A Second Harvest? The potential for meta-analysis of stable isotope data ($\delta^{13}C$ and $\delta^{15}N$) to examine large-scale climatic, environmental and palaeodietary trends

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This study used a large-scale meta analysis of previously published data to examine widespread palaeodietary trends in Roman and Medieval Europe c. AD 1-1500. The purpose was to investigate the dietary effects of the Early Medieval economic depression.

The model: multilevel analysis

Site level effects:
Location
Period

Individual level effects:
Sex, Age, Species
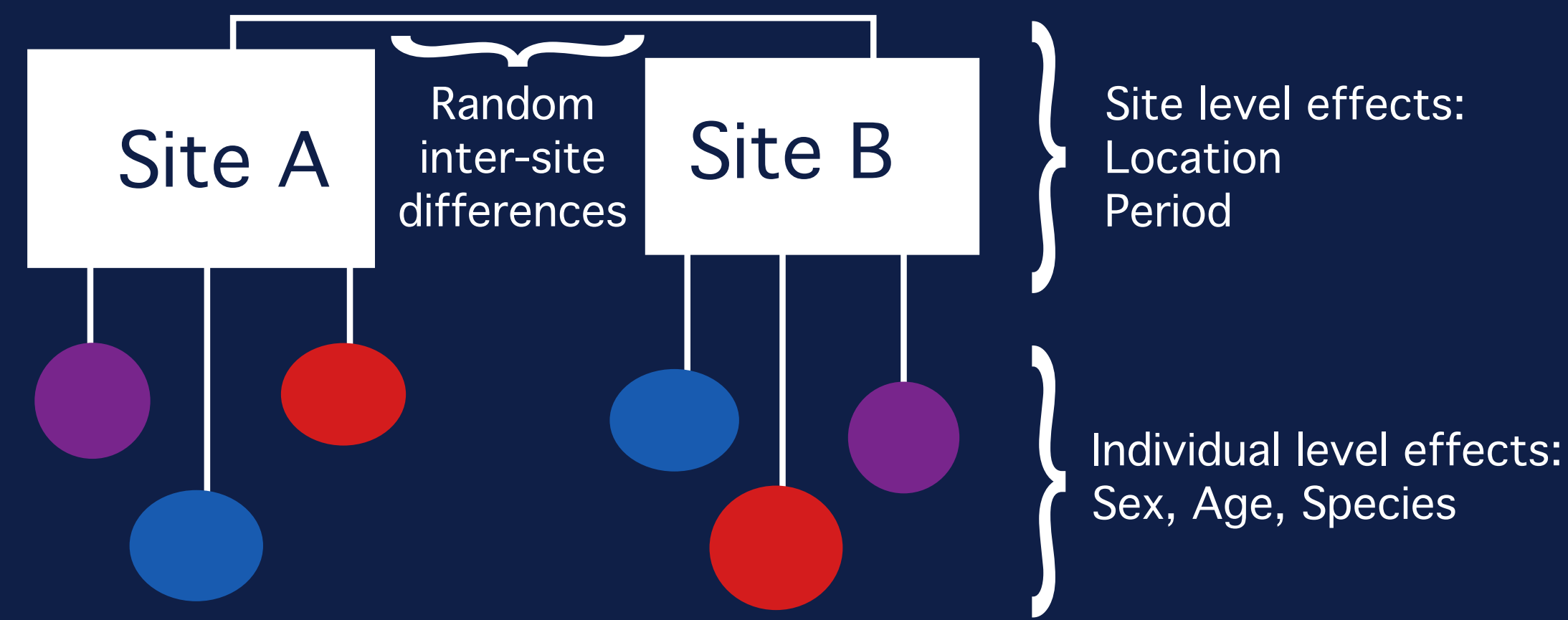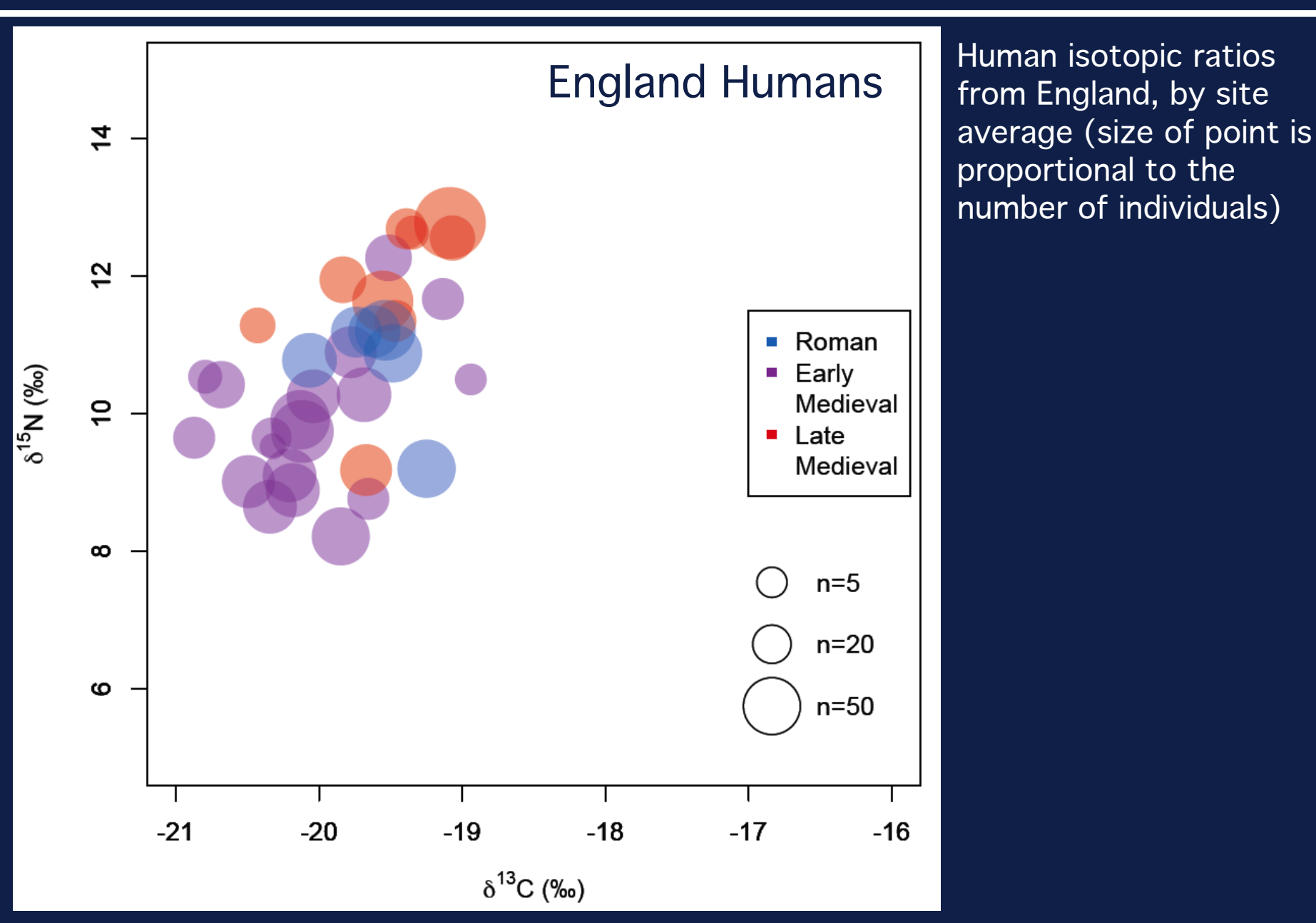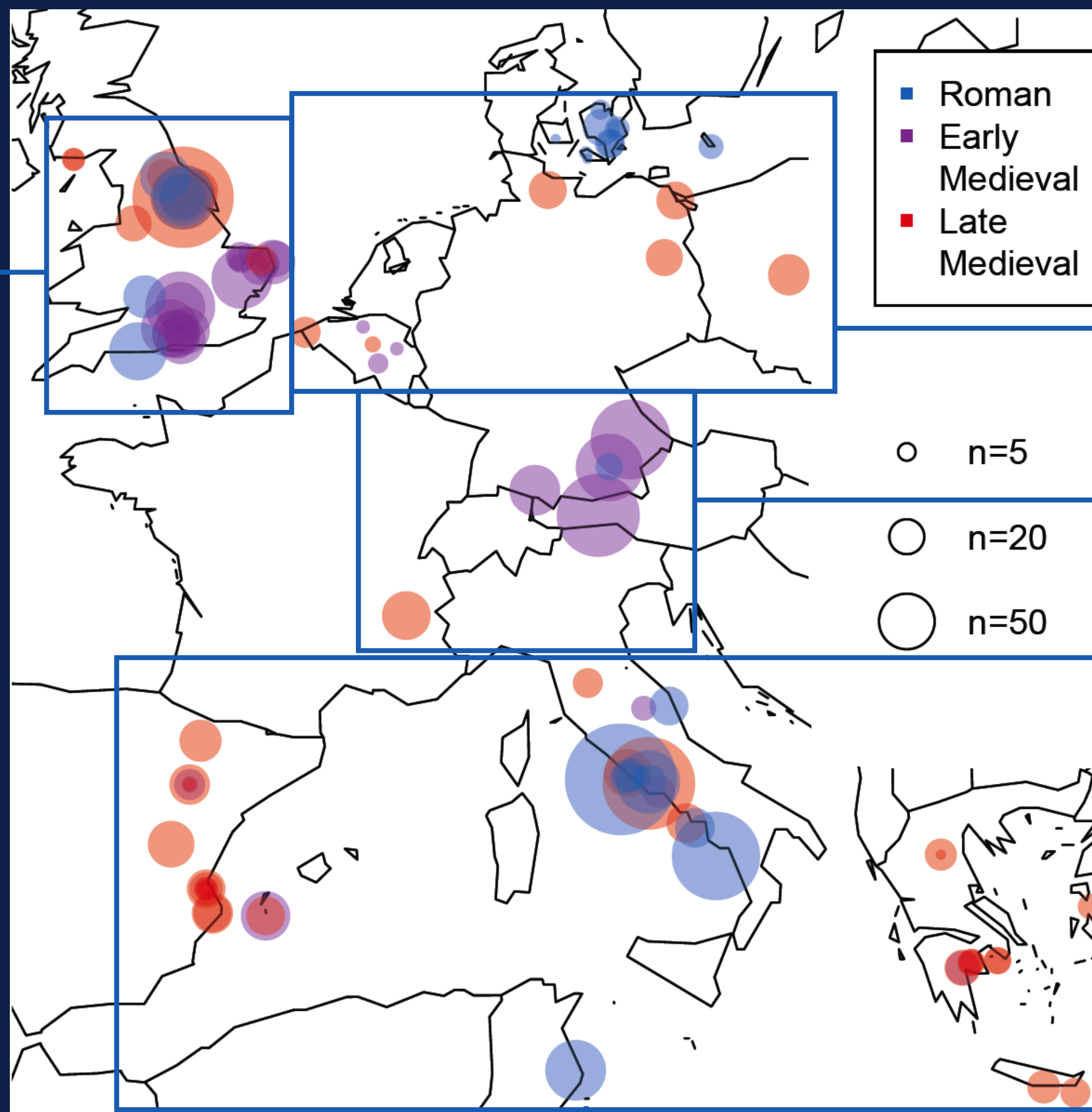
Multilevel analysis was used because it reflected the hierarchical nature of the data. Individual-level data (Age, Sex, $\delta^{13}C$, $\delta^{15}N$) and site-level data (Period, Location) could be assessed. Random site-level effects that could not be explained by any of the factors included in the model accounted for approximately 50% of the variance. Failure to use a multilevel model to account for site-level random effects would overestimate the significance of differences due to other factors.

