distinguished on energetic grounds (body size, work of capture, and/or processing costs).

Figure 6. Geographic origins of the three Mediterranean faunal series (Stiner 2001), spanning three of four biogeographic quadrants of the Mediterranean Basin (following Blondel & Aronson 1999): (1) western coast of Italy, 16 assemblages; (2) Wadi Meged, inland Galilee of Israel, 9 assemblages; (3) Hatay coast of south-central Turkey, 7 assemblages.

Figure 7. Evenness in the representation of Linnean genera for the faunal series from Italy (circle), Israel (square), and Turkey (triangle), using the Reciprocal of Simpson's Index (20 = most even). Time and oxygen isotope climate cycles (Shackleton & Opdyke 1973) are expressed on a logged scale; (c) cold stage, (w) warm stage (from Stiner 2001).

Figure 8. Evenness among three prey categories within the small game fraction of the Mediterranean faunal series only, based on prey defense mechanisms (slow game, quick running terrestrial mammals & quick flying birds), and using on the Reciprocal of Simpson's Index (3 = most even). Symbols as in Figure 7 (from Stiner 2001).

Figure 9. (a) Trends by region (lines) in the percentage of slow small prey within the small game fraction of each assemblage in (is) Israel, (it) Italy, and (tu) Turkey; (b) the percentage of ungulate remains (inverted triangle) in the total count of each assemblage (from Stiner 2001).

Figure 10. Comparison of hunting tolerance thresholds for tortoise (4-7%), partridge (22-66%), and hare (18-53%) populations under high (HGM) and low (LGM) growth conditions. The upper horizontal bars represent crash thresholds, above which a predators' dependence on the designated prey type is no longer sustainable; vertical bars

represent natural variation in population resilience, as defined by the LGM and HGM (from Stiner et al. 2000). The modeled range for rabbits (*Oryctolagus*) is not shown but is about the same as for hares and partridges (N. D. Munro, unpublished research).

Figure 11. Relative frequencies of edible marine mollusks in time-ordered assemblages from the Rocha das Gaivotas, Vale Santo I, and Barranco das Quebradas 1 and 3 shell middens, expressed as percentage of total MNI. Only the larger assemblages are shown; date ranges are in calibrated radiocarbon years B.C. (Table 3).
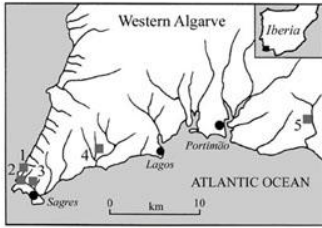
Fig 1
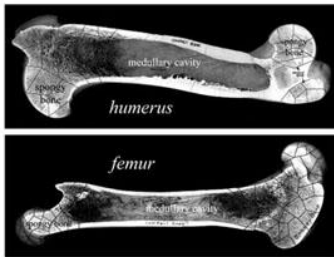
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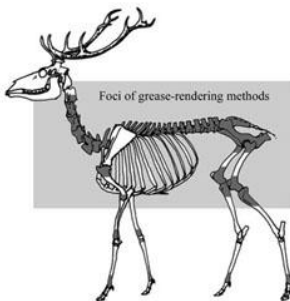
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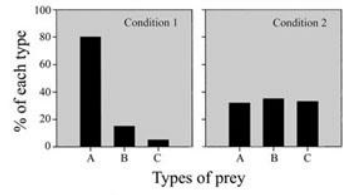
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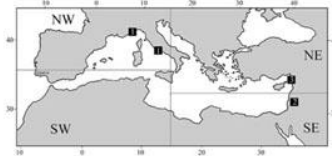
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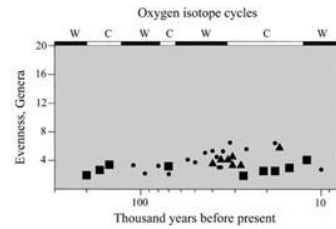
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