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# Human-environment dynamics in the ancient Mediterranean

## Keywords of a research field

### Abstract

Human-environment dynamics in past societies has been a major field of research in the Mediterranean for a long time, but has grown significantly following the increase in the number and quality of palaeoclimate and palaeoenvironmental records in the last two decades. Here we sketch the outline of this field of research based on 1,531 author keywords from 280 peer-reviewed articles published in 78 different scientific journals during 2016–2021. Sourced from the *Web of Science*, the selected studies cover the time span from the Neolithic to the Roman period across the Mediterranean and provide a large number of entry points for the interested reader regardless of their prior knowledge and specific interests. The results make evident the breadth and interdisciplinary nature of this research and show that it is possible to approach questions of human-environment dynamics in many and diverse ways. Among other things, our overview outlines the importance of temporal and spatial scales, as well as the elusive nature of causality, and highlights that monocausal models connecting climate events and societal collapse are increasingly replaced by scenarios favouring more nuanced renditions of the sequence of events within which internal societal factors are given more room for play.\*

*Keywords:* human-environment dynamics, ancient societies, Mediterranean, climate, systematic review, *Web of Science*, keywords

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### Introduction

Human-environment dynamics in past societies has been a major field of research in the Mediterranean for a long time, with new lines of research and increased level of detail being added continuously. Erosion and landscape evolution were prominent early topics, and environmental mapping has been a part of most field archaeological survey projects.<sup>1</sup> Considerations of climate were a natural part of these discussions but initially, when palaeoclimate proxy records were few, climate of the past was addressed on a hypothetical level or with reference to modern conditions or ancient textual records. In parallel with a growing concern for current-day global environmental change, the last two decades have seen a significant increase in the number and quality of palaeoclimate and palaeoenvironmental records, enabling closer analyses of specific climate, environmental and societal anomalies. The level of integration between different types of data, and between researchers of different disciplines, has also increased significantly during the same time but especially during the last decade, along with a growing understanding of the complexities of human-environment dynamics. It is fair to say that research on human-environment dynamics in past societies has exploded over the last decade and the Mediterranean is no exception.

The challenges we face today in terms of environmental and climate change are manifold, not least in the Mediterranean, which, for example, is projected to lose a substantial amount of the present-day winter precipitation that is so vital for the region.<sup>2</sup> These challenges raise new questions and issues for our current-day society but also for scholars of past human-environment dynamics. The question is if and how knowledge of the past can provide clues for the present and

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<sup>1</sup> Bintliff 2002; Butzer 2005; Izdebski *et al.* 2016; Knapp & Manning 2016, all with further references.

<sup>2</sup> Lionello & Scarascia 2018; Tuel & Eltahir 2020, 5829 (locally up to 40% reduction).

future,<sup>3</sup> but also how current issues and concerns can open up new frameworks of research and provide new ways of approaching past human-environment dynamics. A crowd-sourcing enterprise ten years ago resulted in a list of 25 grand challenges for archaeology to tackle the next 25 years.<sup>4</sup> The challenges were organized into five topics, two of which are of primary interest for human-environment dynamics: “resilience, persistence, transformation and collapse” and “human-environment interactions”. The questions/challenges posed in the former related to the differential persistence of societies, the “roles of social and environmental diversity and complexity in creating resilience and how do their impacts vary by social scale”, and definitions of social collapse as well as any signs forewarning it.<sup>5</sup> The second topic entailed the scale and timing of human impacts on the environment, drivers of population growth and health and well-being in ancient societies, human response to abrupt environmental change (mentioning tsunamis, earthquakes, volcanic eruptions, short-term weather events, and wildfires), as well as the perception of and response to climate and environmental change.<sup>6</sup> Although not clearly stated, these are topics clearly anchored within current concerns for the future of our own society, and there are many parallels to be found with the 17 sustainable development goals set up by the UN in 2015, for full implementation by 2030.<sup>7</sup> Moreover, although crafted with reference to archaeology, meeting many of the 25 challenges would entail more intensive collaboration across disciplines.<sup>8</sup> The challenges listed by Kintigh *et al.* also find many parallels with the 50 priority research questions put forward for palaeoecology<sup>9</sup> as well as for historical ecology.<sup>10</sup> These two additional crowd-sourcing efforts have also pinpointed the need to address different temporal and spatial scales to deal with uncertainties and to find workable methods and tools to manage for comparability between records within and between disciplines.<sup>11</sup> The three crowd-sourcing attempts to define common questions are now five years old or more. The question is how studies of human-environment dynamics in the Mediterranean have managed to answer these open questions, even if not in direct response to the original crowd-sourcing enterprise.

<sup>3</sup> See e.g. efforts within Past Global Changes (PAGES, [www.past-globalchanges.org](http://www.past-globalchanges.org)) and *Integrated History and future of People on Earth* (IHOPE, [www.ihopenet.org](http://www.ihopenet.org)).

<sup>4</sup> Kintigh *et al.* 2014. The crowd-sourcing effort was started online in the spring 2012 and followed by a workshop the same year.

<sup>5</sup> Kintigh *et al.* 2014, 11–12.

<sup>6</sup> Kintigh *et al.* 2014, 15–19.

<sup>7</sup> United Nations 2015.

<sup>8</sup> Kintigh *et al.* 2014, 19.

<sup>9</sup> Seddon *et al.* 2014, resulting from a workshop in 2012.

<sup>10</sup> Armstrong *et al.* 2017, drafted during workshops in 2014 and 2015.

<sup>11</sup> Seddon *et al.* 2014, 263; Armstrong *et al.* 2017, 7–8.

In order to capture the content of the very expansive field of human-environment dynamics research, the present article revolves around a bibliometric-based selection of research articles on human-environment dynamics in the Mediterranean since 2016.<sup>12</sup> The results make evident the breadth of research and show that it is possible to approach questions of human-environment dynamics in many and diverse ways. Moreover, the overview provides a large number of entry points for the interested reader regardless of their prior knowledge and specific interests. In order to explore both the depth as well as the breadth of the research field, the present article is a study in two parts. In the first part, the method and basic parameters of the bibliometric overview are presented, followed by an analysis of the patterns provided by the keywords chosen by the authors of each of the articles selected for the overview. The general composition of these keywords pinpoints the primary avenues of research during the last six years. In the second part, we delve into the details of some of the studies and focus specifically on key analytical concepts for understanding change across time and space. The aim of the second part is to provide glimpses of current research thematics from diverse environmental settings located around the Mediterranean. In combination with the analysis of keywords, these brief insights into current projects provide an opportunity to take the pulse of human-environment dynamics research in relation to the highlighted calls for action. Here, special attention is paid to the contribution of different disciplines to the study of human-environment dynamics and to interdisciplinary collaboration on these topics.

## Material and methods

The bibliometric analysis is based on articles derived from the *World of Science* (*WoS*) database,<sup>13</sup> and three general criteria

<sup>12</sup> Despite an extensive bibliography, this review leaves out a significant number of recent publications relevant to the topic. Some additions are made in order to look back in time or beyond the boundaries of the present review, but the content as well as in-text references are dominated by articles that were selected through our bibliometric search. Cited articles that are *not* among the selected articles are marked by an asterisk (\*) in the bibliography. It should also be noted that not all of the selected articles are cited; those that are cited represent examples of the outlined research trends. Full details of the selected articles can be found in *Supplemental information* at <https://doi.org/10.30549/opathrom-15-07>.

<sup>13</sup> *Web of Science Core Collection* 2021. According to the information provided by the Web of Science Core Collection, the collection contains articles from over 21,100 peer-reviewed journals published worldwide and these journals cover more than 250 disciplines in natural sciences, social sciences, and arts and humanities (Clarivate 2021: <https://clarivate.com/webofsciencelibrary/solutions/web-of-science-core-collection/>). A study of the use of *WoS* for research articles and review articles (Li *et al.* 2018, 5–6) shows that *WoS* plays an important role in the overall academic com-

were used to make the corpus of articles manageable. We have not wanted to single out any specific part of the Mediterranean or focus specifically on a limited time period. The criteria related to chronology and geography are therefore broadly set. This study deals with the human-environment dynamics from Neolithic to Roman times across the full circumference of the Mediterranean (with a delimitation set roughly at 300 km inland from the coastline of the Mediterranean Sea). The beginning of the time period in absolute years differs with the timing of the onset of the Neolithic period in each region but the end is set to *c.* AD 300. Studies with a primary focus on the Palaeolithic and Mesolithic Mediterranean as well as the Late Roman (and later periods) have been excluded. Fortunately, there are several recent reviews of human-environmental studies focusing on later historical periods that may serve to close this latter gap.<sup>14</sup> A third general criterion is of topical nature and based on our understanding of “research on human-environment dynamics” as research with a clear interdisciplinary intent that aims to give focus to both humans and the environment, and the linkages between the two, even if an equal balance is not achieved. Special emphasis is put on climate-related studies, reflecting the expertise of the present authors as well as the common concern for climate change effects on the persistence of human societies today.

The bibliometric search was conducted on 27 September 2021, and includes articles published from January 2016 up to the day of the search.<sup>15</sup> The searches were directed towards the content of the “Title”, “Author keyword”, “WoS Keywords Plus” (generated from the items cited in each article), and the “Abstract”. In all, 19 English-language search strings were used, all encompassing “climate” in combination with one geographical determinant (“Mediterranean”, “Spain”, “Italy”, “France”, “Greece”, “Aegean”, “Turkey”, “Syria”, “Lebanon”, “Israel”, “Levant”), as well as one of the chronological determinants: “An-

cient history”, “Antiquity”, “Bronze Age”, “Neolithic”, “Classical archaeo\*” “Roman”, “Greek”, or, one of the keywords “Archaeo\*” or “Human-environment”. The North African countries along the south coast were not searched individually, but studies of this region appeared among those tagged with “Mediterranean”. The selection of *WoS* and these specific search strings was a measure to facilitate easy access and relative speed in the analysis, but also a way to delimit the number of records. Even with these delimitations, the 19 search strings resulted in 1,301 articles, which decreased to 776 articles after the deletion of duplicates. The 776 articles were thereafter sorted based on chronology, geography and overall topic according to the criteria listed above. Articles falling outside the chronological (Neolithic to Roman) and geographical (Mediterranean) scope of the present study and articles without an interdisciplinary intent were removed. The final list includes a total of 280 articles spread across 78 journals (*Supplemental information*, see <https://doi.org/10.30549/opathrom-15-07>). The use of English-language search strings and thereby the exclusion of non-English articles as well as other types of publications (articles in non-indexed journals, monographs, edited books, book chapters, etc.) was necessary to limit the data. The result may therefore be biased in terms of language and type of publication. Importantly, however, the results likely encompass a broader and more diverse corpus of publications than would have been the case if a selection was made on the basis of the prior knowledge of the authors of the present review or the citation repertoire in individual articles.

## Part one: outline of a research environment

The bibliometric overview provides a picture of a productive and diverse research field. The overall output of the 280 articles has been roughly equal between the years since 2016, with a notable drop in 2020, which would seem to be an effect of the pandemic (*Fig. 1A*). All these articles combined represent a scholarly group of 1,264 unique authors. A large majority (78%) of these authors have only contributed to one article, and authors contributing to three or more articles make up only 10% of the total number of authors. The gender distribution among the lead authors is relatively balanced (60/40 in favour of male lead authors). This balance changes to 70/30 (in favour of male-led) when considering the top 40 scholars who have contributed to most articles. The numbers clearly outline a very broad interest in human-environment dynamics, but also a field of study that is primarily driven by a more limited number of scholars.

In order to explore the thematics among the corpus, the “Author keywords” of the selected articles were analysed for

munity and the number of review articles utilizing the platform has steadily increased since the beginning of the 21st century, showing the importance of *WoS* and *WoS* data “to find new research areas based on existing efforts” (Li *et al.* 2018, 6). The usefulness of other databases and/or data-search engines (e.g. *Google Scholar*) to cover broad topics and large geographical areas is demonstrated by Moreno-de-las-Heras *et al.* (2019) and Ljungqvist *et al.* (2021).

<sup>14</sup> Xoplaki *et al.* 2016; Decker 2017; Haldon & Rosen 2018; Marx *et al.* 2018; Sessa 2019; Huhtamaa & Ljungqvist 2021; Ljungqvist *et al.* 2021.

