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Archaeological Evidence for Community Resilience and Sustainability: A Bibliometric and Quantitative Review

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Abstract: Archaeology is often argued to provide a unique long-term perspective on humans that can be utilised for effective policy-making, for example, in discussions of resilience and sustainability. However, the specific archaeological evidence for resilient/sustainable systems is rarely explored, with these terms often used simply to describe a community that survived a particular shock. In this study, a set of 74 case studies of papers discussing archaeological evidence for resilience/sustainability are identified and analysed using bibliometric methods. Variables from the papers are also quantified to assess patterns and provide a review of current knowledge. A great variety of scales of analysis, case study locations, stressors, resilient/sustainable characteristics, and archaeological evidence types are present. Climate change was the most cited stressor (n = 40) and strategies relating to natural resources were common across case studies, especially subsistence adaptations (n = 35), other solutions to subsistence deficiencies (n = 23), and water management (n = 23). Resilient/sustainable characteristics were often in direct contrast to one-another, suggesting the combination of factors is more important than each factor taken individually. Further quantification of well-defined variables within a formally-produced framework is required to extract greater value from archaeological case studies of resilience/sustainability.

Keywords: archaeology; resilience; sustainability; citation analysis; collapse; climate change; agriculture; natural resources

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Citation: Jacobson, M.J. Archaeological Evidence for Community Resilience and Sustainability: A Bibliometric and Quantitative Review. *Sustainability* **2022**, *14*, 16591. https://doi.org/10.3390/su142416591

Academic Editors: Andrea Zerboni, Filippo Brandolini, Francesco Carrer and Guido S. Mariani

Received: 31 October 2022
Accepted: 9 December 2022
Published: 11 December 2022

1. Introduction

Resilience and sustainability are buzzwords with associated theory articles that are widely cited [1–13]. In the field of archaeology, the concepts have also been the focus of extensive theoretical discussions [14–23] and are commonly used to describe communities in global case studies (e.g., [24–97]). However, definitions of resilience and sustainability remain debated and vary between and within research fields, as well as over time. In this study, the following definitions are used, which appear frequently in theory articles (e.g., [9,16]) and have been adopted in reports by the Intergovernmental Panel on Climate Change (IPCC: e.g., [98,99]): resilience is the capacity of a system to retain or rapidly restore its essential functions under changing conditions, whereas sustainability is the ability of a system to meet the needs of the present without compromising the needs of the future. Whilst the two concepts are distinct, they are studied together in this paper as they have significant overlap and are often (incorrectly) used interchangeably.

Archaeological case studies that aim to assess resilience/sustainability are often accompanied by the claim that insights from the past can be used to predict and prepare for future challenges [23]. This logic has demonstrated its value elsewhere, for example, with earth systems research providing invaluable information that has been used to predict and mitigate against the impacts of geological and environmental events [100]. However, the specific archaeological evidence for resilient/sustainable characteristics and the combination of characteristics that best enable human survival are rarely explored; these terms are often used simply to describe a community that survived a particular shock.

The current paper acts as a starting point for more effective research into this topic. For this, bibliometric analysis is conducted on the ten top-cited papers discussing resilience/sustainability theory, both from the wider literature [1–13] and archaeology [14–23], and from 74 case study papers detailing archaeological evidence for resilience/sustainability [24–97] (Supplementary Table S1). Subsequently, the 74 case study papers are reviewed and several of their characteristics are quantified: Location, Scale, Period, Stressor (i.e., why was resilience/sustainability required?), Characteristic (i.e., how were the community resilient/sustainable?) and Evidence (used to claim resilient/sustainable characteristic). The results of these analyses enable a summary of past research, provide new insights from existing data, and highlight several important next steps for realising the full potential of archaeology in studying resilience/sustainability.

2. Materials and Methods

2.1. Case Study Identification

To find suitable "papers" (this terminology is chosen to encompass both journal articles and book chapters) that can act as case studies of archaeological evidence for resilience/sustainability, a three-pronged approach was taken; this is depicted in Figure 1, with search terms are recorded in Table 1. All searches were conducted on 11 July 2022. This bibliometric method for identifying papers was based on previous research by Werner Marx and colleagues [101–104], with literature extracted from Web of Science (WoS: https://webofknowledge.com, accessed on 11 July 2022) and analysed using the software packages VOSviewer v1.6.18 [105] (http://www.vosviewer.com, accessed on 11 July 2022) and CitNetExplorer v1.0.0 [106] (www.citnetexplorer.nl, accessed on 11 July 2022). This analysis was selected as a first step for looking at archaeology's unique contribution to resilience/sustainability [107–109] because it assesses the history of research whilst avoiding the bias of a traditional literature review, whereby experts inadvertently focus on their own research interests at the expense of others. Alternatives to WoS were also considered for this analysis but were not selected due to certain limitations and challenges (see [110–112]). Scopus (https://www.scopus.com, accessed on 11 July 2022) provided near-identical results to WoS for the searches, both in terms of specific papers and overall quantity, and was thus not further utilised. Google Scholar (https://scholar.google.com, accessed 11 July 2022) could not be utilised due to limited options for filtering of results, bibliometric analyses, and data extraction. Dimensions (https://www.dimensions.ai, accessed on 11 July 2022) provides more exhaustive coverage but uses automated approaches that leads to significant amounts of non-academic literature and duplicates. Sorting through these irrelevant results would have been too time-consuming for the small number of additional articles it would have provided. If the findings of this paper relied more heavily on complete coverage of publications, a combination of multiple databases would be preferable; however, some Google Scholar results have been included where appropriate (see below).