The dataset:
3139 humans, 782 animals (54 species) from 38 studies, 118 sites, c. AD 1-1500

Data recorded:

| Study | Location: UK, NE, CE, Med | $\delta^{15}N$ | $\delta^{13}C$ | Age: Infant, Juvenile, Adult | Coastal/Inland: (coastal = < 10km from coast) | Species: human, sus, ovicaprid etc. | Sex: Male, Female, Unknown | Date: Roman, Early Medieval, Late Medieval | Elevation | Longitude | Latitude |

Results:

Early Medieval humans have slightly but significantly lower $\delta^{13}C$ and $\delta^{15}N$ compared to the Roman and Late Medieval periods. For $\delta^{13}C$ the effect size is 0.35‰ for EM-R (p = 0.0001) and 0.52‰ for EM-LM (p < 0.0001). For $\delta^{15}N$ the effect size is 0.52‰ for EM-R (p = 0.0025) and 0.77‰ for EM-LM (p < 0.0001). This effect is most significant for England, and less significant for other regions.
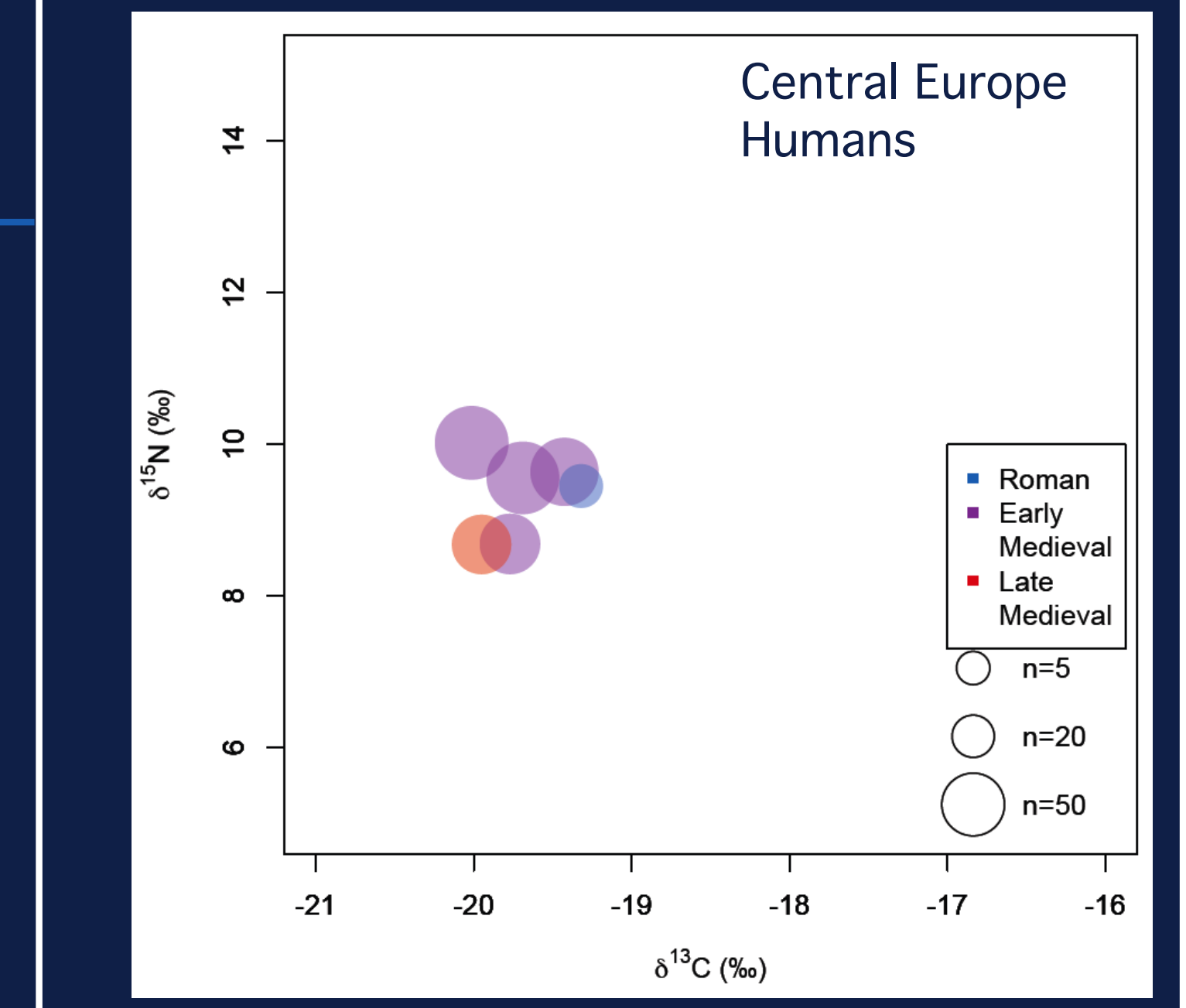