<sup>15</sup> The start date of the search period is linked to the publication of the special issue *Mediterranean Holocene climate, environment and human societies*, edited by Alexandra Gogou, Adam Izdebski and Karin Holmgren, and published in *Quaternary Science Reviews* in March 2016 (Gogou, Izdebski & Holmgren 2016). The special issue was a direct result of an influential workshop held at the Navarino Environmental Observatory (NEO), Costa Navarino, Greece, in April 2014 with participants from 16 countries. It marks the decisive move by the workshop participants to engage in better scientific integration and all papers were co-authored by scientists representing different disciplines.

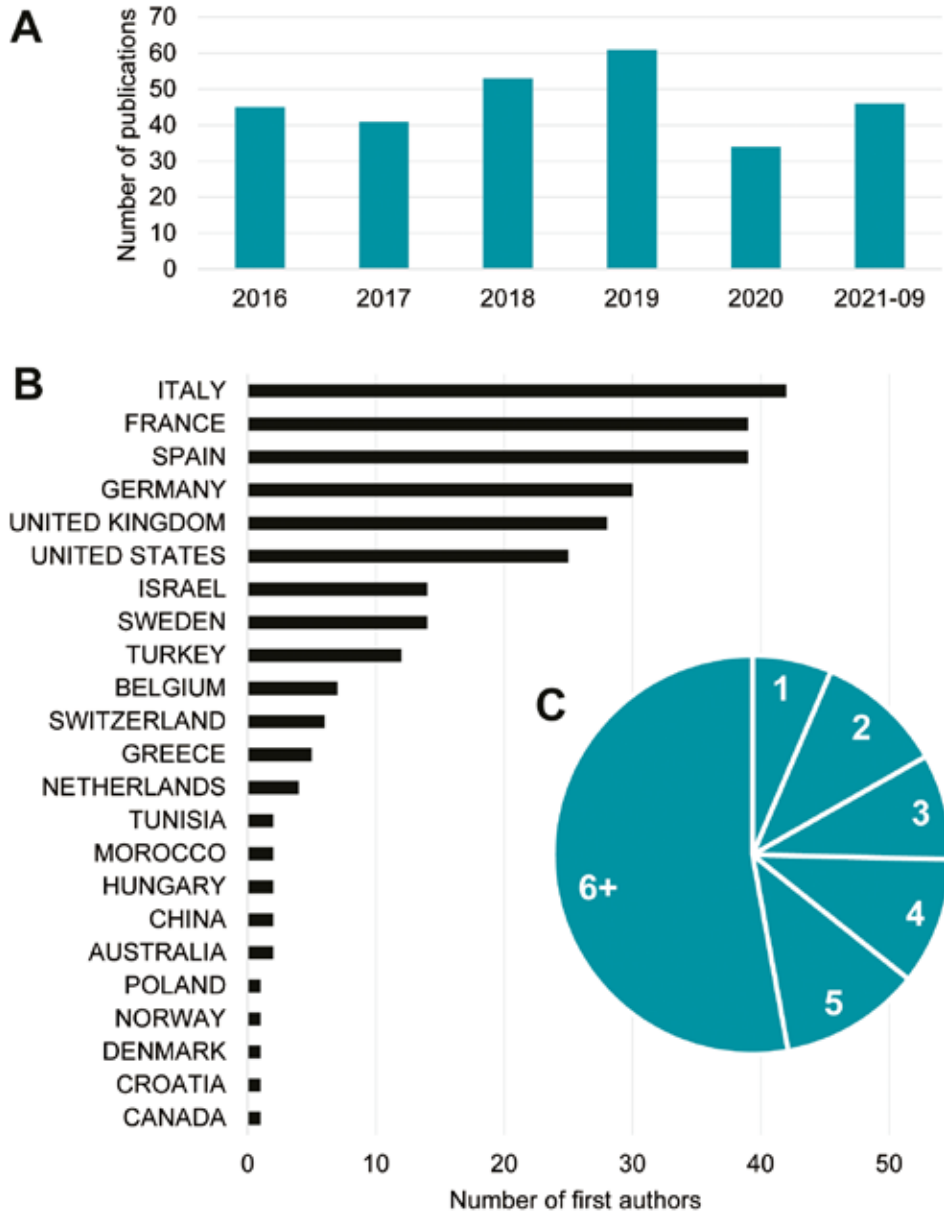


Fig. 1. Considerations of a research environment, including (A) the number of articles per year (2021 only up to 27 September), (B) the country of affiliation of the first authors, and (C) the number of authors per article. Illustration by E. Weiberg and M. Finné.

content and research foci (Fig. 2) in an approach similar to that of Pesta *et al.*<sup>16</sup> Not all journals use author keywords and 44 articles were thereby excluded from this part of the exercise, leaving 236 articles and a total of 1,531 keywords, resulting

in 817 unique keywords.<sup>17</sup> These unique keywords were first categorized according to seven general categories: Geography, Discipline, Chronology, Method, Archive, Proxy, and Topic, and thereafter into subcategories to explore the variability (for

<sup>16</sup> Pesta *et al.* 2018, 2, 11. Author keywords represent the most important *c.* five words in an article based on the opinion of the authors and can be used to detect common and perhaps trending research topics.

<sup>17</sup> The number of separate keywords counted after standardization of variabilities due to spelling, singular/plural use or the use of abbreviations. Articles with and without keywords are specified in *Supplemental information* at <https://doi.org/10.30549/opathrom-15-07>.

full details, see *Appendix*). The author keywords do not give a full picture of the content but serve to gauge the central points of the articles from the perspective of the authors. The following sections will use the seven general categories to sketch the outline of the research environment dedicated to the study of human-environment dynamics in the Mediterranean from the Neolithic period to the Roman era.

## GEOGRAPHY

Keywords denoting the geographical focus ( $n=255$ ) of the studies illustrate the pan-Mediterranean perspective of the present review. A majority of the keywords are rather general, defining the studied region in relation to relatively large geographical areas, such as the whole or parts of the Mediterranean ( $n=43$ ), or modern countries and parts thereof (for details, see *Appendix*). Although less common, a number of studies nevertheless are considerably more local and even in a few examples linking to one site specifically, such as Arslantepe, Kultepe, Petra, Phaistos, Pompeii and Utica.<sup>18</sup> Overall there is a reasonable balance between different parts of the Mediterranean, although with some dominance of its central and eastern parts. The facts that we used English-language search strings did not have any clear effect on the affiliation of the authors. Rather than an Anglo-Saxon academic environment of the authors, the top affiliations are: Italy, France and Spain (*Fig. 1B*). A second group comprised Germany, the United Kingdom and the United States. Given the prominence of these countries in most fields of research, the composition of this second ground was an expected outcome, but that these three are followed by Israel and Sweden is noteworthy. Israel-led projects may perhaps be put down to geography and relatively high per capita research funding.<sup>19</sup> The Swedish contributions, on the other hand, testify to a long research history in Greece, and in the Peloponnese particularly, and more recently to a strong research environment of collaborative efforts focused on human-environment dynamics, initiated by an innovative and very consciously interdisciplinary research effort in 2008 that led on to multiple research projects.<sup>20</sup> There are only a handful of lead authors with a Greek affiliation, although keywords belonging geographically to the Balkans—predominantly Greece—are

the most common. Case-studies from Iberia (predominantly Spain) and Italy are also common and can in some respect be correlated with the frequency of lead author affiliations. Near Eastern and Anatolian case-studies are only partially correlated with the affiliations, signifying, as in the case of Greece, a considerable degree of international involvement, something that is the most apparent among the southern Mediterranean/north African case-studies. Importantly, these conclusions are based on the affiliation of the lead authors and not their actual nationalities and do therefore not capture academic mobility in either direction.<sup>21</sup>

## DISCIPLINE AND CHRONOLOGY

Human-environment dynamics is a topic that brings together a large number of disciplines, a circumstance that is clearly evident among the selected articles. Here we use “discipline” in a loose sense, denoting separate fields of research that are either academic disciplines, such as archaeology, or subdisciplines, such as archaeobotany, which is commonly regarded as a subdiscipline of archaeology. The keywords denoting a “discipline” are tied to specific interests, materials and scientific approaches but commonly also have an effect on chronological perspectives as well as the choice of journals and the size of the author groups.<sup>22</sup>

All in all, 168 keywords were deemed to reflect a discipline (see details in *Appendix*), divided into the subcategories of *Humanities and Social sciences*, *Natural science*, and *Intermediate*, the latter of which is tied together by a concern for the reconstruction of cultural landscapes from an environmental perspective. The Humanities and Social science subcategory of articles is dominated by keywords relating to the discipline of archaeology with only three keywords tied to the history discipline. “Archaeology” is in fact the most common individual keyword in this subcategory, followed by “geoarchaeology”, “palynology” and “archaeobotany” in the Intermediate subcategory. The Natural science subcategory is more fragmented and “palaeoclimatology”, for example, is less frequent than might be expected given the search strings, but this is offset by the high frequency of keywords related to palaeoclimate and climate change. The low frequency of “history” as a keyword, however, deserves special consideration. To some extent this outcome is expected. Via our search strings, we have favoured archaeological studies, and, we have excluded later historical periods (later than *c.* AD 300). Still, it is a noted fact that archaeologists and archaeological per-

<sup>18</sup> Bouchaud *et al.* 2017; Ghilardi *et al.* 2018; Masi *et al.* 2018; Şenkul *et al.* 2018; Pleuger *et al.* 2019; Vignola *et al.* 2021.

<sup>19</sup> OECD n.d.

<sup>20</sup> Sinclair *et al.* 2010. We would like to extend our gratitude to the directors of this effort—the *Urban Mind* project—Professors Gullög Nordquist and Paul Sinclair, Department of Archaeology and Ancient History, Uppsala University, who brought the current authors together and set us on the way towards interdisciplinary collaborations in general and human-environment dynamics in particular.

<sup>21</sup> Only the first-mentioned affiliation was included and although some authors have double affiliations, or more, these are a minority and most relate to institutions in the same country.

<sup>22</sup> Izdebski *et al.* 2016, 16–17.

spectives have dominated in interdisciplinary collaborations on human-environment dynamics and that (ancient) historians have shown less interest in these questions.<sup>23</sup> The lack of studies among our set of articles that focus on the Greco-Roman period—only 10% of the keywords denoting chronology (n=202) indicate a focus on a historical period (c. 1000 BC–AD 300)—shows that this is not only a disciplinary gap (archaeologists versus ancient historians) but a notable invisibility of the Greco-Roman period as such in this type of studies. This is not to say that the historical periods are not covered in the present articles. Many of the studies apply long-term chronological perspectives, but compared to the larger quantity of Neolithic and Bronze Age studies, the lack of historical case-studies stands out. The most common chronological indicator is “Holocene”, emphasizing the long-term perspectives of many studies, but this particular concept also indicates a natural science bias of these studies. Given the overall dominance of the relative chronology among the chronological keywords (e.g. “Neolithic”, “Late Bronze Age”, etc.), however, it seems fair to say that a majority of the studies, including the more natural science-oriented ones, are adapted to relative chronologies and periodization used within archaeology.