Table 1. Web of Science searches.

Query	Search Term	Results
1a: "Title	TI = ((resilien * OR sustainab *) AND (archaeology * OR archeolog * OR ancient))	1231
1b: "Topic"	TS = ((resilien * OR sustainab *) AND (archaeology * OR archeolog *))	
2: "Archaeology Resilience"	TS = ((resilien * OR sustainab *) AND (archaeology * OR archeolog *) AND theory)	10
3: "Resilience Theory"	TS = ((resilien * OR sustainab *) AND (theory)	13 *

* Three additional resilience theory articles found in Google Scholar's top ten most-cited.

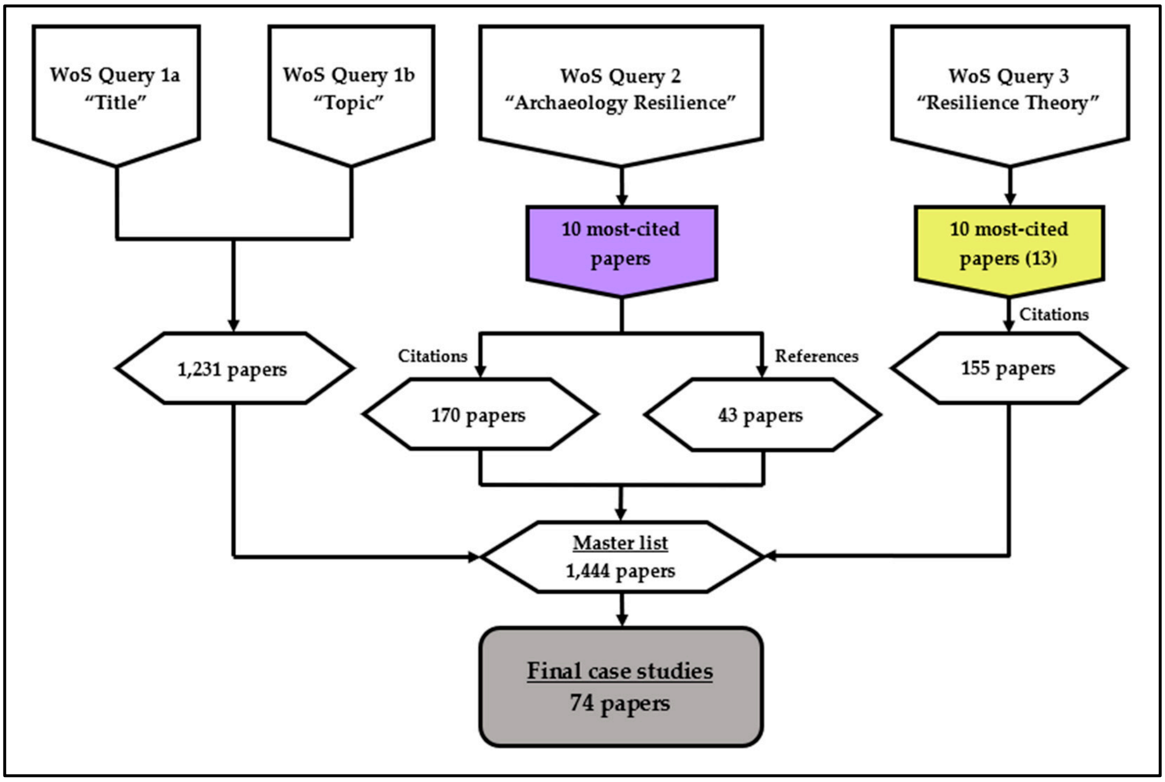

Figure 1. Flow diagram of Web of Science search steps.

The first step was to search directly for relevant papers by title (Search Query 1a) and topic (Search Query 1b), using the terms "resilien *", "sustainab *" and "archaeology *" (and "archeolog *" to accommodate American English). Topic searches provide articles that use the terms in their title, abstract and keywords. In WoS, an asterisk (*) is a wildcard that can represent any group of characters; it was utilized in these searches to enable any variant of the above words (e.g., resilience and resilient).

As there are likely many papers that discuss archaeological evidence for resilience/sustainability—without including the terms in their title, abstract or keywords—additional steps were taken to ensure the highest amount of recall possible. For this, the ten top-cited resilience/sustainability theory papers from the field of archaeology [14–23] and all fields [1–13] were identified (Table 2). Archaeology theory/summary papers were found by topic searching with the terms "resilien *", "sustainab *", "theory" and "archaeology *" (Search Query 2). Theory papers from all fields were found by topic searching with the terms "resilien *", "sustainab *" and "theory" (Search Query 3). A similar search in Google Scholar identified three additional theory papers, which were included in this study (see Table 2).

Table 2. Resilience theory papers and archaeological resilience theory/summary papers, ordered by publication date.