Human isotopic ratios from England, by site average (size of point is proportional to the number of individuals)

Map showing location of sites included in the meta-analysis. Size of point is proportional to number of individuals.
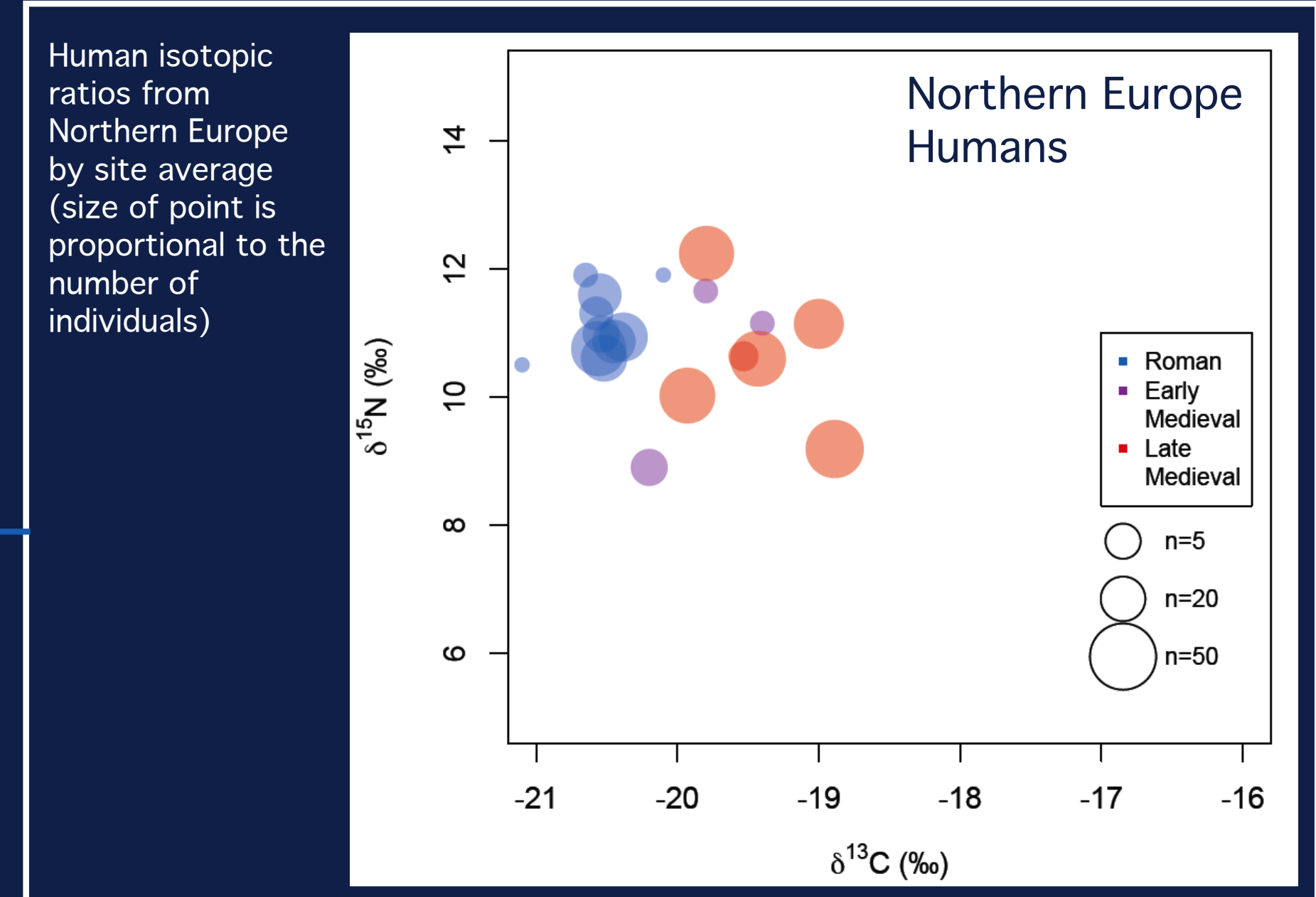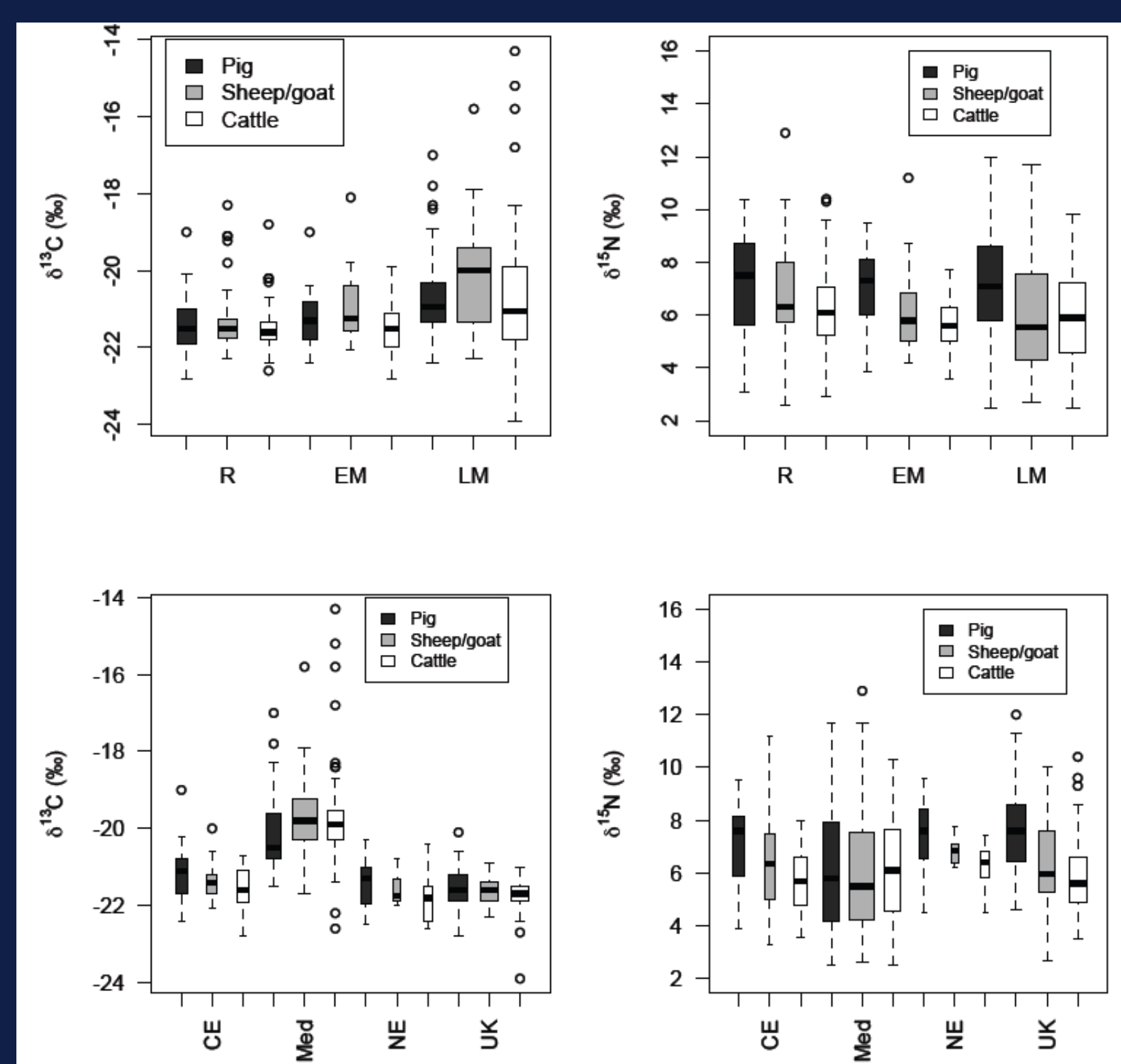

Human isotopic ratios from Northern Europe by site average (size of point is proportional to the number of individuals)


Human isotopic ratios from Central Europe by site average (size of point is proportional to the number of individuals)

Faunal trends:

Box plots of pig, sheep/goat and cattle isotopic ratios by period (Roman, Early Medieval, Late Medieval) and Location (Central Europe, Mediterranean, Northern Europe, England). Box width is proportional to the number of individuals.