Turning to the choice of journals, a majority of the studies captured in our search of *WoS* looks beyond the common archaeological outlets. While 26% of the 78 journals are indeed archaeological journals, they have only attracted 19% of the articles included here, and half of these are found in the science-oriented *Journal of Archaeological Science (JAS)* and *JAS Reports*. In contrast, 36% of the articles are to be found in three high-ranked, primarily natural-science-based journals: *Quaternary Science Reviews*, *Quaternary International* and *The Holocene*. Archaeology articles typically have a limited number of authors but over half of the articles analysed here list six or more authors, which is more typical of natural sciences. Only 17% of the articles have one or two authors as is more common in archaeological publishing (Fig. 1C). The common occurrence of articles with many authors highlights the complexity of many of the studies and their multidisciplinary (if not always interdisciplinary) nature. It also reflects the tradition of natural science publishing, within which e.g. analytical or methodological contributions often merit co-authorship. Publishing in science-based journals has a number of advantages: they have often a quick turn-over time, the addition of supplementary online information is commonplace, and they often have a high-impact factor. From an archaeological point of view, what you lose in terms of intra-disciplinary visibility and disciplinary competence, you gain in interdisciplinary visibility and citations. Archaeologists have a long tradition of multidisciplinary work and archaeol-

ogy as a discipline incorporates science-based subdisciplines such as geoarchaeology, archaeobotany and zooarchaeology. The threshold for an archaeologist to publish in science-based journals is likely to be considerably lower than for a historian, for example.<sup>24</sup>

## METHOD, ARCHIVE AND PROXY

The keywords specifying the type of method employed to investigate past human-environment dynamics in the Mediterranean (n=119) provide an overview of the range of methods used. These are in turn linked to specific archives (n=31), and proxies (indirect indicators) (n=126). Lacustrine and wetland sediments and speleothems (cave stalagmites)—the most commonly utilized natural archives for palaeoenvironmental and palaeoclimate studies—make up roughly two-thirds of the archive keywords. The vast majority of the proxy keywords can be directly attributed to studies of palaeoenvironments and palaeoclimate and broadly divided into fossils (on-site macrofossils such as seeds and charcoal, but including also charcoal particles, pollen grains and other microfossils from off-site sediment cores) and different types of isotopes (represented by oxygen, hydrogen, nitrogen, strontium and carbon isotopes) (see details in *Appendix*).

The versatility of isotope analysis transcends conventional disciplinary boundaries, its use spanning from palaeoclimate analyses<sup>25</sup> to the study of human population migration.<sup>26</sup> The development during the last decade of stable nitrogen and carbon isotope analyses have allowed for reconstructions of ancient agricultural strategies and palaeodiets.<sup>27</sup> Climate is generally not a direct focus in these studies but implicit through discussions on water availability, or water status conditions, frequently necessitating comparison with palaeoclimate records to sort out natural factors from active water management, either by direct watering or by seeking out more naturally well-watered fields for some crops.<sup>28</sup> Pollen, however, remains the most prevalent proxy for environmental reconstructions, crucial for our understanding of land cover (vegetation) as well as land use. Also here, there has been a considerable method development during the last decade or so, primarily in terms of the inclusion of a wider spectrum of proxies from within the same sediment core, such as biomarkers<sup>29</sup> and micro-charcoal.<sup>30</sup> Such multi-proxy analyses

<sup>23</sup> Izdebski *et al.* 2016; Post 2017; see also Haldon *et al.* 2018.

<sup>24</sup> Izdebski *et al.* 2016, 16–17; Ljungqvist *et al.* 2021, 16.

<sup>25</sup> Finné *et al.* 2019; Surić *et al.* 2021.

<sup>26</sup> Gregoricka & Sheridan 2017.

<sup>27</sup> Bogaard *et al.* 2013; Nitsch *et al.* 2017; Styring *et al.* 2017.

<sup>28</sup> Mora-González *et al.* 2018; Dotsika & Diamantopoulos 2019; Mora-González *et al.* 2019.

<sup>29</sup> Thienemann *et al.* 2017; Norström *et al.* 2018; Katrantsiotis *et al.* 2019.

<sup>30</sup> López-Merino *et al.* 2017; Connor *et al.* 2019; Lestienne *et al.* 2019.



have been sought after to facilitate chronological correlation between datasets, and are crucial for considerations of causality.<sup>31</sup> But the desire for multi-proxy analyses goes further and brings to the fore the need to establish other datasets, specifically for human activity, as a basis for what can be called multi-*archive* analyses of human-environment dynamics.<sup>32</sup> In that vein, there has been a recent upsurge in numerical methods to investigate demographic change. One such method, summed probability distributions (SPD), utilizes and synthesizes the wealth of radiocarbon dates from the Mediterranean as a population proxy. Results of SPD analyses have been correlated with traditional analyses of settlement patterns using sites identified in field surveys, which remains the most common archaeological proxy for demographic change and for large-scale comparisons with environmental data. These correlations have made clear that radiocarbon SPD have a positive correspondence with patterns based on archaeological site data, and that SPD can be very useful when archaeological settlement data are lacking or for highlighting variability within relative chronologies.<sup>33</sup> However, the SPD results should be seen as an indicator of relative rather than absolute change.<sup>34</sup> Archaeologists selectively radiocarbon date certain chronological periods, leading at times to exaggerations of inferred demographic fluctuations. Parallel developments can be seen in the synthesis of regional site surveys into larger, supra-regional datasets,<sup>35</sup> and especially the testing of new methods to process these datasets for comparison with environmental records. One example is the aoristic approach that compensates for the sometimes very unequal lengths of archaeological periods and thus helps to offset some of the chronological staticness of regional survey data.<sup>36</sup> In parallel, different varieties of kernel density estimations have been developed that convert point pattern data to land use areas that are better equipped to estimate the overall spatial extent of land use and the environmental specifics of any fluctuations therein.<sup>37</sup>

<sup>31</sup> Izdebski *et al.* 2016, 15–16; Servera-Vives *et al.* 2018, 11.

<sup>32</sup> Izdebski *et al.* 2016, 15; e.g. Bevan *et al.* 2019 and the articles included in the 2019 *Holocene* special issue stemming from the *Changing the Face of the Mediterranean* project.

<sup>33</sup> Lillios *et al.* 2016; Bevan *et al.* 2019; Roberts *et al.* 2019a; Palmisano *et al.* 2017. See also Palmisano *et al.* 2021a; Parkinson *et al.* 2021.

<sup>34</sup> Weiberg *et al.* 2019a, 755; Palmisano *et al.* 2021a, 5–8.

<sup>35</sup> What constitutes a “region” is something of a grey area and can differ vastly between disciplines. A region is generally smaller in archaeology (a survey region, or a culturally defined area) than in palaeoclimatology, for which an archaeological region more likely would be considered a part within a larger region. Notably, “region” is only one of several concepts that need special attention in interdisciplinary collaborations; others include for instance long-term/short-term and other chronological terminologies, see e.g. Lane 2015; Izdebski *et al.* 2016.

<sup>36</sup> Palmisano *et al.* 2017; Weiberg *et al.* 2019a; Woodbridge *et al.* 2019.

<sup>37</sup> Bonnier & Finné 2020; Lawrence *et al.* 2021; Weiberg *et al.* 2021.

Notable among the method keywords are also the modelling approaches, predominantly linked to land use. These are connected to agricultural productivity and water availability, modelling runoff, irrigation or crop yields,<sup>38</sup> and to ways of assessing the content and spatial extent of land use and potential climate change impacts.<sup>39</sup> Comprehensive Earth System Models (ESM) have made it possible to simulate the climate system and the interactions and feedbacks among the climate subsystems, e.g. physical, chemical and biological processes, in order to improve our understanding of the past, current and future climate system. Recent efforts among archaeologists aim towards quantification of ancient land use in a way that can be used to improve the understanding of anthropogenic land cover change, specifically assumptions regarding per capita land use currently used in global-scale ESM models.<sup>40</sup> While these efforts are predominantly directed towards the needs of developing data and models to predict future scenarios, modelled climate information is also increasingly used to understand past human-environment interactions in the Mediterranean world. The usefulness of modelled climate sequences (ESMs as well as lower-resolution and hence less computationally demanding Global Circulation Models, GCMs) to investigate and understand societal change have been demonstrated by ongoing work in Anatolia, Mesopotamia and France.<sup>41</sup>

## TOPIC

The largest category of keywords (n=630, 41%) was divided into nine general subcategories: Climate, Environment, Hydrology and soil, Land cover, Landscape, Land use, Dynamics, Theory and concepts, and Archaeology and history (*Fig. 3*, and *Appendix*). Due to the great number and variety of topics, keywords in these subcategories were further divided into additional thematic keyword-based groups (called “thematic groups”) based on the materials used and the aspect of human-environment dynamics primarily indicated. Space does not allow a full consideration of the details of these themes or of the results of the individual studies. The following overview will therefore focus on the major themes, each exemplified by references to relevant studies, while a more detailed view of some of the studies will be given in the second part of this article. The brief

<sup>38</sup> Meister *et al.* 2018; Bruins *et al.* 2019; Contreras *et al.* 2019; Kaptijn & Ertsen 2019; Whitford 2019; Van Loo & Verstraeten 2021; Ankan *et al.* 2016.

<sup>39</sup> Knitter *et al.* 2019; Bernigaud *et al.* 2021; Vidal-Cordasco & Nuevo-López 2021.

<sup>40</sup> Weiberg *et al.* 2019b; Morrison *et al.* 2021. See also the *Past Global Changes* (PAGES) LandCover6k project: <https://pastglobalchanges.org/science/wg/landcover6k/intro>.

<sup>41</sup> Ankan & Yıldırım 2018; Gauthier 2016; Contreras *et al.* 2018b; see also Cookson *et al.* 2019.

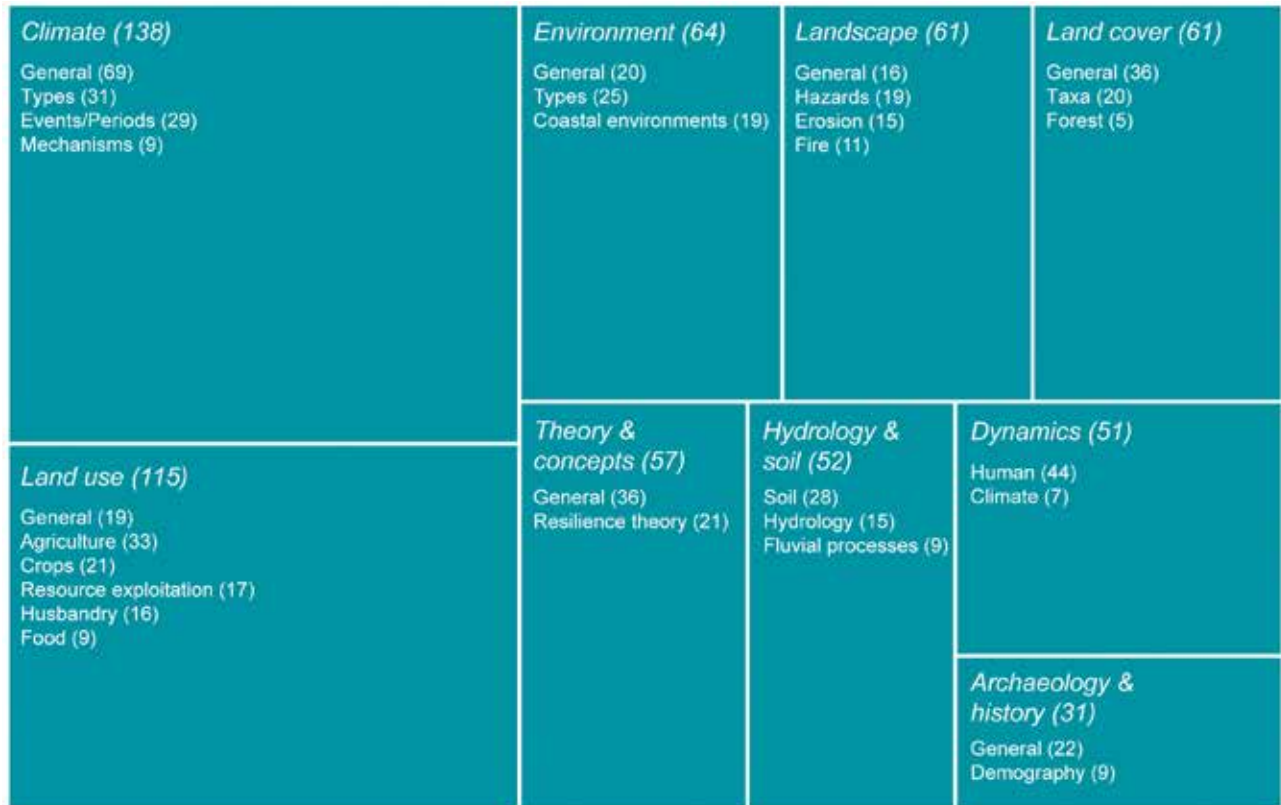


Fig. 3. The relative importance of the groups of keywords in the Topic category illustrated as a tree map, with the size of each box indicating the number of keywords assigned to each specific subcategory and further divided into thematic groups. Absolute number of keywords are given for each subcategory as a whole as well as for the thematic groups. See also Appendix. Illustration by M. Finné and E. Weiberg.

overview below provides a smorgasbord of avenues for further study based on the readers’ interests. Overall, the themes highlight the special climatic and environmental conditions in the Mediterranean, as well as the challenges these bring. Notably, however, many of the themes are important for our understanding of human-environment dynamics in the past and for understanding how changes in the past may provide insights for the future of these and similar environments, and resonate very well with the grand challenges and priority research questions listed for archaeology, historical ecology and palaeoecology.