Authors & Year	Title	Citations
	Resilience Theory	
Holling, 1973	Resilience and stability of ecological systems [1]	8179
Adger, 2000	Social and ecological resilience: are they related? [2]	2127
Holling, 2001	Understanding the complexity of economic, ecological, and social systems [6]	2034

Table 2. *Cont.*

Authors & Year	Title	Citations
	Resilience Theory	
Carpenter et al., 2001	From Metaphor to Measurement: Resilience of What to What? [7]	1832
Holling & Gunderson, 2002	Resilience and adaptive cycles [8]	99 *
Walker et al., 2004	Resilience, Adaptability and Transformability in Social– ecological Systems [9]	2106
Folke, 2006	Resilience: The emergence of a perspective for social-ecological systems analyses [10]	3718
Gallopín, 2006	Linkages between vulnerability, resilience, and adaptive capacity [11]	1438
Nelson et al., 2007	Adaptation to environmental change: Contributions of a resilience framework [12]	1135
Brand & Jax, 2007	Focusing the Meaning(s) of Resilience: Resilience as a Descriptive Concept and a Boundary Object [13]	688 *
Norris et al., 2008	Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness [3]	2142
Folke et al., 2010	Resilience Thinking: Integrating Resilience, Adaptability and Transformability [4]	1116
Cote & Nightingale, 2012	Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research [5]	623 *
	Archaeological Theory/Summaries	
Redman & Kinzig, 2003	Resilience of past landscapes: Resilience theory, society, and the Longue Durée [14]	213
Redman, 2005	Resilience theory in archaeology [15]	201
Redman, 2014	Should sustainability and resilience be combined or remain distinct pursuits? [16]	166
Sundstrom et al., 2014	Transdisciplinary Application of Cross-Scale Resilience [17]	24
Cumming & Peterson, 2017	Unifying research on social-ecological resilience and collapse [18]	78
Bradtmöller et al., 2017	Resilience theory in archaeological practice—an annotated review [19]	42
Middleton, 2017	The show must go on: Collapse, resilience, and transformation in 21st-century archaeology [20]	18
Haldon et al., 2018	History meets palaeoscience: Consilience and collaboration in studying past societal responses to environmental change [21]	63
Haldon & Rosen, 2018	Society and Environment in the East Mediterranean ca 300–1800 CE. Problems of Resilience, Adaptation and Transformation. Introductory Essay [22]	11
Nicoll & Zerboni, 2020	Is the past key to the present? Observations of cultural continuity and resilience reconstructed from geoarchaeological records [23]	11

* Resilience theory articles that were in the top ten most-cited in Google Scholar.

Citations were extracted from the two key literature datasets and references were extracted from the archaeological summaries. Here, "citations" refers to later papers citing the key literature whilst "references" refers to earlier papers cited in the key literature.

The results of Search Query 1a,b and the citations/references extracted from Search Query 2 and Search Query 3 were compiled into a "Master List" containing 1444 papers. This list was manually sifted for identification of suitable case studies that claim archaeological evidence for resilience/sustainability and was found to have very low precision (i.e., many irrelevant papers were included). Manual sifting mitigates against a key challenge in bibliometric assessments: recall and precision are inversely correlated, meaning that when attempting to find all relevant papers there will be many irrelevant papers in your results [102,113]. In the "Master List", most papers focused on how to conduct archaeology sustainably or the resilience of something other than communities (e.g., plant or animal populations); others discussed community resilience/sustainability but provided no evidence, simply stating that a community which persisted (or "collapsed") was (not) resilient/sustainable. A total of 74 case studies [24–97] were identified which discuss archaeological evidence for resilience/sustainability (Supplementary Table S1).

2.2. Dataset Visualization

VOSviewer v1.6.18 [105] was used to map co-authorship and keywords of the two key literature datasets (23 papers) and the case studies (74 papers), using the bibliographic data extracted from WoS.

The co-authorship map is a "Network Visualization" based on full counting of all authors, which are represented by nodes. The size of the nodes is proportional to the number of papers included in this dataset by the author. Nodes (i.e., authors) are positioned close to, clustered with, and connected by lines to other nodes they have published in collaboration with (i.e., their co-authors). For the analysis, clusters were normalised by their "Association strength", cluster resolution was set to 1.00, and clusters with multiple papers were manually coloured. The co-authorship map can be used to assess collaborations between authors and identify key research groups.

The co-occurrence keyword map is an "Overlay Visualization" based on full counting of any keyword that appears in at least three papers, which are represented by nodes. All keywords were used, which includes both those supplied by the paper authors and "KeyWords Plus", which are provided by WoS. The size of the nodes is proportional to the number of occurrences of the keyword (i.e., how many papers it appears in). The width of lines connecting nodes and their proximity is proportional to the number of co-occurrences of the two keywords (i.e., how many papers they appear in together). For the analysis, clusters were normalised by their "Association strength" and cluster resolution was set to 1.00. The overlay is a colour scale representing the mean publication date of papers containing each keyword. Therefore, the keyword map can be used to easily identify related research topics and the evolution of keyword prevalence ("buzzwords") over time.

CitNetExplorer v1.0.0 [106] was used to visualize the citation network of the two key literature datasets (23 papers) and the case studies (74 papers), using the bibliographic data extracted from WoS. For the analysis, all 97 papers were included in the network and the two key literature datasets were manually coloured; all other parameters are left as their default. The citation network orders the papers (nodes) by publication date and connects later papers to those they cite, thus producing a history of research into archaeological evidence for resilience/sustainability.