Fauna from the Mediterranean can be distinguished from other regions because of their signicantly higher $\delta^{13}C$, which is consistent across all periods and species. Some Late Medieval Spanish sites have especially high faunal $\delta^{13}C$. Cattle and sheep/goat have similar isotopic ratios, but pigs tend to have significantly higher $\delta^{15}N$ and somewhat significantly higher $\delta^{13}C$. This is consistent for all regions. Early Medieval fauna have lower $\delta^{15}N$ compared Roman fauna (0.76‰, p = 0.05) and are slightly significantly lower compared to Late Medieval fauna (effect size 0.55‰, p = 0.10). Late Medieval fauna tend to have slightly higher $\delta^{13}C$ compared to Roman and Early Medieval fauna (effect size 0.25‰, p = 0.05).
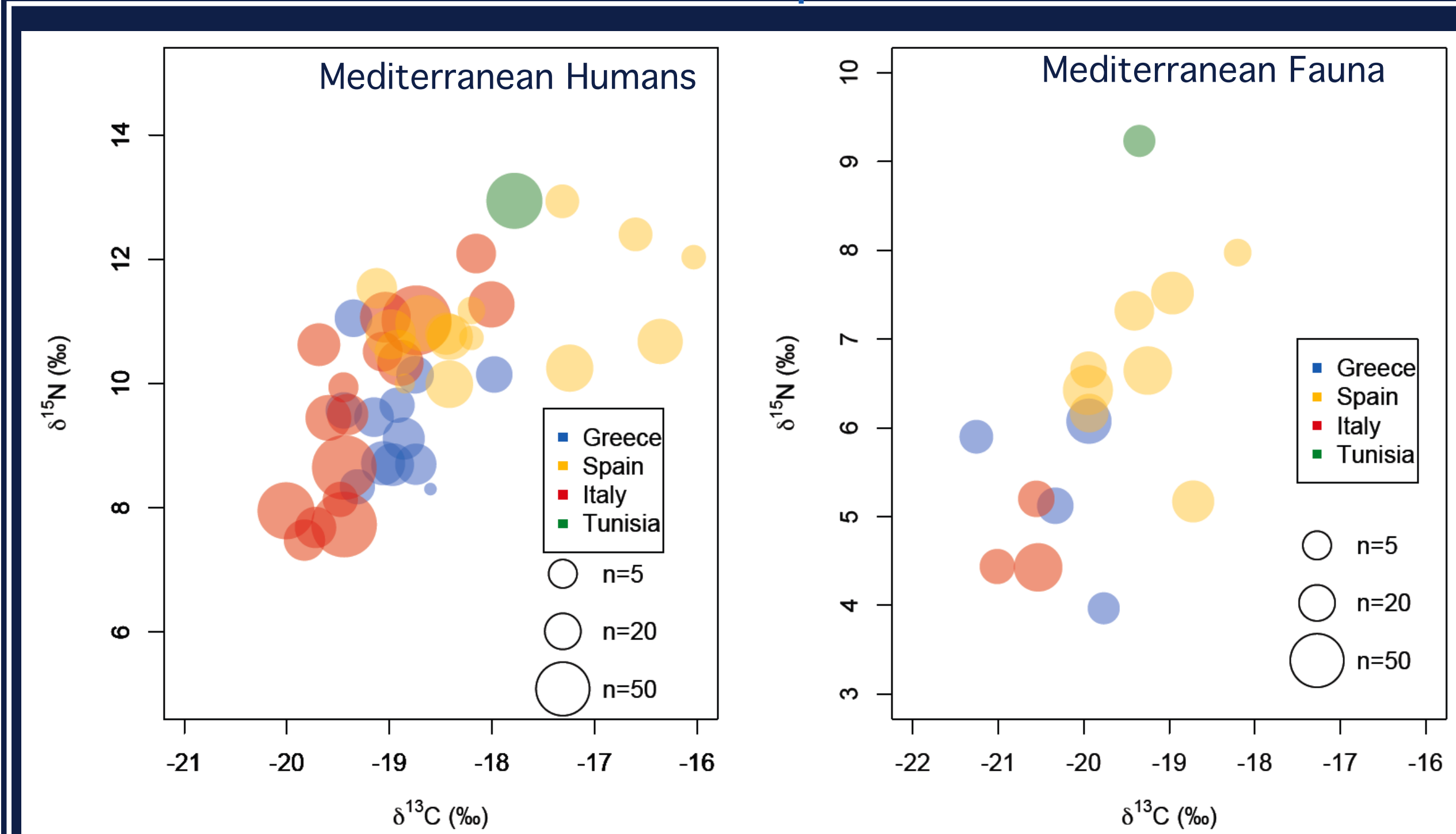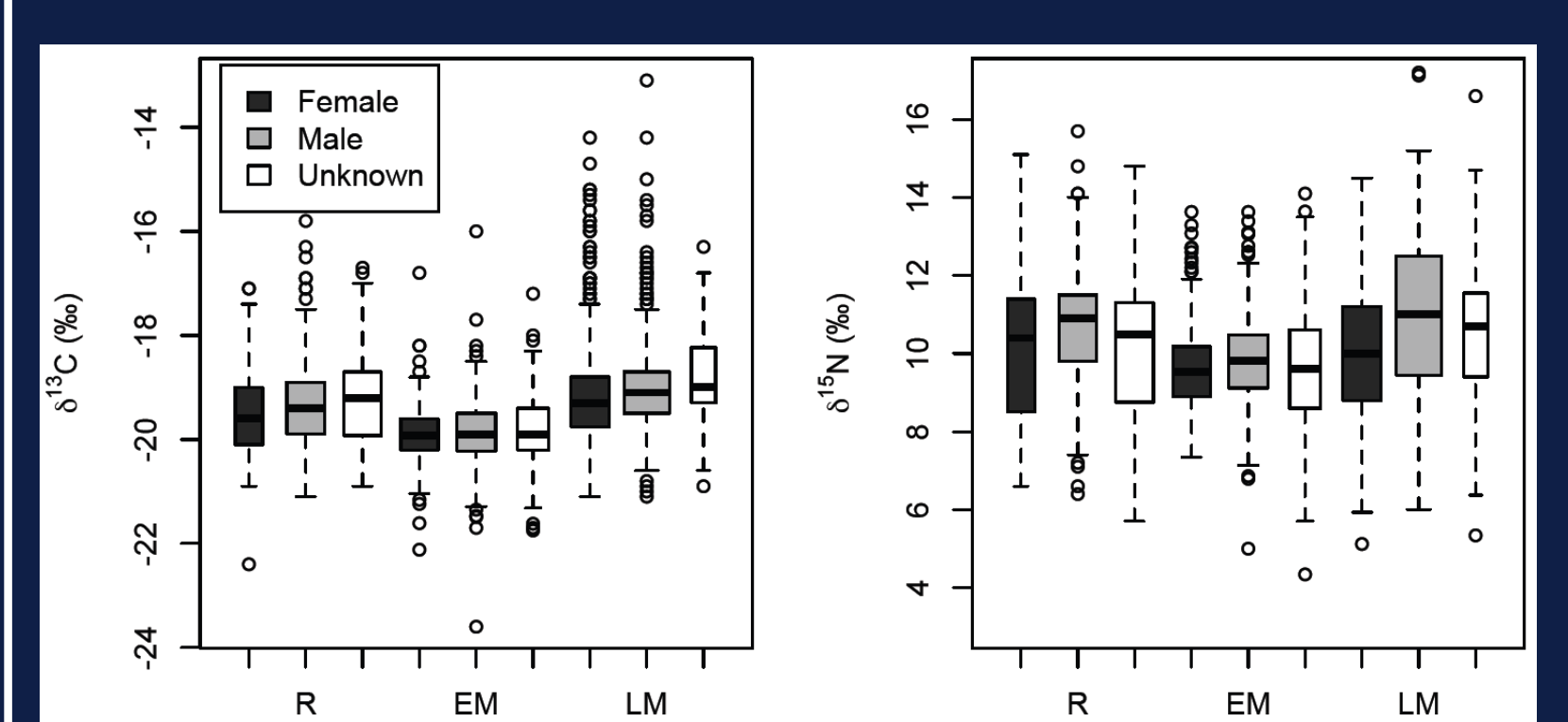