As a reflection of the search strings used, *Climate* (n=138) is the single largest subcategory, dominated by general keywords such as climate and climate change. Specific keywords in this subcategory signify the continued interest in chronological periods allegedly connected to rapid climate change (RCC) (“events”) and their detrimental effects on human societies, most notably the rapid climate events at 4.2 ka BP (i.e. 2250 BC).<sup>42</sup> A clear

focus on hydroclimate, primarily controlled by precipitation and evapotranspiration, is evident, reflecting the importance of water and water availability in the relatively dry Mediterranean. This stands in contrast to northern Europe, for example, where temperature is a more decisive factor for human activities and specifically for agriculture, and studies favouring temperature are also more prominent as shown by a recent research overview of climate and society in later European history.<sup>43</sup>

As with climate, many of the keywords denoting *Environment* (n=64) are general in nature, signifying the interest in reconstructing palaeoenvironments, while other keywords describe types of environments or places that lack specific geographical markers, such as “dune”, “karstic cave” and “wetland”. A special interest can be discerned for the dynamic coastal environments that can be found around the Mediterranean Sea and their evolution across time, including investigations of sea

<sup>42</sup> Lillios *et al.* 2016; Blanco-González *et al.* 2018; Jalali *et al.* 2019; Jalali & Sicre 2019; Ocakoğlu *et al.* 2019; Whitford 2019; Schirmacher *et al.* 2020; Lawrence *et al.* 2021.

<sup>43</sup> Ljungqvist *et al.* 2021, 4.

level and sea-level fluctuations,<sup>44</sup> with clear links to projected sea-level rise linked to the warming of the Mediterranean.<sup>45</sup>

The subcategory *Hydrology and soil* (n=52) comprises a set of keywords that relates to hydrology and hydrological processes, and describes soils, soil types and processes affecting and altering soils, as well as a number of fluvial processes and landforms. Many of the keywords related specifically to soils are linked to agricultural practices highlighting an interest in understanding how soil and soil quality affects agricultural potential of an area.<sup>46</sup> A related set of keywords signals a special interest in water availability and links to projects on agricultural terrace systems in the Mediterranean.<sup>47</sup> Overall, this is a rather technical subcategory with a strong natural science emphasis but with important links to agriculture and forms of human land use.

Various aspects of vegetation dynamics, including the evolution of natural vegetation, and aspects of Mediterranean land cover beyond agricultural areas are captured in the *Land cover* (n=61) subcategory. Included in this subcategory are keywords that relate to vegetation on a general level while another group of keywords is more botanic/systematic and contains plant types, families and species. The latter thematic group includes species and taxa that primarily represent the Mediterranean-type forest and woodlands, with studies focusing specifically on pine, fir, beech or oak.<sup>48</sup> Overall, most keywords in the subcategory come from pollen-based studies that take long-term perspectives on vegetation change and its causes, with additional links to anthracology and the exploitation of woodland resources.<sup>49</sup>

The keywords in the subcategory *Landscape* (n=61) are in different ways linked to landscapes and landscape types but also to processes that occur at landscape level and are important agents in shaping the landscape. A general focus on landscapes per se are complemented by studies of fire, erosion and other types of environmental hazards. While erosion has been a core topic among human-environment interaction studies for a long time,<sup>50</sup> the interest in fire and hazard studies seems to have increased more recently. Studies on fire regimes cover the full span of the Mediterranean, although with an emphasis on the central and western parts, and explore the impact of fires—anthropogenically induced and/or natural—on the

vegetation cover.<sup>51</sup> Many of the studies relating to fire provide a clear view towards current and future woodland management by raising issues of biodiversity and wild fire control.<sup>52</sup> A small group of keywords relate specifically to flood hazards,<sup>53</sup> while other keywords are directly linked to tectonic hazards (i.e. earthquakes, tsunamis and volcanoes),<sup>54</sup> highlighting how tectonically active parts of the Mediterranean are, especially the central and the north-eastern parts.

The second largest subcategory relates to *Land use* (n=115), which beyond general mentions of “land use” showcases core economic components of ancient Mediterranean societies, namely—in order of quantity—agriculture, crops, husbandry, resource exploitation, and food (*Fig. 3* and *Appendix*). Most commonly the keywords are of a general kind, defining the studies as relevant to agriculture/farming in general terms, while others link to husbandry in a similarly general way. The thematic group incorporating crops, however, clearly reflects the three traditional staples in the Mediterranean: grain, olive oil, and wine (the Mediterranean triad), of which olive is the most prevalent.<sup>55</sup> Perspectives of resource exploitation are dominated by wood management for fuel and water management/harvesting.<sup>56</sup> A final and smaller group refers to issues of food production and storage with considerations of the sustainability of food production.<sup>57</sup> With food security being a key topic in current sustainability debates, the studies of this topic within archaeology is likely to increase.<sup>58</sup>

The subcategory *Dynamics* (n=51) captures keywords that define human-environment-climate dialectics. The most common unique keyword here is “human impacts” (the third most frequent keyword used overall, a position shared with the chronological keyword “Bronze Age”) and covers a broad range of studies that are mostly multi-proxy with a focus on vegetation histories and environmental reconstructions studying the strength and variety of the impact of human socie-

<sup>44</sup> Geraga *et al.* 2017; Dean *et al.* 2019; Gzam *et al.* 2019; Ronen & Almagor 2021.

<sup>45</sup> Vacchi *et al.* 2021.

<sup>46</sup> Braje *et al.* 2017; Contreras *et al.* 2018b; French *et al.* 2018; Van Loo & Verstraeten 2021.

<sup>47</sup> Stavi *et al.* 2018; Bruins *et al.* 2019; Moreno-de-las-Heras *et al.* 2019; van Bommel *et al.* 2021; see also Brown *et al.* 2020.

<sup>48</sup> Beffa *et al.* 2016; Aranbarri *et al.* 2020; Tinner *et al.* 2016; Morales-Molino *et al.* 2021; Moser *et al.* 2017.

<sup>49</sup> Deckers 2016; Picornell-Gelabert *et al.* 2021.

<sup>50</sup> Bintliff 2002; Butzer 2005.

<sup>51</sup> López-Sáez *et al.* 2018; Marriner *et al.* 2019; Mercuri *et al.* 2019b; Norström *et al.* 2021.

<sup>52</sup> Tinner *et al.* 2016; Connor *et al.* 2019; Lestienne *et al.* 2019; Morales-Molino *et al.* 2021; Pedrotta *et al.* 2021.

<sup>53</sup> Liritzis *et al.* 2019; Rapuc *et al.* 2019; Bini *et al.* 2020; Pennos *et al.* 2021. Hazards denote events that may cause adverse consequences for humans and societies and objects and things of value to them.

<sup>54</sup> Katrantsiotis *et al.* 2016; Liritzis *et al.* 2019; Werner *et al.* 2019; Zanchetta *et al.* 2019.

<sup>55</sup> D'Auria *et al.* 2017; Finkelstein & Langgut 2018; Langgut *et al.* 2019 (overview article); Mercuri *et al.* 2019b; Caracuta 2020; Galili *et al.* 2021; Jouffroy-Bapicot *et al.* 2021.

<sup>56</sup> Fuel: Bouchaud *et al.* 2017; D'Auria *et al.* 2017; Janssen *et al.* 2017; Marinova & Ntinou 2018; Picornell-Gelabert *et al.* 2021. Water: Pustovoytov & Riehl 2016; Enrich & Mejias 2017; Junge *et al.* 2018; Meister *et al.* 2018; Bruins *et al.* 2019; Kaptijn & Ertsen 2019.

<sup>57</sup> Meister *et al.* 2018; Kaniewski *et al.* 2019; Dibble & Finné 2021; Gastra *et al.* 2021; Jazwa & Jazwa 2021; Weiberg *et al.* 2021.

<sup>58</sup> Cf. Nelson *et al.* 2016

ties on their environment. While most keywords put humans in primary focus (“human impact”, “human-environment interaction”),<sup>59</sup> a small group favours climate (“climate impact”, “climate adaptation”),<sup>60</sup> which leaves humans in a more responsive position vis-à-vis the environment.

The keywords in the subcategory *Theory and concepts* (n=57) also highlight human-environment-climate dialectics and specifically how humans relate, react and adapt to their environment and any changes therein. It is a very diverse set of keywords and the only grouping that can be discerned is made up of keywords related to the framework of resilience theory, such as the concept “resilience” itself,<sup>61</sup> which together with keywords such as “sustainability”, “adaptation”, “adaptive cycle”, “vulnerability” and “mitigation” signify an interest in current sustainability debates. In conjunction with the continued interest in periods of rapid climate change highlighted above, this group of keywords also signifies an interest in nuancing our understanding of the linkages between environmental and societal change.

Finally, keywords related to *Archaeology and history* (n=31) constitute the smallest subcategory, which perhaps can be seen as a reflection of the lack of significant archaeological proxies for studies of human-environment dynamics beyond those signifying demography in some sense, based on settlement patterns and radiocarbon SPD.<sup>62</sup> Such demographic indicators make up the only group of keywords that stands out in this subcategory and, as already noted, this is also a topic that has seen considerable methodological development recently.

## SUMMARY: THE SIGNIFICANCE OF KEYWORDS

The nine subcategories within the Topic category provide insight into the main themes of present-day research on human-environment dynamics in past Mediterranean societies. Moreover, the keywords of many articles are spread across these subcategories, signifying the interdisciplinary nature of this research environment unified by an interest in human-environment dynamics. Together with the keywords of the other categories (Geography, Discipline, Chronology, Method, Archive and Proxy), they provide the outlines of a research environment that is continuously developing in parallel with new techniques and new lines of enquiry. Considerations of author affiliation and the composition of author groups sup-

port the diversity of the group of scholars, both in terms of numbers of authors as well as regarding disciplinary and national affiliation.

Moreover, a survey based on keywords allows some focus on the motivations behind the choices of keywords. There are likely to be differences in how much thought goes into the choice of keywords, whether they are selected quickly and by necessity or after more thorough consideration and for a specific purpose. The purpose may be to define the study thematically, geographically and chronologically. It could also be to highlight the source material used and/or specifically to spark the interest of an intended readership or link to current trends. The choice to include “archaeology” among the keywords, for example, marks a discipline but is also closely tied to a specific type of source material. The keyword can be used to set the study apart from studies using historical sources, or it can be a way of highlighting the use of archaeological source material within a research field commonly more directed towards sources beyond the humanities and social sciences. In the latter case it could be to emphasize that the study includes direct evidence from the human side of human-environment dynamics. Such details are difficult to pick out from the keywords themselves, but allow room for future and more detailed studies of the links between keywords, affiliations, citations and the actual content of the articles.<sup>63</sup> Based on the present review, it can nevertheless be concluded that the keywords are generally rather technical in nature, providing information on the ingoing datasets, the source material and the methods, and sometimes the theoretical perspectives, rather than the results of the studies themselves.

## Part two: understanding change across time and space

In this second part of the article, we range beyond the keywords and go into some further detail regarding the results in some of the 280 articles. The purpose is to discuss some overarching considerations relevant to them all, specifically issues of time and scale and their relevance for our understanding of causality within human-environment dynamics. These issues will provide insights into the challenges as well as the potentials of studying human-environment dynamics, and the key importance of interdisciplinary efforts. Notably, there are calls for action among the selected articles, and others published during the last five years, that highlight the need for such interdisciplinary research, showing that human-environment dynamics is a vibrant field of study that remains under scru-

<sup>59</sup> Contreras *et al.* 2018a; López-Sáez *et al.* 2018; Marinova & Ntinou 2018; Marriner *et al.* 2019; Mercuri *et al.* 2019b.

<sup>60</sup> Marston & Branting 2016; Contreras *et al.* 2019.