2.3. Case Study Quantification

The 74 case study papers were manually reviewed, and several aspects were quantified: Scale, Location, Period, Stressor (i.e., why was resilience/sustainability required?), Characteristic (i.e., how were the community resilient/sustainable?) and Evidence (used to claim resilient/sustainable characteristic). These are categorised as follows:

- Scale—case studies analyse resilience/sustainability for: (1) a household, (2) a single settlement/city, (3) a locality, roughly defined as a group of fewer than 10 settlements in an area smaller than 100 km^2, (4) a sub-region, one area containing numerous settlements within a polity, (5) a region, a single polity or similar in scale (6) a macro-region, the size of multiple polities.
- Location—latitude and longitude coordinates from the centre of the case study region are provided, which is then defined according to scale (settlement/city, locality, sub-region, region, macro-region) and by continent.
- Period—the start and end date of the case study, as provided by the authors, are recorded.
- Stressor, characteristic, and evidence—each of these variables was noted whilst reading the case study papers and were then re-evaluated to create consistent groups. They are also counted (i.e., the number of stressors is noted). The full list of these variables can be found in Supplementary Table S1.

3. Results

3.1. Co-Authorship Map

A co-authorship map of the two key literature datasets (23 papers) and the case studies (74 papers) was produced to assess collaborations between individual authors, represented by nodes in Figure 2. This analysis reveals the field to be largely collaborative, with archaeologists frequently working alongside researchers that produce reconstructions of the stressors (e.g., ecologists, palaeoclimatologists, or volcanologists). Only 10 of the papers have a single author and the largest number of authors on a single paper is 42; there are an average of 4.1 authors per paper. However, there is a complete paucity of connections between the 67 total clusters. Of these, 58 clusters are comprised of only a single paper (86.6% of clusters, 60% of papers), partially resulting from the fact that 367 of the total 397 authors (92.4%) have only published a single relevant paper in this dataset. This is indicative of resilience and sustainability as buzzwords. Of the remaining authors, only five published three papers (Carpenter, Dunning, Lancelotti, Walker, and Weiberg) and two published four (Holling and Redman).

The remaining eight clusters (i.e., those containing multiple papers) are numbered by author count. Cluster 1 is the largest cluster and contains six papers discussing resilience in case studies across Eurasia, with a total of 88 authors. The lefthand side of this cluster is comprised of two papers with a high number of co-authors discussing prehistoric resilience during the last glacial [87] and early Holocene [61]; the other side of the cluster contains four papers discussing agricultural and using radiocarbon dates [36,51,67,82]. Cluster 2 links together four papers from 24 authors. Three of these papers discuss resilient/sustainable land-use in pre-Columbian Amazonia [37,46,90] whilst the last is focused on Mayan resource management in Belize [28]. Cluster 3 is comprised of six papers authored by members of the Climate Change and History Research Institute (CCHRI), Princeton University, and colleagues (22 authors). Two of these are key archaeological theory/summary papers [21,22]. This interdisciplinary group focuses on the impact of ancient climate change, which these papers discuss for the Neolithic period in SW Asia [72,74] and the Late Antique Eastern Mediterranean [73,91]. Many other key papers relating to historical climate change impacts have been published by this group, with a focus on collaboration between paleo-scientists and archaeologists/historians, especially relating to the Byzantine Empire [114]. Cluster 4 is centred around three papers by Carla Lancelotti [29,63,68], with 19 total authors. These papers focus on human-environment dynamics using archaeobotanical remains and how this relates to human resilience. Lancelotti has also published an important archaeological theory paper that provides a framework indicating key variables for resilience in small-scale societies [115]. This paper was the 11th top-cited paper in WoS Query 2 and is discussed further below. Cluster 5 is the largest in terms of papers, with 11 by 19 authors. This cluster encompasses many of the key literature datasets, with three of the archaeological theory papers by Charles Redman [14–16] and seven of the theory papers [1,4,6–10]. One additional paper is included here that has Redman as a co-author [56]. Redman and Holling are the only two authors in this dataset to have four papers included, this is visualized by the size of their node in Figure 2. Cluster 6, similarly to cluster 4, is centred around three papers by one author, Nicholas Dunning [59,85,88], with 13 total authors. These papers discuss both resilience and sustainability, as well as collapse, for the ancient Maya in the Yucatán Peninsula. Two of the papers are specific to the city of Tikal, Guatemala, whilst the other is a comparison of sites across the Maya lowlands. One paper from Cluster 2 [28] could arguably have been included here if they were manually sorted by theme. Cluster 7 is comprised of five authors, with two publications summarizing water technologies and changing climatic conditions on Crete [76,84]. Cluster 8 is another centred around three papers sharing one author, Erika Weiberg [32,62,70], and three total authors, colleagues from Uppsala University. The Peloponnese, and Aegean region more broadly, are the focus in these papers. Weiberg and colleagues have written extensively about climate-society interactions in the Eastern Mediterranean, including detailed sophisticated analyses of resilience and persistence [116,117].