Mediterranean isotopic site averages, for humans and fauna, by country.

Within the Mediterranean, there is a strong geographic influence for both $\delta^{13}C$ and $\delta^{15}N$. Human and domesticated faunal isotopic ratios are similar for different countries. Individuals from the hottest and driest climates (Spain, Tunisia) have higher isotopic ratios.

Sex-based differences:

Overall, males tend to have slightly but significantly higher isotopic ratios compared to females +0.13‰ for $\delta^{13}C$ (p < 0.0001) and +0.31‰ for $\delta^{15}N$ (p < 0.0001). This effect is largest for the Late Medieval period, and smallest for the Early Medieval period.

Period	$\delta^{13}C$	p	$\delta^{15}N$	p
Roman	0.15	0.0038	0.30	0.0057
EM	0.04	0.27	0.13	0.0584
LM	0.19	0.0000	0.47	0.0000
All values expressed in ‰				

Human isotopic ratios by site average showing coastal/inland differences (size of point is proportional to the number of individuals)

There are no significant differences in fauna for coastal vs. inland sites. Humans from coastal sites tend to have significantly higher $\delta^{13}C$ (effect size 0.34‰, p = 0.035) and $\delta^{15}N$ (effect size is 0.65‰, p = 0.016) compared to inland sites.Humans from coastal sites are more likely to have significant correlation between $\delta^{13}C$ and $\delta^{15}N$ (Pearson's R > 0.3, p < 0.05) compared to humans from inland sites (60% vs. 30%). A correlation with an approximately 1:1 relationship is expected in a population of humans consuming variable quantities of marine protein (8-10‰ higher in $\delta^{13}C$ and $\delta^{15}N$ compared to terrestrial protein).

Intra-site human-faunal differences:

Box plots of intra-site $\delta^{15}N_{human-fauna}$ and $\delta^{13}C_{human-fauna}$ relationships, for different regions.