<sup>61</sup> Flohr *et al.* 2016; Alcock 2017; Primavera *et al.* 2017; Weiberg & Finné 2018; Kaptijn & Ertsen 2019; Azuara *et al.* 2020; Weinelt *et al.* 2021.

<sup>62</sup> Drake *et al.* 2017; Berger *et al.* 2019; Palmisano *et al.* 2019; Weiberg *et al.* 2019a.

<sup>63</sup> E.g. Pesta *et al.* 2018.

tiny in terms of best practice, ways forward and the remaining challenges.<sup>64</sup> A special emphasis is put on the need for reliable communication across disciplines, between the humanities and natural sciences,<sup>65</sup> but also between more closely related fields of study, such as between palaeoecology and ecology.<sup>66</sup> Only through such joint attempts are we likely to come close to disentangling and understanding, for example, the variable effects of natural and anthropogenic changes on the environment or the intricacies of human-climate relationships. Such collaborative efforts entail hard work and a mutual understanding of the potential, but importantly also the challenges and uncertainties of each of the discipline-specific datasets employed in interdisciplinary studies in order to avoid simplistic explanations.<sup>67</sup> The methods for combining discipline-specific datasets need also to be carefully considered and the choices made transparent, not least in terms of chronological comparability and means for identifying and critically assessing causal relationships between processes and events.<sup>68</sup> In the same vein, we find a concern for more theoretical and interpretative issues associated with questions of time, scale and complexity.<sup>69</sup> These strongly interlinked issues are quintessential to the study of human-environment dynamics and for studies of past human societies overall.

As a reflection of the prominence of “climate” in the search strings used, the discussion below focuses on issues of climate and climate change relative to human societies, which will inevitably also include issues of more environmental concern. Climate conditions and climate change can have far-reaching effects and impacts on many variable aspects of human societies. These effects can be seen as variables connected to climate change itself: there are direct physical effects (first-order impacts) that may affect the quantity and quality of agricultural production, for example, which in turn can influence human livelihoods and the socio-economic system (second-order impacts), which can have considerable social and demographic implications (third-order impacts), and trigger cultural responses (fourth-order impacts), and all along this trajectory, any change that occurs can initiate adaptation strategies and mitigation measures to deal with the effects of change.<sup>70</sup> Generally, the climate of the Mediterranean area is characterized by dry summers and mild wet winters modulated by altitude,

creating a number of climate and vegetation zones.<sup>71</sup> Precipitation displays strong interannual variability across the region, and there is a general decline in the amount of rainfall and in the length of the wet season towards the east. Due to high interannual variability and rainfall constraints, climate is often seen as a limiting factor and as a key parameter for agriculture, fresh water supply as well as for vegetation change.<sup>72</sup> In academia, due to these limiting factors, the formation, growth and durability of societies during the Holocene has frequently been linked to climate and to climate change, correlations which have also been challenged.<sup>73</sup>

### TIME: LONG-TERM VERSUS SHORT-TERM PERSPECTIVES

The temporal scope of a study will affect the level of contextual detail that can be incorporated and will thereby also influence the questions that can be asked and answered. A wider temporal scope will inevitably require higher degrees of generalization.<sup>74</sup> Evaluation of long-term processes serves nevertheless the key purpose of highlighting general patterns and completed trajectories of change that are more easily compared to other case-studies.<sup>75</sup> Short-term perspectives allow more room for details but run the risk of overlooking the effects of slower working processes of relevance for a specific outcome.

Looking from the perspective of the entire Holocene, the scale of human presence and the impact of this presence on the environment has increased exponentially across the millennia.<sup>76</sup> Notably, the general population growth runs in parallel with a general and continuous aridification trend that is especially noticeable in the southern and eastern Mediterranean.<sup>77</sup> On this level, it must be concluded that ancient societies developed despite the deterioration of climatic conditions and, if anything, climate served as “a prompt and stimulus to innovation rather than retarding societal development”.<sup>78</sup> This seems especially true from the beginning of the Bronze Age onwards, when several studies note a decoupling of climate and demographic trends.<sup>79</sup> There is also evidence for simultaneous decoupling of climate and vegetation, with changes

<sup>64</sup> Among the selected articles: Izdebski *et al.* 2016; Marignani *et al.* 2017; Post 2017.

<sup>65</sup> Izdebski *et al.* 2016.

<sup>66</sup> Marignani *et al.* 2017.

<sup>67</sup> Izdebski *et al.* 2016, 19; Marignani *et al.* 2017, 904; Degroot *et al.* 2021, 542.

<sup>68</sup> Contreras 2017, 8–10; Degroot *et al.* 2021, 541–542; Ljungqvist *et al.* 2021, 15.

<sup>69</sup> Holmgren *et al.* 2016, 3–4; Knapp & Manning 2016; Degroot *et al.* 2021, 542; Ljungqvist *et al.* 2021, 16.

<sup>70</sup> Luterbacher & Pfister 2015, 248, fig. 2; Ljungqvist *et al.* 2021, 4, fig. 2.

<sup>71</sup> Izdebski *et al.* 2016, 6, fig. 2.

<sup>72</sup> García-Ruiz *et al.* 2011.

<sup>73</sup> E.g. Middleton 2012; Jung & Wéninger 2015; Knapp & Manning 2016; Haldon *et al.* 2020.

<sup>74</sup> Lane 2015, 15–16; Izdebski *et al.* 2016, 16.

<sup>75</sup> Lawrence *et al.* 2016, 10–11; Allcock 2017, 79.

<sup>76</sup> Roberts *et al.* 2019a.

<sup>77</sup> Finné *et al.* 2019, 854, fig. 4.

<sup>78</sup> Roberts *et al.* 2019a, 931.

<sup>79</sup> Lawrence *et al.* 2016, 2; Palmisano *et al.* 2021b, 22–23.

in land cover being increasingly human-induced from the Bronze Age onwards.<sup>80</sup>

Scaling down to a centennial scale, settlement and population cycles can be noted in most Mediterranean regions, based on the number of identified sites in archaeological surveys and in the fluctuations in radiocarbon SPD.<sup>81</sup> These fluctuations can be chronologically aligned to similarly timed oscillations in climate. Focus remains here on periods of negative climate change (periods of aridity) and their effect on societies; but evidence of the positive effects of wetter climate conditions is also mounting and even evidence of societal expansion despite what is generally seen as unfavourable (i.e. drier) climate conditions on centennial timescales. Studies considering long-term societal development relative to short-term climate change come from across the Mediterranean, most notably studies of the periods leading up to and beyond the 4.2 ka BP (2250 BC) and 3.2 ka BP (1250 BC) climate events. Studies of the vegetation history of the Terramare civilization (1550–1170 BC) confirm the coincidence between arid conditions and the collapse of this civilization. Aridity may have impeded successful management of natural resources and thereby contributed to the societal breakdown, but it also noted that climate could have been one of the main enabling factors for the initial settlement expansion of the Terramare civilization.<sup>82</sup> Similar arguments have been forwarded for Late Bronze Age Greece and the Chalcolithic and Early Bronze Age Fertile Crescent, arguing that periods with above-average rainfall contributed to increased productive capacity and supported settlement expansion, as noted by increased site numbers and arguably population numbers, and resulted in an economic boom.<sup>83</sup> Notably, in both cases, the largest-scale expansion and contraction of settlements occurred in marginal and arguably less fertile areas. The expansion into marginal areas clearly added to the overall vulnerability. In these two cases, as well as in the case of the Terramare civilization, climate change was a factor both in the growth and decline of societies, by facilitating expansion that ultimately led to an unsustainable socio-economic system. Similarly, the Copper and Bronze Ages on the Iberian peninsula have been extensively investigated in relation to demographic cycles and climate change, in terms of long-term change (c. 6000–3000 BP/4050–1050 BC) relative to the 4.2 ka climate event and the Copper to Bronze Age

transition (c. 2400–1900 BC).<sup>84</sup> By contrast to the previous examples, it is concluded in one article that several occupation phases, and especially the El Argar culture (2200–1400 BC) “all partially occurred under preponderantly unfavourable climate constraints.”<sup>85</sup> The authors emphasize the high resilience of these societies enabled by a number of possible adaptive strategies pertaining to the agro-economic system. They also suggest that the progressive erosion of cultural developments and of the efficacy of the adaptive strategies led to socio-environmental “collapse”, especially when reinforced by aggravated climate circumstances and demographic stress.<sup>86</sup> Significantly, the zenith of the El Argar culture is connected to signs of rapid deforestation and changes in the herb community observed in palaeoecological sources, signalling high human pressure and the degradation of natural resources over time.<sup>87</sup>

## SCALE: GEOGRAPHICAL AND CHRONOLOGICAL RESOLUTION

When we now turn to a consideration of scales, it should be noted that temporal and spatial scale do not always go hand in hand. Most notably, vegetation histories and landscape reconstructions generally provide very local data but outline changes in the local environment developing over millennia. An appreciation of chronological resolution is thereby paramount for integration of the results with archaeological and historical information, and other datasets that may be equally local but chronologically more (and sometimes less) highly resolved.<sup>88</sup> From a palaeoclimatological point of view it is primarily at the level of larger regions within the Mediterranean (e.g. the Aegean) that we can detect coherent trends of climate change,<sup>89</sup> and climate model output tends to be similar and often even more large-scale. However, this scale contrasts with the intrinsically local scale of human activities as well as of much archaeological and historical data on which we base our understanding of past human societies. The imbalance between the local human histories and the regional to global character of the climate data presents a challenge. Consequently, there have been recent calls for the need to downscale climate model data.<sup>90</sup> In a local case-study from Provence (south-east France), Contreras *et al.* use low-resolution climate data from a GCM to generate data at the landscape scale by using statistical downscal-

<sup>80</sup> Jaouadi *et al.* 2016, 1349–1350; Miebach *et al.* 2016, 588–589; Glais *et al.* 2017, 418–419; Mercuri *et al.* 2019a.

<sup>81</sup> Allcock 2017; Bevan *et al.* 2019, and all case-studies in that special issue; Lawrence *et al.* 2021; Weinelt *et al.* 2021.

<sup>82</sup> Cremaschi *et al.* 2016, 154, 168–170.

<sup>83</sup> Weiberg & Finné 2018, 593–597; Lawrence *et al.* 2021, 14–16; Weiberg *et al.* 2021, 9–10.

<sup>84</sup> Lillios *et al.* 2016; Blanco-González *et al.* 2018; Schirmacher *et al.* 2020; Weinelt *et al.* 2021.

<sup>85</sup> Weinelt *et al.* 2021, 13–14.

<sup>86</sup> Weinelt *et al.* 2021, 14.

<sup>87</sup> Azuara *et al.* 2020, 9.

<sup>88</sup> Izdebski *et al.* 2016; Knapp & Manning 2016, see also Lane 2015; Finné & Weiberg 2018.

<sup>89</sup> Finné *et al.* 2019; see also Roberts *et al.* 2011.