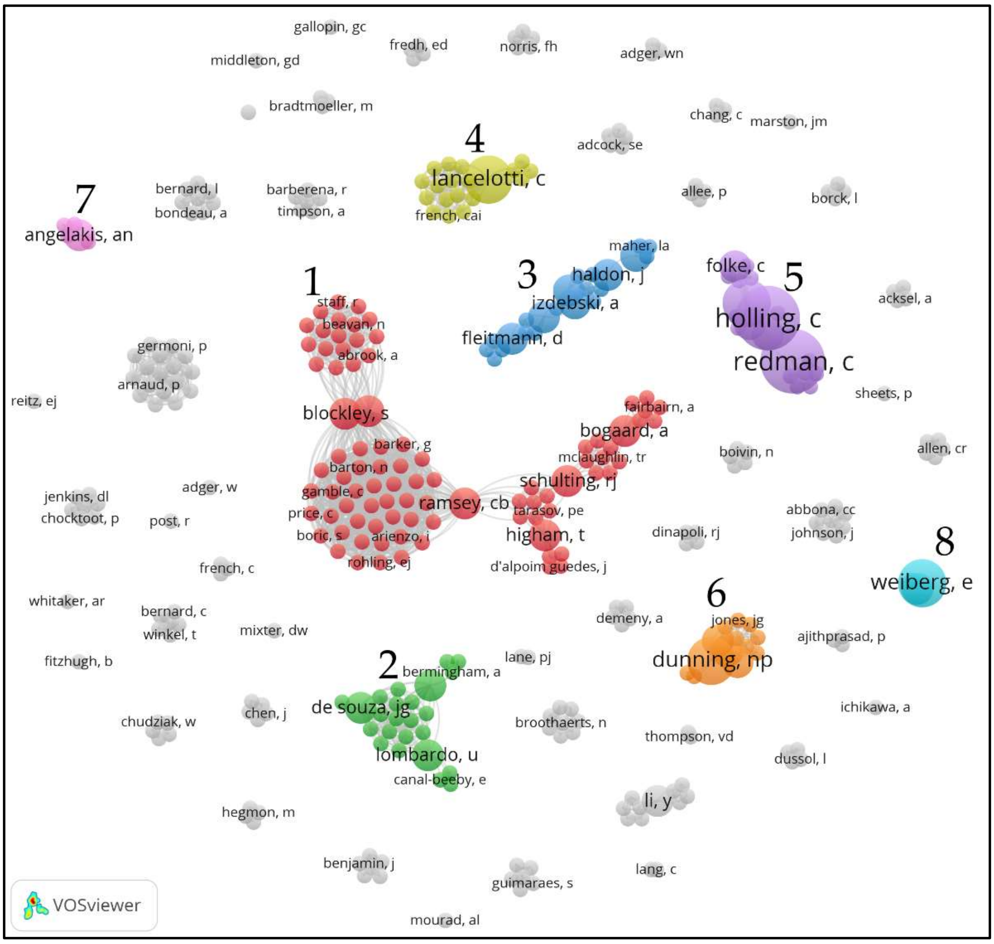

Figure 2. Co-authorship map of all 397 authors from the two key literature datasets (23 papers) and the case studies (74 papers). Nodes represent individual authors and their size is proportional to the number of papers by the author included in this dataset. Clusters with multiple papers are coloured and numbered by author count. Figure produced in VOSviewer.

3.2. *Keyword Map*

A keyword map was produced to assess the changing trends of focus among the two key literature datasets (23 papers) and the case studies (74 papers), presented in Figure 3. For this map, all keywords were used; this includes both those supplied by the paper authors and "KeyWords Plus", which are provided by WoS.

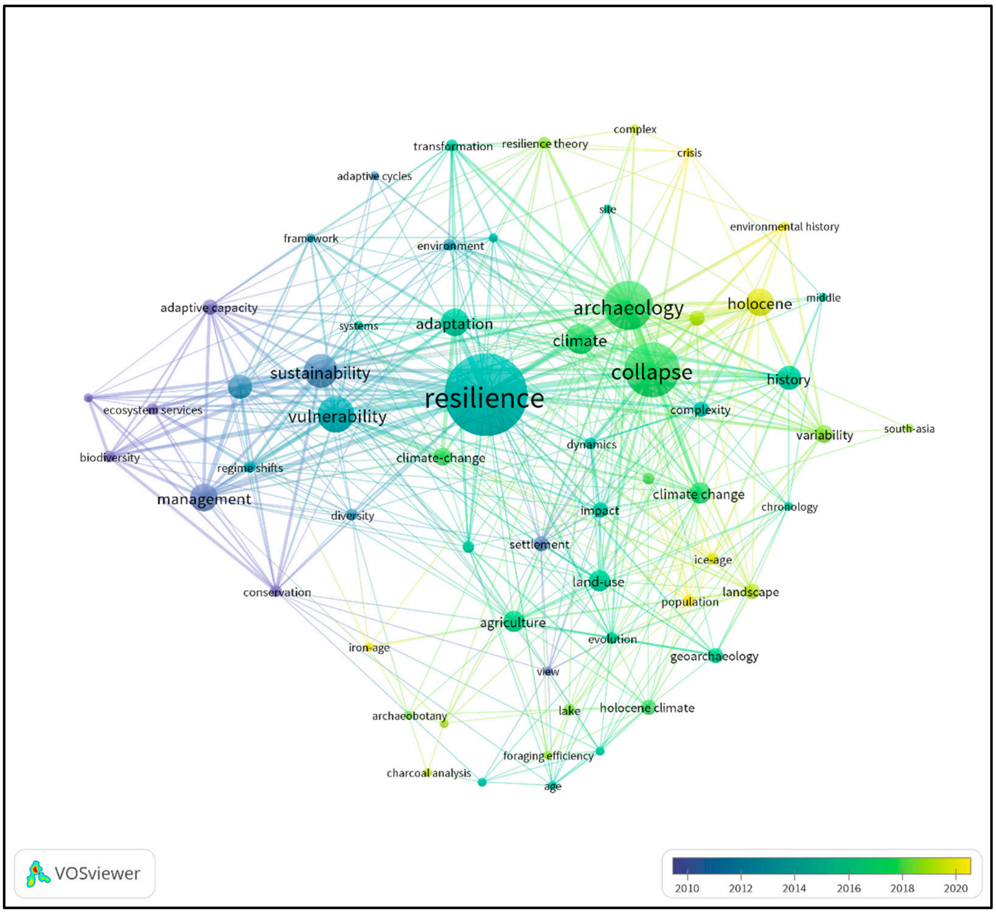

Figure 3. Co-occurrence map for keywords with a minimum of 3 occurrences (n = 60) in the two key literature datasets (23 papers) and the case studies (74 papers). Nodes represent keywords, their size is proportional to occurrences, and the width of connecting lines is proportional to the number of co-occurrences. The colour of nodes corresponds to their average publication date. Figure produced in VOSviewer.