Attempting to use differences in $\delta^{15}N$ between humans and faunal baseline can be used to establish trophic level relationships and estimate relative quantities of animal protein in the diet may be problematic, especially since "typical" human-faunal $\Delta^{15}N$ differences are not well-characterised. (Hedges and Reynard, 2007). Human-faunal isotopic differences were calculated from 64 sites where faunal remains were preserved (or nearby proxies could be used). A weighted average of sheep/goat, pig and cattle was used. Although a difference of ~1‰ $\delta^{13}C$ and ~3-5% $\delta^{15}N$ is expected for a full trophic level shift (i.e. 100% animal protein diet), the 64 human-faunal isotopic differences calculated from the available data show a wide range:

Coastal	N	$\delta^{13}C$ max	min	$\delta^{15}N$ max	min
All Coastal	27	1.58	3.6	-0.2	4.4	6.42	2.22
All Inland	37	1.73	2.74	-0.05	4.32	7.3	1.36

Large inter-individual variation in faunal and human isotopic ratios makes conclusions based from these estimates unreliable. Large sample sizes are required to make meaningful assessments.

Coastal-inland differences:

Conclusions:

Large-scale geographic and chronological trends can be observed in stable isotope ratios using a large sample size and with the application of appropriate statistical models, including multilevel analysis. In this study, slightly lower $\delta^{15}N$ ratios were observed in humans and fauna from the Early Medieval period (AD 500-1000), even when complicating factors like age, sex, proximity to coast and random site-level effects were taken into account. Inter-regional comparisons of the existing isotopic dataset are a potential fruitful source of palaeodietary and palaeoclimatic information, although further work on inter-laboratory comparison, and climatic influences is needed.

References:

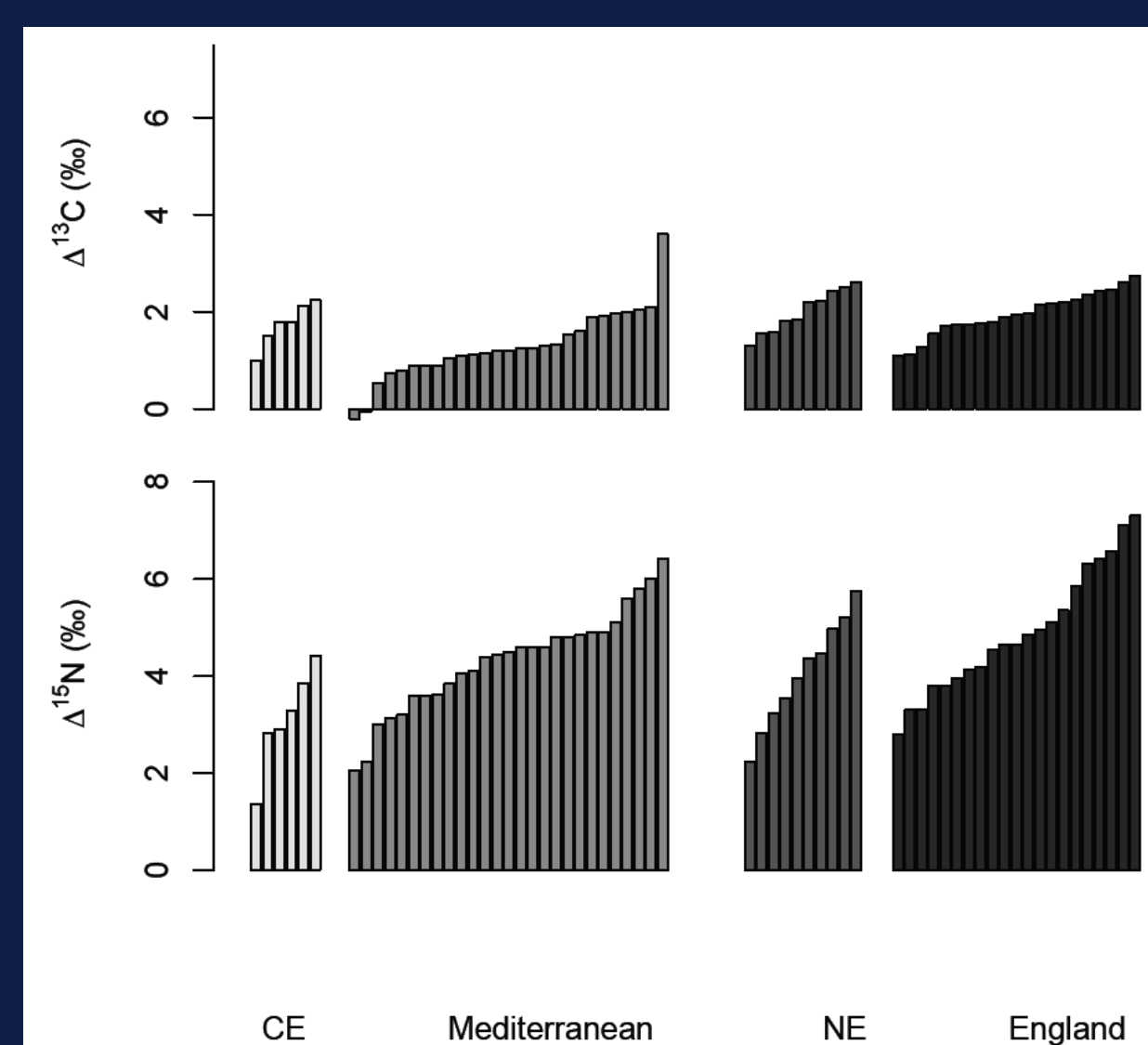Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. Journal of Archaeological Science 34, 1240