<sup>90</sup> Contreras *et al.* 2018a.

ing.<sup>91</sup> From the downscaled results they explore how modelled precipitation amounts and temperature may have affected the distribution of settlements in the area over time, showing the potential of downscaling climate parameters. By capturing both spatial variability and interannual variation in climatic factors, the authors argue that it is possible to build better and more complex scenarios regarding how agriculture was affected and what repercussions climate change had for local societies.<sup>92</sup> Ongoing efforts to increase the number and geographical distribution of climate proxy data is another factor that can contribute to better understanding of the regional character of climate change across the Mediterranean (i.e. similarities and differences) but also at the smaller scale. With a denser network of climate records, an opportunity opens up for more locally based comparisons with archaeological and historical data.<sup>93</sup> Some of the highest-resolved and chronologically best constrained climate proxy data come from cave speleothems (stalagmites), although these archives are still relatively few.<sup>94</sup> The number of sediment archives is more substantial and they provide important palaeoenvironmental information.<sup>95</sup> More importantly, they offer the opportunity for multi-proxy analyses that can reveal natural as well as anthropogenically induced changes using proxies from coeval levels. Adding to this are new proxies from wetland and lacustrine sediments, such as highly resolved geochemical data,<sup>96</sup> and stable hydrogen isotopes in leaf wax n-alkanes,<sup>97</sup> both of which record climate-related conditions such as moisture balance, temperature and precipitation. Efforts are also initiated to add new types of climate archives for locally based climate studies utilizing, for instance, shells from land snails to investigate the climate at the very smallest spatial scale.<sup>98</sup> To reach the full potential of the variety of climate archives and proxies, there are still issues to be resolved, specifically related to regional variability and the synchronous differences between nearby climate archives, taking into account varying forcing factors, site-specific responses and chronological precision.<sup>99</sup>

The local environment in a valley or on an island was probably most important for humans and human activities, but comparisons between regions and contexts allow more generalized understandings of the variable societal trajectories,

the range of decisions made, as well as the relevance of climate and other environmental forcing factors. Integrated studies of archaeology and climate have shown, for example, that it is possible to outline disparities in settlement patterns between regions that may indicate variable local responses to regional climate change due to environmental and/or socio-economic circumstances.<sup>100</sup> By scaling up local (and regional) datasets to more general estimates of land use (based on historical sources, archaeology, archaeobotany, zooarchaeology, etc.), it is possible to begin to outline changes in land use across time and space.<sup>101</sup> The spatial requirements of specific livelihoods (the land footprint) can then be estimated and used to quantify the scale of human impact on the environment and thereby the potential vulnerability of human societies to climate change and other external forcing factors. Of great relevance for current-day state of affairs, studies have stressed the considerable impact of diet on our overall footprint,<sup>102</sup> the likely dependency of large (Mycenaean) settlements on non-local food supplies,<sup>103</sup> as well as the considerable impact of climate conditions (due to changing yields) on the overall land footprint.<sup>104</sup> A common denominator is the overriding importance of population levels for the overall human imprint on the landscape, raising the need for further estimates of population densities at both local and regional levels for accurate assessments of human-environment dynamics. This need is currently met by refining available demographic proxies, but we take this opportunity to encourage archaeologists to more frequently attempt to quantify (in absolute numbers) the spatial scale of settlements and/or population numbers, even if the data are less than satisfactory.<sup>105</sup> Many land-use estimates currently used in global-scale models rely on quantifications that are weakly or not at all based on archaeological evidence.<sup>106</sup> Even with broad estimates—of land use as well as population—archaeologists can potentially make important contributions.

When upscaling or downscaling, or when comparing between scales and between disciplines, however, the comparability of the ingoing datasets must be assessed. For the best fit between research questions and data and for the best

<sup>91</sup> Contreras *et al.* 2018b; 2019.

<sup>92</sup> Contreras *et al.* 2018b, 20–21.

<sup>93</sup> Izdebski *et al.* 2016, 18; Degroot *et al.* 2021, 541–542.

<sup>94</sup> Finné *et al.* 2019, table 1, 850–851.

<sup>95</sup> These can be chronologically very well-constrained in rare cases of annually laminated sediments (e.g. Lake Nar: Allcock 2017; Roberts *et al.* 2019b, with references therein).

<sup>96</sup> Allcock 2017; Seguin *et al.* 2019; 2020a.

<sup>97</sup> Katrantsiotis *et al.* 2018; Norström *et al.* 2018.

<sup>98</sup> Lewis *et al.* 2017; Yanes & Fernández-Lopez-de-Pablo 2017; Prendergast *et al.* 2018.

<sup>99</sup> Seguin *et al.* 2020b, 175–177.

<sup>100</sup> Bonnier & Finné 2020; Lawrence *et al.* 2021; Weinelt *et al.* 2021.

<sup>101</sup> Morrison *et al.* 2021; see also Stephens *et al.* 2019. Both studies stem from LandCover6k working group within the *Past Global Changes* (PAGES) project: <https://pastglobalchanges.org/science/wg/landcover6k/intro>.

<sup>102</sup> Hughes *et al.* 2018, 11–12.

<sup>103</sup> Knitter *et al.* 2019, 7–9.

<sup>104</sup> Hughes *et al.* 2018, 12–13; Knitter *et al.* 2019, 7–9.

<sup>105</sup> The propensity for quantified estimates does vary between contexts, partly as a reflection of the natural visibility of settlements and their extension (e.g. in the flat landscape of Mesopotamia: Lawrence *et al.* 2016) and/or on the scale of archaeological activity in any one location (e.g. the urban survey around the palace of Knossos on Crete: Whitelaw 2019).

<sup>106</sup> Weiberg *et al.* 2019b, 2–3; Morrison *et al.* 2021, 3–4.

complementary datasets across disciplines, especially when taking into account the heterogeneous nature of the Mediterranean climate and environments both in the present and in the past, palaeoenvironmental information and archaeological/historical data should come from the same location or at least nearby. Luckily, with the increasing availability of climate proxies across all regions of the Mediterranean, spatially congruent studies are an achievable goal, as the reliance on distantly located palaeoclimate data is reduced in favour of more locally based datasets. In terms of chronology, the key is to let the lowest resolution data guide the overall resolution of the study. On a regional scale, this may mean coarsening the resolution of the climate data to match the relative chronology of the archaeological survey data. Studies of the time from the Middle Bronze Age to the Roman period in the Peloponnese have shown coarsening to be a very effective way to identify coeval cyclicality of climate and societal development. In this case, stable isotope values interpreted to show drier (wetter) conditions in each archaeological period were summed and considered to indicate the overall climate during that specific period.<sup>107</sup> Given that archaeologists generally cannot judge the contemporaneity of sites assigned to each period, an aggregate of sites is thereby compared to an aggregate of climate indicators, and what is lost in climate detail (short-term events) is gained in terms of comparability between the datasets.<sup>108</sup>

### CAUSATION: HUMAN AND CLIMATIC DRIVERS OF CHANGE

The question of anthropogenic versus climatic impacts is a theme that brings to the fore issues of both time, space and resolution of records, and transcends several of the topics highlighted among the selected articles. It is also a theme that is targeted head-on by several of the studies discussed here, showing that the complex question of causation is far from resolved despite considerable research. Something that is increasingly clear, however, is that the answer more often than not lies in the context-specific details. A multiplicity of parallel data series as well as careful considerations of the comparability between them is crucial to move from correlation to causation. In the *Holocene* special issue resulting from the *Changing the Face of the Mediterranean* project, for example, multiple datasets were binned into 200-year time windows.<sup>109</sup> At this level of comparability, it is possible to statistically test the correspondences and potentially the causal linkages be-

tween human, climate and environmental factors of change over millennial and centennial timescales.<sup>110</sup>

Many of the studies, across the Mediterranean, make evident that anthropogenic impacts are strong. The drivers of soil erosion, for example, have been widely debated for several decades, i.e. whether the impact of climate or anthropogenic activities dominates or if it is a combination of the two factors.<sup>111</sup> A 2019 review concluded that there is an overall trend of increased sediment dynamics during the last four millennia (i.e. from the Bronze Age), developing alongside an aridification trend *and* overall population growth. These general trends are complemented by notable local and regional-scale oscillations in the intensity of sediment flux for which few supra-regional correlations can be found.<sup>112</sup> A study based on a very highly resolved varved sediment record from Lake Nar in central Anatolia shows that although in some time windows, high erosion rates concur with arid climate conditions, climate factors alone are not enough to explain erosion and that there is a chronological match between peaks in the total influx of sediments into the lake and indicators of human activity (based on archaeological and/or pollen indicators).<sup>113</sup> Both the 2019 review and the Anatolian case-study assign climate change an amplifying role, acting as pacemaker for erosion events, but that climate change alone, in the absence of human impact, is unlikely to result in increased erosion.<sup>114</sup>

The strength of the human impact is clear also when it comes to the fluctuation of tree cover across time, but the drivers of vegetation change are complex, with climate and human effects interacting. Deforestation constitutes a significant component of the anthropogenic activities influencing erosion, and the statistical evaluation of linkages between demographic proxies and forest extent (as indicated by mean percentage of arboreal pollen [AP]) in 200-year time windows resulted in a significant correlation across time in many of the studied regions, but also that the degree and the sign of the correlation coefficient varied across the Mediterranean.<sup>115</sup> The strongest negative correlation was found in the originally most-wooded areas of the western and central Mediterranean, where mean AP percentages were >65% prior to major human impacts (prior to *c.* 2000 BC).<sup>116</sup> In regions with medium-extent forest cover (30–60% AP), no significant correlation was found and in some regions with <30% AP there was even a positive correlation, signalling that human activities led to

<sup>107</sup> Bonnier & Finné 2020, 1489–1491; Weiberg *et al.* 2021, 4–5.

<sup>108</sup> Weiberg *et al.* 2021, 9.

<sup>109</sup> Roberts *et al.* 2019a, 924–925.

<sup>110</sup> Roberts *et al.* 2019a, 930–935.

<sup>111</sup> Bintliff 2002; Butzer 2005.

<sup>112</sup> Walsh *et al.* 2019, 876–879.

<sup>113</sup> Roberts *et al.* 2019b, 44–46.

<sup>114</sup> Walsh *et al.* 2019, 879; Roberts *et al.* 2019b, 46.

<sup>115</sup> Roberts *et al.* 2019a, 930–931.

<sup>116</sup> See also Berger *et al.* 2019; Fyfe *et al.* 2019.

an overall increase in woodlands.<sup>117</sup> The variations in original tree cover, however, is of course predicated by the climate and vegetation zones of each specific region, and climate effects on forest cover cannot be disregarded. In a study exploring the effect of the 4.2 ka BP climate event on AP in the central Mediterranean, evidence supports an increase and decrease of forest due *primarily* to climate change and only secondarily to human activity (by way of amplification). These effects, however, differed with latitude, with no significant vegetation change noted for locales north of 43° N, but with a marked forest decline south of 43° N indicating a sensitivity of forest communities to arid events, especially south of 39° N (including the southernmost part of mainland Italy and Sicily).<sup>118</sup> A number of Iberian case-studies tie into the same human-climate conundrum relative to the drivers of vegetation change. In north-east Spain, a review of several pollen profiles, with specific attention to Aleppo pine (*Pinus halepensis*), seems to show that vegetation changes were driven more by climate than human factors (e.g. by use of fire for clearing purposes), at least in earlier periods. Here, moister conditions during the Neolithic (7500–3400 BP, or 5550–1450 BC) led to a considerable reduction of the Aleppo pine that was better adapted to the more arid conditions in the preceding and succeeding periods during which this pine species was more prevalent in both palynological and archaeobotanical records.<sup>119</sup> This conclusion stands in some contrast to a study of fire regimes spanning the whole of the Iberian Peninsula that favours the interpretation that the opening of the woodlands during the Neolithic was due to increased anthropogenic use of fire for the management of agricultural lands.<sup>120</sup>

Adding even further to the complexity of understanding human-environment dynamics is the fact that ingoing parameters—climate, environment and human societies—are decidedly complex entities in themselves. As we have seen, the local climate and vegetation zone must be taken into account. If we now turn from a focus on vegetation to the effects of climate change on human societies, there are a number of climate parameters that could be taken into account that likely impacted human societies in different ways. Most studies deal with relative changes in hydroclimate, i.e. periods of wetter or drier conditions, which is the most common parameter in the climate records of the Mediterranean,<sup>121</sup> but a growing number of studies also attempt to incorporate changes in temperature as well as the timing and amplitude of any changes.

Schirmacher *et al.* provide a detailed analysis of a large variety of climate proxies across the Iberian peninsula, discussing trends of seasonality and the impact of superimposing trends of both temperature and precipitation in 200-year time windows (3250–1450 BC), with important considerations also of the quality of the ingoing datasets.<sup>122</sup> Another consideration is the stability of the climate over the short-term (years and decades), with the assumption that increased interannual volatility affects the predictability and therefore the success rate of any social strategies to deal with “normal” variability. Stability in climate, on the other hand, regardless of the exact climate conditions (whether “good” or “bad”), allows societies time to establish productive (risk) management strategies.<sup>123</sup>

These adaptive measures are studied by several of the articles reviewed here. Many articles link to the framework of resilience theory and social-ecological systems (SES), in a few instances using the conceptualization of the adaptive cycle,<sup>124</sup> but more commonly forwarding the ideas of resilience and/or vulnerability in more general terms. In most cases, the level of resilience is gathered from an appreciation of the level of social/economic/environmental/political/demographic change in the face of disturbances, while in other cases the focus is rather on resilience as a measure of societies’ capacity to adapt to changing circumstances and the content of these adaptive strategies. In the first instance, studies suggest a pattern of no-change in the face of climate change, such as the resilience of certain types of vegetation,<sup>125</sup> or the lack of any significant pattern of demographic change.<sup>126</sup> In the second instance, studies highlight, for example, changes in agricultural strategies based on specific environmental conditions and/or following climate change,<sup>127</sup> the benefits of irrigation and rainwater harvesting for cultivation in arid climates and in response to arid events,<sup>128</sup> or the sail as a technology of resilience for small-world connectivity in troubled times.<sup>129</sup> Several studies highlight that the level of resilience—or of adaptive capacity—was dependent on a number of factors, impacting the overall vulnerability of the affected parties to climate change (and other stressors).<sup>130</sup> When dealing with a multitude of both social and natural factors (e.g. connectivity, demography, economy, agricultural strategies, soil productivity, water availability), we need also to consider that

<sup>117</sup> See also Palmisano *et al.* 2019.