The highest occurring keywords include the search terms of resilience (36), archaeology (18), and sustainability (15), as well as related terms such as collapse (20) and vulnerability (13). Additionally, climate and adaptation appear frequently but with multiple variations: 33 counts of climate, climate change or climate-change; 17 counts of adaptation, adaptive capacity, or adaptive cycles. The map also reveals keyword changes over time, with sustainability and related terms (e.g., biodiversity, management, adaptive capacity) averaging older publication dates; the associated graph shows that sustainability was a keyword in only six papers in the last five years (12.2%) compared to eighteen uses of resilience (36.7%). Keyword occurrences over time can also be seen in Figure 4. Terms relating to climate have seen more frequent use in recent years as well, with the first use in 2007 and are featured in 46.9% of papers published in the last five years. Overall, more recent keywords relate to specific types of archaeological analysis/evidence (e.g., charcoal analysis, archaeobotany), variables impacted by stressors (e.g., agriculture, land-use, landscape), or study periods (e.g., iron-age, ice-age, Holocene). Keywords featuring in older papers are more frequently ecological terms (e.g., sustainability, biodiversity, management, adaptive capacity), their older average dates are partially the result of the key theory papers, which are largely from the field of ecology.

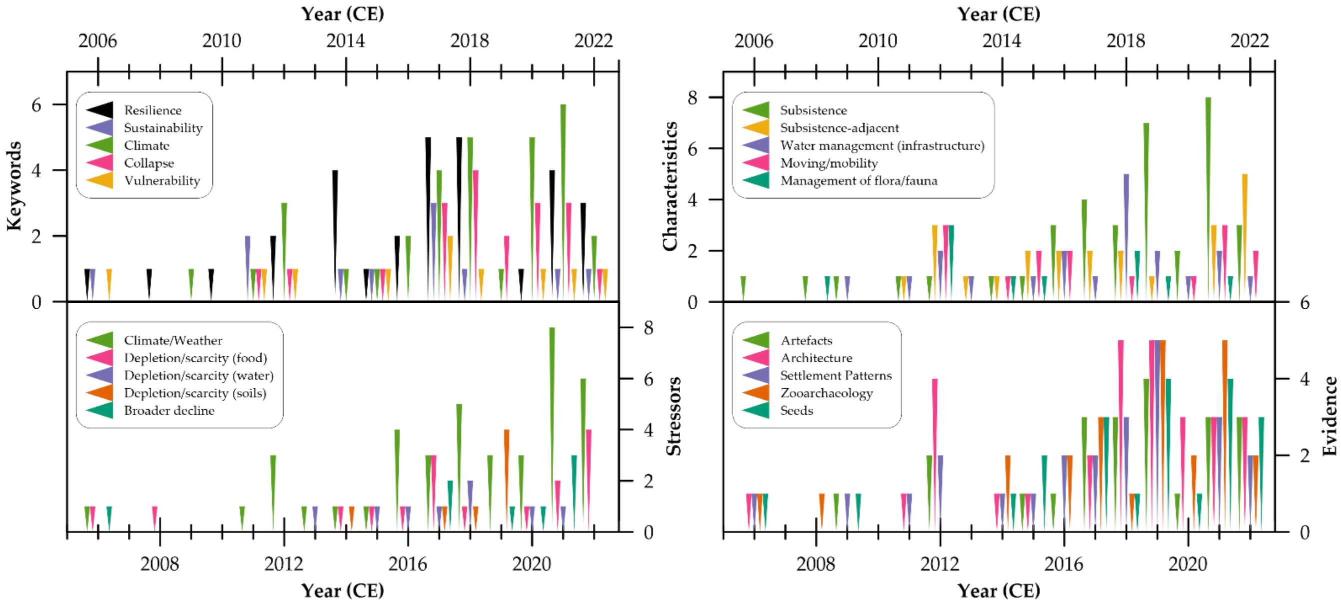

Figure 4. Patterns of the keywords, stressors, characteristics, and evidence included in the 74 case study papers over time. The five most common examples of each are included; "archaeology" as a keyword was ignored.

3.3. Citation Network

The citation network of the two key literature datasets (23 papers) and the case studies (74 papers) is presented in Figure 5; this visualises which papers cite one-another. CitNet-Explorer also identifies cited papers not in the dataset, these were removed from Figure 5. The highest internally-cited papers (i.e., papers cited by those within the dataset [106]) are: (1) the key resilience theory papers by Holling [1,6,8]—with 20 citations (1973), 16 citations (2001), and 12 citations (2002), as well as the book containing the 2002 chapter [118], which was cited 21 times; (2) the paper "Resilience Theory in Archaeology" by Redman [15], with 19 citations; (3) a popular book [119] and a journal article [120] discussing the concept of "collapse", with 13 and 11 citations, respectively; (4) a summary of the "Grand challenges for archaeology" which highlights resilience and human-environment interactions as important [121], with 10 citations; and (5) another key theory paper by Carpenter et al. [7], with 8 citations.