<sup>118</sup> Di Rita & Magri 2019, 245–248.

<sup>119</sup> Aranbarri *et al.* 2020, 10–12.

<sup>120</sup> Connor *et al.* 2019, 894–896, which is in line with the strong human impact on vegetation history during the El Argar period (Azuara *et al.* 2020, 8–14) as noted above.

<sup>121</sup> Finné *et al.* 2019.

<sup>122</sup> Schirmacher *et al.* 2020. Notably, given discussions above, using decreasing AP percentages as a climate proxy reflecting decreasing winter precipitation (Schirmacher *et al.* 2020, 5).

<sup>123</sup> Weiberg & Finné 2018, 590.

<sup>124</sup> Allcock 2017; Weiberg & Finné 2018.

<sup>125</sup> Tinner *et al.* 2016; Servera-Vives *et al.* 2018, 20–21; Jouffroy-Bapicot *et al.* 2021.

<sup>126</sup> Flohr *et al.* 2016.

<sup>127</sup> Marston & Branting 2016; Primavera *et al.* 2017; Dibble & Finné 2021.

<sup>128</sup> Junge *et al.* 2018; Kaptijn & Ertsen 2019; Brandolini & Carrer 2021.

<sup>129</sup> Jarriel 2021.

<sup>130</sup> Flohr *et al.* 2016, 35; Contreras *et al.* 2018b, 20–21.

these were unlikely to be equally distributed between—or within—societies and regions.<sup>131</sup> As concluded by Roberts *et al.*, the Mediterranean landscape is a mosaic of regions with distinctive human-environment trajectories and it is imperative to analyse several scales reaching from the pan-Mediterranean to the very local (e.g. a coastal plain or an inland valley) to avoid making simplistic causal relationships.<sup>132</sup> Some but not all climate events led to notable socio-economic changes, and when they did, the effects were unequally distributed within and between societies. The actual impact and the coping strategies therefore differed between contexts. Large-scale syntheses need to be complemented by regional and local, and context-specific analyses, since simplified and monocausal explanations will never adequately address the complexity of human-environment-climate dynamics.<sup>133</sup>

## Concluding remarks

Human-environment dynamics in past Mediterranean societies is a flourishing field of research. This review has sketched the outline of this particular field of study based on 280 separate articles published since 2016. This is by no means the totality of publications during these years, but we propose it to be a representative sample of a very diverse and expansive whole. The search strings favoured studies with some mention of climate, but the bibliometric search picked up an all-encompassing range of thematics. It is still obvious, however, that climate and climate change are prominent issues within Mediterranean human-environment dynamics. Scholarly consideration of these issues has a long history, but this review shows that the discussion on the role of climate and climate impact has matured. Monocausal models connecting climate events and societal collapse, for example, are increasingly replaced by scenarios favouring more nuanced renditions of the sequence of events within which internal societal factors are given more room for play. Still, evidence that shows clear chronological correlation between climate and societal change is mounting and an exclusion of the climate factor would decidedly reduce our understanding of the processes. It is also very clear that establishing causality remains a problem and thereby inhibits a full understanding of the exact mechanisms of change. One way to deal with this problem is to address change—whether human, environmental or climatic—from as many perspectives as possible and through multiple time-series, with attention to their comparability in space and time. As is clearly shown by the results of the selected

articles, mechanisms of change in either domain may not look the same across time and space, and attention needs to be paid to the small-scale as well as to the large-scale.

We set out to investigate how well recent research on human-environment dynamics in the Mediterranean aligns with the grand challenges and priority research questions with which we began this article. Following this review, we would like to argue that considerable ground has been covered towards a better understanding of some of the issues raised. Much research has gone into the variable persistence of societies in the face of climate change, addressing different temporal and spatial scales. Important method development is ongoing in terms of the handling of uncertainties and comparability, as well as the development and utilization of new archaeological, environmental and climate proxies. Moving across both temporal and spatial scales allow scholars of past human-environment dynamics to approach different types of questions and different audiences. Interdisciplinarity is well established today as groups of scholars from a variety of disciplines meet over local and regional case-studies, even if best practice for such collaborative engagements remains under scrutiny. In parallel to these local and regional studies, however, we suggest that there is still room to use the context-specific results for broader and larger-scale comparisons between regions and time periods. Moreover, there is still a lack of studies addressing the role of social and environmental diversity within human-environment dynamics. Such diversity likely contributed to the capability of human societies to establish adaptive strategies in the face of climate change. Adaptive capacity is an important part of the overall vulnerability of past and present societies to external and internal stressors.<sup>134</sup> Here, we believe, there is more to be done, but also that the Mediterranean provides the necessary means to do it. Vulnerability assessments provide new avenues for research on human-environment dynamics in past (Mediterranean) societies and a common language between the past and the present. Along with the need for greater multiplicity and diversity of time-series data characterizing human societies and environmental factors, this is probably an essential (but largely untapped) next step to gain a fuller understanding of the variable persistence of human societies in the face of climate change and the overall workings of human-environment dynamics.

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<sup>131</sup> Marston & Branting 2016; Bonnier & Finné 2020; Lawrence *et al.* 2021; Weinelt *et al.* 2021.

<sup>132</sup> Roberts *et al.* 2019a, 934–935.

<sup>133</sup> Clarke *et al.* 2016, 97, 117; Lespez *et al.* 2016, 240–241; Allcock 2017, 79–80.

<sup>134</sup> Biggs *et al.* 2012; United Nations 2015; Kok *et al.* 2016.

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## Appendix: keywords in categories and quantity

Details of the keywords according to CATEGORY (upper case), *Subcategory (Italics)* and Thematic groups (only found under the subcategory Topic), with quantities specified within parenthesis. The number of separate keywords counted after standardization of variabilities due to spelling, singular/plural use or the use of abbreviations.

<b>GEOGRAPHY (255)</b>
<i>Mediterranean</i> (43): Mediterranean (21); western Mediterranean (7); eastern Mediterranean (6); Mediterranean Sea (4); Mediterranean Basin (2); central-west Mediterranean; north-east Mediterranean; south-east Mediterranean
<i>Balkans</i> (44): Greece (13); Crete (5); Peloponnese (5); Croatia (3); Balkans (2); north-east Greece (2); south-east Balkans (2); Aegean; Akrotiri; Ancient Greece; Argosaronic gulf; Cyclades; Early Iron Age Greece; Gulf of Corinth; Lake Dojran; Late Bronze Age Greece; northern Greece; Phaistos; Bulgaria
<i>Central Mediterranean</i> (41): Po Plain (3); Corsica (2); Northern Italy (2); southern Italy (2); Tuscany (2); Vesuvius (2); Alps; Apulia; Basilicata; central Adriatic coast; central Italy; Cilento; Eastern Sardinia; France; Gaul; Ggantija and Santa Verna temples; Istrian peninsula; Italy; Malta; Middle Rhone valley; Northern Apennines; north-west Italy; Pompeii; Puglia; Rome; Sila uplands; Sinis Peninsula; south Italy; southern Alps; southern France; Tharros; Tiber River; Tyrrhenian Calabria coast; Tyrrhenian Sea
<i>Near East</i> (37): Levant (6); Near East (5); southern Levant (5); Middle East (3); south-west Asia (3); Dead Sea (2); Sea of Galilee (2); Atar Haroa; Ayn Abu Nukhayla; Fertile Crescent; Iran; Israel; Jordan; Mesopotamia; northern Levant (coastal Syria); Petra; Syria; Tel Megiddo
<i>Iberia</i> (32): Iberian Peninsula (8); Spain (5); Iberia (2); north-east Iberia (2); Balearic Sea; Central Iberia; Cova de Can Sadurni; Cova de la Guineu; Ebro Basin; Huelva Estuary; Lake Medina; Mallorca (Balearic Islands); Mediterranean Iberia; Portugal; Pyrenees; southern Iberia; south-west Iberia; Spanish Pyrenees; south-west Spain
<i>Anatolia</i> (27): Cappadocia (3); Turkey (3); Anatolia (2); Arslantepe (2); western Anatolia (2); Bor Plain; Catalhoyuk; Central Anatolian Volcanic Province (CAVP); Delice Valley; Eastern Anatolia; Ephesos; Istanbul-Turkey; Konya; Kultepe; Lake Tuzla; Phrygia; Rough Cilicia; south-west Anatolia; Ulucak Hoyuk; Western Turkey
<i>Southern Mediterranean</i> (23): North Africa (3); Egypt (2); Gredos range (2); Morocco (2); Tunisia (2); Algeria; Fayum; Gulf of Gabes; Haoua Fteah; Holocene North Africa; Libya; Lower Egypt; Maghreb; Mediterranean Africa; Middle Atlas; north-west Africa; Utica
<i>Other</i> (8): western Europe (3); eastern Europe (2); Europe; European and Mediterranean regions; Okmok
<b>DISCIPLINE (168)</b>
<i>Intermediate</i> (71): geoarchaeology (15); palynology (14); archaeobotany (10); palaeoecology (9); archaeozoology (5); anthracology (4); environmental archaeology (3); palaeobotany (2); palaeoecology and land-use history (2); archaeopalynology; historical ecology; human ecology; island ecology; local ecology; pedoanthracology; socioecology

<i>Natural science</i> (50): geochemistry (6); palaeogeography (6); sedimentology (5); palaeoclimatology (7); geomorphology (4); coastal geomorphology (3); micromorphology (3); hydrology (2); palaeolimnology (2); alluvial geomorphology; biogeography; geology; geophysics; historical biogeography; hydrogeology; micropalaeontology; natural sciences; palaeohydrology; palaeopedology; soil micromorphology; volcanology
<i>Humanities and Social sciences</i> (47): archaeology (21); landscape archaeology (9); demography (5); history (3); prehistoric archaeology (2); anthropology; archaeo-demography; California archaeology; Greek & Roman archaeology; maritime archaeology; palaeodemography; settlement archaeology
<b>CHRONOLOGY (202)</b>
<i>Holocene</i> (76): Holocene (52); Late Holocene (12); Mid-Holocene (6); Mid- to Late Holocene (2); Early Holocene; Mediterranean Mid-Holocene; Middle and Early Holocene; second half Holocene
<i>Bronze Age</i> (59): Bronze Age (23); Chalcolithic (7); Early Bronze Age (6); Late Bronze Age (3); Middle Bronze Age (3); Minoan (2); Amorites; Argar period; Argaric culture; Copper Age; EB-MB transition; Eneolithic/Bronze Age; First Intermediate Period; Hatti; Middle-Recent Bronze Age; Minoan civilization; Mycenaean influence; Old Kingdom; Sea Peoples; Subapennine culture; Terramare culture
<i>Neolithic</i> (30): Neolithic (21); Early Neolithic (4); Pre-Pottery Neolithic (2); Fifth millennium cal BC; Late Neolithic; Middle Neolithic
<i>Historical</i> (20): Iron Age (5); Classical Antiquity (2); Roman period (2); Antiquity and Late Antiquity; Archaic and Classical periods; Graeco-Roman period; Historic period; last millennia; last three millennia; (pre-)Roman age; protohistory; Punic period; Roman Age; Roman and Byzantine times
<i>Other</i> (17): Aegean prehistory (3); prehistory (3); Anthropocene (2); Quaternary (2); Late glacial (2); Apulian prehistory; Epipalaeolithic; Late Pleistocene-Holocene; Pleistocene; Upper Quaternary
<b>METHOD (119)</b>
<i>Environment</i> (27): pollen analyses (8); carbon isotope analysis (5); wood charcoal analysis (4); charcoal analysis (4); anthraco-typology; isotope analysis; pollen identification; seed and fruit analysis; sequential isotope analysis; stable isotope geochemistry
<i>Archaeology</i> (17): geographic information systems (GIS) (4); archaeological site survey (2); radiocarbon summed probability distribution (2); aoristic weights; archaeological interpretations; least-cost path analysis; point pattern analysis; site count; summed calibrated date distributions; summed probability densities; survey; visibility analysis
<i>Modelling</i> (17): modelling (3); agent-based model (2); agro-ecosystem modelling; agrosystem modelling; computational modelling; crop modelling; eco-cultural niche modelling; geographical information modelling; geomorphic modelling; irrigation modelling; land use modelling; palaeoclimate modelling; spatially explicit hydrological model; surface process modelling
<i>General</i> (16): multiproxy (2); boreholes; change analysis; classification; coring; data analysis; downscaling; fuzzy; high-performance computing; high-resolution proxy records; multi-proxy approach; multi-proxy records; proxy synthesis; statistical downscaling; stratigraphy
<i>Dating</i> (16): radiocarbon dating (8); tephrochronology (2); uranium series dating (2); Optically stimulated luminescence (OSL); sclerochronology; (U-Th)/He; Zircon double-dating
<i>Computational</i> (9): cluster analysis (2); Canonical discriminant analysis (CDA); D-Infinity algorithm; Geometric morphometrics; Principal Component Analysis (PCA); XylArch; cumulative probability functions of C-14 ages; non-metric multidimensional scaling (nMDS)

<i>Other</i> (17): tephrostratigraphy (3); magnetic susceptibility (2); organic residue analyses; geomorphometry; magnetostratigraphy; thin section micromorphology; clay mineralogy; morphostratigraphy; side scan sonar; X-ray fluorescence (XRF); XRF analysis; bathymetry; sub-bottom profiler; last growth episode
<b>ARCHIVE (31)</b>
<i>Sediments</i> (23): lake sediment (4); speleothem (4); stalagmite (3); lacustrine sediment (2); clastic cave sediments; geoarchive; ice core; lake fills; lake record; laminated sediments; sediment cores; speleothem data; varved lake sediments; varves
<i>Other</i> (8): ancient shipwreck; archaeological data; archaeological mound; archaeological sediment; historical maps; land snails; literary sources; Unio
<b>PROXY (126)</b>
<i>Fossil</i> (97): pollen (32); charcoal (5); biomarkers (3); microfossils (3); micro-charcoal (3); soil (3); diatoms (2); fossil pollen (2); n-alkanes (2); non-Pollen Palynomorphs (NPP) (2); ostracods (2); phytolith (2); aeolian dust; alkenone; ancient DNA; anhydrosugars; anthropogenic indicators; archaeological leaves; biological indicators; Coleoptera; dark-filled pollen; dung fungi; fossil records; fungal spores; galactosan; glycerol dialkyl glycerol tetraether (GDGT); glomalin-related soil protein; human remains; human settlement patterns; Levoglucosan; lipid biomarker; long-chain alkane; macro-charcoal; macrophytes; mannosan; marine sand; microfossils; Minoan tephra; planktonic foraminifera; plant macrofossils; pollen records; pumices; seeds; sheep morphotypes; soot; spherulite; tooth enamel; wood charcoal
<i>Isotopes</i> (23): stable isotopes (8); carbon isotopes ( $\delta^{13}\text{C}$ ) (4); hydrogen isotopes ( $\delta\text{D}$ ) (2); oxygen isotopes ( $\delta^{18}\text{O}$ ) (2); stable isotope compositions (2); leaf wax carbon isotope; leaf wax hydrogen isotope; nitrogen isotopes ( $\delta^{15}\text{N}$ ); stable isotope ratios; strontium isotopes
<i>Other</i> (6): archaeological site (4); demographic proxies; magnetic properties
<b>TOPIC (630)</b>
<i>Climate</i> (138)
General (69): climate change/s (30); palaeoclimate (24); climate (8); climate dynamics (2); climate variability (2); Mid Holocene climate change; past climate change; historical climate change
Types (31): hydroclimate (3); precipitation (2); seasonality (2); rainfall; humidity; temperature; rainfall variability; seasonal climate; arid desert climate; aridification; hydroclimate changes; hydroclimate variability; Holocene hydroclimate; effective rain; monsoons; seasonal; sea surface temperature (SST); snow
Events/Periods (29): 4.2 ka BP climate event (7); rapid climate change (5); 8.2 ka BP climate event (4); 3.2 ka BP climate event (2); drought (2); 8.2 and 7.7/7.1 ka BP climate events; 9.2 ka BP climate event; aridity events; climate events; Late Antique Little Ice Age; Younger Dryas; climatic events; Roman Climate Optimum; Roman Warm Time
Mechanisms (9): North Atlantic Oscillation (NAO) (2); climate forcing; atmospheric circulation; North Sea Caspian Pattern (NCP); ocean circulations; solar activity; glacier fluctuations; atmospheric $\text{CO}_2$
<i>Environment</i> (64)
General (20): palaeoenvironment (9); palaeoenvironmental reconstructions (4); environment; environmental change; environmental management; environmental stress; Mediterranean palaeoenvironment; palaeoenvironmental changes; palaeogeographical evolution

Types (25): dune (2); lake (2); Mediterranean island (2); mountain (2); volcano (2); wetland (2); alpine wetland; boulder; islands; karstic cave; lagoon; maritime; marshland ecosystems; mound; mountain belts; mountain environments; salt lake; subalpine environment; wet habitats
Coastal environments (19): Sea-level change (2); coastal change; coastal evolution; coastal floodplains; coastal lagoon; coastal stratigraphy; delta progradation; deltaic evolution; estuary; Holocene sea level rise; littoral drift; millennial scale transgressive-regressive cycles; regression; ria infilling; sea level changes; sea-level; shoreline; transgression
<i>Hydrology and soil</i> (52)
Soil (28): anthropogenic soils; argillic; biocrusts; brown/red Mediterranean soils; calcification; clast pavements; degree of soil development; grain size variations; Holocene geomorphodynamic activity; loess; nutrients; palaeosoil; peat initiation; pedosedimentary processes; rubefication; ruin soil; salinization; sediment connectivity; sediment texture; soil chronosequence; soil depletion; soil fertility; soil thickness; surface soil; synlithogenic pedogenesis; tempesteite; turbidites; vesicular layer
Hydrology (15): runoff coefficient (2); aquatic productivity; aquifers; calcareous tufa; groundwater; hillslope vs. channel hydrology; hydrological connectivity; hydrological cycle; rainfall:runoff ratio; rainfall-runoff analysis; runoff; spatio-temporal distribution of mires; stop-and-go transport; transmission loss
Fluvial processes (9): alluvial phases; alluvial-coastal plain; fluvial metamorphosis; fluvial system; fluvial wetland; fluvio-glacial and fluvial terraces; Late-Holocene river migration; Po and Dora Baltea rivers evolution; river avulsions
<i>Land cover</i> (61)
General (36): vegetation dynamics (9); vegetation (6); land cover (5); vegetation history (3); biodiversity (2); ecological succession (2); palaeovegetation; palaeo-vegetation; past vegetation; potential natural vegetation; stomata; vegetation and climate change; vegetation changes; vegetation cover change; vegetation dynamic synthesis
Taxa (20): Fagus sylvatica (2); Pinus halepensis Miller; Abies alba; Abies nebrodensis; Alnus; Brassicaceae; Buxus sempervirens; $\text{C}_4$ vegetation; Characeae; deciduous Quercus; Erica scoparia and E. arborea; Laurus nobilis; oak distribution; palm leaves; Pinus halepensis; Pinus laricio; Posidonia oceanica; Quercus ilex forests; Astragalus
Forest (5): deforestation (2); forest clearance; forest disruption; forest history
<i>Landscape</i> (61)
General (16): landscape (4); landscape changes (2); landscape ecology (2); site formation processes (2); desertification; landscape stability; landscape taphonomy; landscape transformations; landscape use; Roman landscape
Hazard (19): coseismic uplift; deluge; earthquakes; eruption impact; explosive eruptions; extreme wave events; flood; flood chronicle; flood events; natural disaster; palaeoflooding; palaeotsunami; Plinian eruption; rainstorm and floods; seismicity; Southern Italian volcanoes; tectonic events; tsunami; volcanoclastic mass flow
Erosion (15): erosion (4); soil erosion (3); badland; incised valley systems; land erosion; mass movements; piping; stabling areas; surface erosion; weathering conditions
Fire (11): fire (3); fire history (2); palaeofire (2); biomass burning; fire ecology; fire practices; fire regimes

<i>Land use</i> (115)
General (19): land use (15); land use change (2); land use history (2)
Agriculture (33): agriculture (5); crop yield (2); cultivation (2); domestication (2); early agriculture (2); farming (2); subsistence (2); agricultural revolution; agricultural sustainability; agro-pastoral farming; alpine farming; ancient agriculture; ancient desert agriculture; ancient farming; ancient runoff farming; cultivation terraces; irrigation; manuring experiments; Nile flow; prehistoric agriculture; runoff/floodwater irrigation; subsistence strategies; terraces
Crops (21): olive (2); Vitis (2); Flax cultivation; fruit growing; fruits; <i>Hordeum distichum</i> ; <i>Linum usitatissimum</i> L.; <i>Olea europaea</i> L.; Olive grove; olive growing; olive oil; olive orchards; olive press; olive tree cultivation; Roman vineyards; small grain crops; tree crops; <i>Triticum aestivum</i> ; wheat
Resource exploitation (17): ancient water management (2); ancient water harvesting system; avian exploitation; birds; ecosystem services; forest resources; fuel management; fuel wood; groundwater management; lead concentration; mining activities; plant use; plant; runoff water harvesting; trade; wood management
Husbandry (16): pastoralism (3); altitudinal mobility; animal economy; animal husbandry; browsing; herding strategies; livestock management; overgrazing; pastoral nomads; pasture; pasture indicators; secondary products; sheep and goats; transhumance
Food (9): food shortages (2); crop-processing; dairying; famine; food plants; foodways and climate change; palaeodiet; storage
<i>Dynamics</i> (51)
Human (44): human impacts (23); human-environment interaction (6); anthropisation (3); anthropogenic impact (3); human occupancy (2); anthropogenic dynamics; human activities; human inhabitation; human-environment-climate interaction; social-ecological system; socio-ecosystem; socioenvironmental dynamics
Climate (7): climate adaptation; climate and society; climate change impact; climate impact; climate versus human change; climate-environment-society interactions; past climate impacts

<i>Theory and concepts</i> (57)
General (36): interdisciplinarity (3); abandonment (2); culture change (2); Late Bronze Age crisis (2); causal impact; collapse; consilience; crisis; cultural evolution; disaster; global change; historical maximalism; holistic approach; human carrying capacity; identity; interdisciplinary collaboration; mobility; niche construction; resolution; science oversimplification; sedentism; shape; size; social organization; social transformation-abrupt cultural change; societal change; socio-economic aspects; socio-political structures; spatially explicit; state formation; urban
Resilience theory (21): resilience (8); scale (2); adaptive cycle; complexity; emergence; human adaptation; human resilience; legacy effects; mitigation; sustainability; sustainable land use; sustainable use; vulnerability
<i>Archaeology and history</i> (31)
General (22): ancient societies (2); ancient Ostia harbour; architecture; cord impressions; geomorphology; Greek and Roman colonization; myth; mythology; Neolithic dispersal; Neolithic transition; Neolithisation; pottery production; production intensification; Punic harbour; red slip ware; Roman baths; roulette decor; shell middens; stone tool; tabular scraper; tell
Demography (9): demographic dynamics; past population density; population dynamics; population genetics; population proxy; residential mobility; settlement; settlement patterns; settlement strategies

## Supplemental information

Spreadsheet outlining complete records from the *WoS* search pertaining to the 280 articles.

RIS-file (and other formats) with references for the 280 articles, for import into a reference manager system. Available at <https://doi.org/10.30549/opathrom-15-07>.