The earliest publication in the dataset is a paper from 1973 by Holling [1], which introduced the concept of resilience for studying ecological systems. The next papers in the dataset, which were published several decades later in the early 2000s, introduced the concept of resilience for studying socio-ecological systems. Many of these papers are in Cluster 5 of Figure 2, are highly-cited (both internally and externally) and include key authors with multiple publications. Important to note that here, the adaptive cycle and panarchy concepts are introduced, which have remained extensively used in archaeology [19]; this has remained the case despite critiques stating it is a non-scientific narrative device [122]. The first archaeological uses of resilience theory (in this dataset) were also published in the mid-2000s, with Redman as the primary author [14,15]. Here, it is argued that archaeology can be utilised to study a greater variety of socio-ecological systems than available in the present day, and over longer timescales, as in [107]. It is interesting to note here that all of the key theory papers focus primarily on resilience rather than sustainability, there are other papers that do discuss sustainability published in the early 2000s (e.g., Tainter, 2000 [123]); however, these are cited less frequently, despite the fact that sustainability as a keyword is more prominent in earlier articles, see Figures 3 and 4. In 2006, the first case study is published by Nelson [95], who also argued for a resilience framework the following year [12]. Patterns observed in the 74 case study papers were better-assessed by quantification of their key aspects, see below.

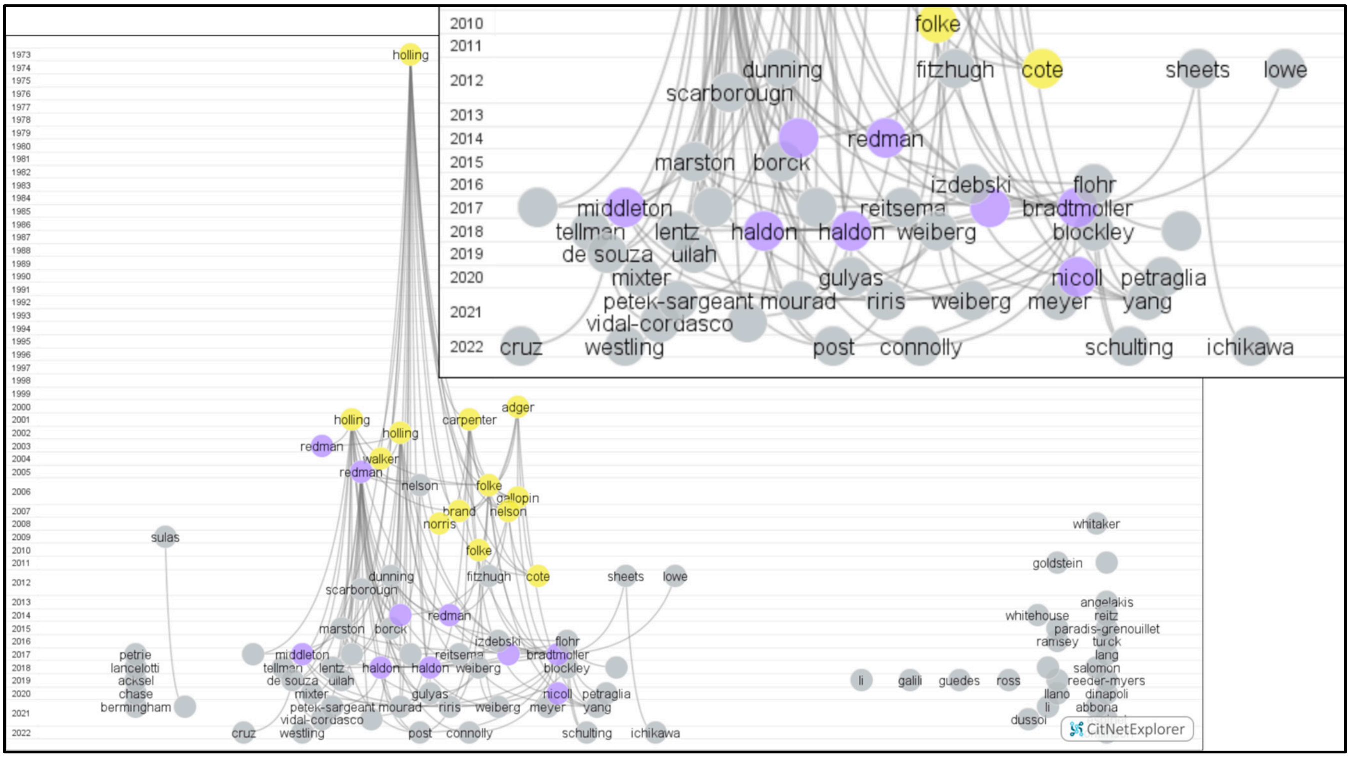

Figure 5. Citation network (221 citation links) of the 74 case study papers (grey nodes), 13 theory papers (yellow nodes), and 10 archaeological theory/summary papers (purple nodes). The top right section shows the central cluster from 2010 to 2022. Figure produced in CitNetExplorer.

3.4. Case Study Metadata

The number of case study papers discussing archaeological evidence for resilience/sustainability has mostly shown a steady increase over time. A total of 14 papers were published in 2021, the year with the most case studies, however, the number published in 2022 (currently 9) may exceed this considering the WoS search was performed on 11 July 2022. There are some exceptions to this pattern, notably 2012 and 2020. Five case study papers were published in 2012, two of which [86,89] resulted from a book titled "Surviving Sudden Environmental Change: Answers from Archaeology" [124]. One of these pertains to the ancient Maya, as do another two published in PNAS with Dunning as one of the authors (from Cluster 6 in Figure 2). Increased interest at this time may result from the Maya calendar-related prediction that the world would end on 21 December 2012, which caused a pronounced peak in publications relating to the Maya collapse in 2012 [101]. In Figure 6, a significant dip in the upward trend of publications is visible for 2020; this is likely due to the COVID-19 pandemic, which lowered the average amount of new publications, submissions, and projects undertaken by scientists [125].

The scale and global distribution of case studies are presented in Figure 7. Regarding scale, the category with the most case studies is sub-regional (29 papers), followed by settlement/city (19 papers), local (12 papers) and macro-regional (9 papers); there are only three papers at a regional scale and two at the household scale. However, going forwards these categories should be better defined (by size) due to variations in the area of countries. Case studies are spread globally, appearing on every continent except Antarctica. Europe and Asia have the most, with 21 case studies each. North and South America have 17 and 8 case studies, respectively. Africa has only five case studies, located entirely in the east. Oceania is the least represented, with only two case studies. Two areas with a high density of case studies are shown as cut-outs in Figure 7: the Yucatán Peninsula, which has six case studies, and the Eastern Mediterranean, with seventeen case studies.

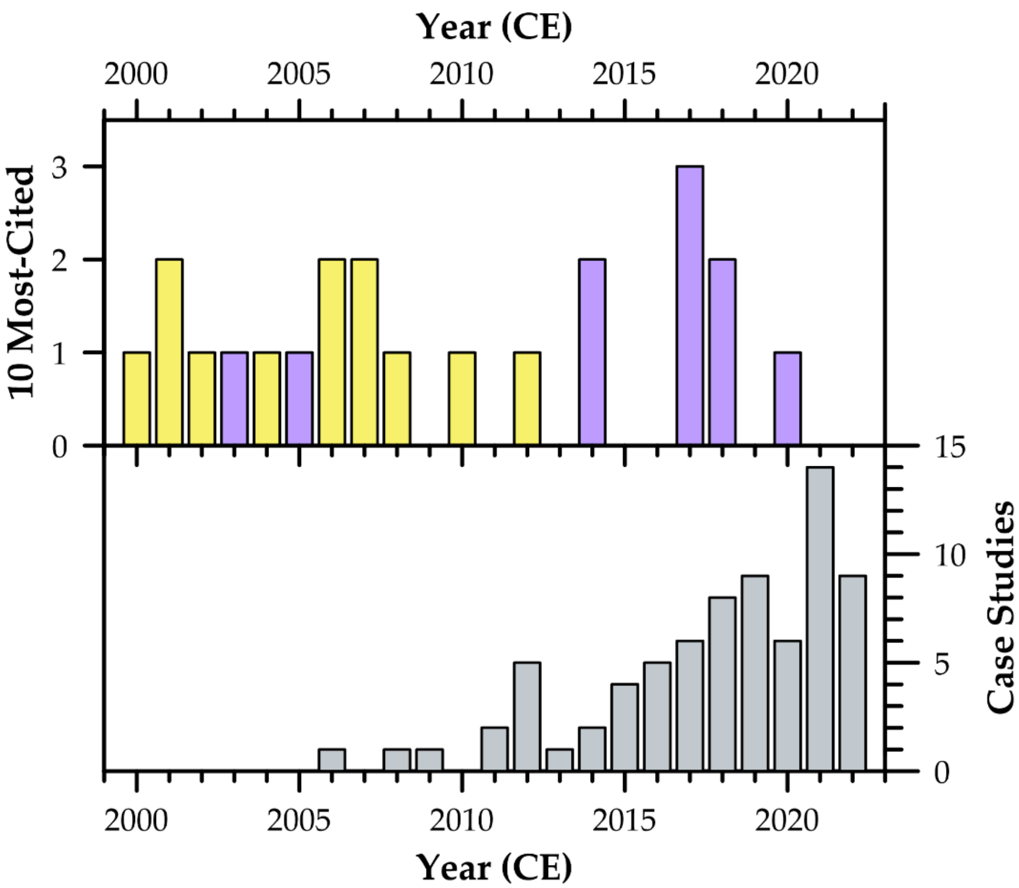

Figure 6. Publication years for the 74 case study papers (grey), 13 theory papers (yellow), and 10 archaeological theory/summary papers (purple). This figure does not display the first paper by Holling (1973) for clarity.

The more important quantified variables of stressor, characteristic, and evidence were identified by reviewing each individual case study paper. The full results of the quantification can be found in Supplementary Table S1; temporal changes in the prevalence of variables are visualised in Figure 4.

Stressors (i.e., why was resilience/sustainability required?) are presented in Figure 8a. There are 23 different stressors, with 138 total occurrences, meaning there is an average of 1.9 stressors in each case study. Climate/weather is by far the most commonly occurring stressor, appearing in 40 (54%) of the case studies. Other stressors can be separated into three main groups. The first group is resource depletion/scarcity, which is observed for food (n = 16:22%), water (n = 8:11%), soils (n = 7:9%), and trees (n = 6:8%). The second group are all anthropogenic challenges, for example broader regional decline (n = 8:11%) and separation (n = 5:7%). The final group is comprised of other environmental stressors, the most common of which are floods (n = 6:8%), erosion (n = 5:7%), and volcanism (n = 4:5%).

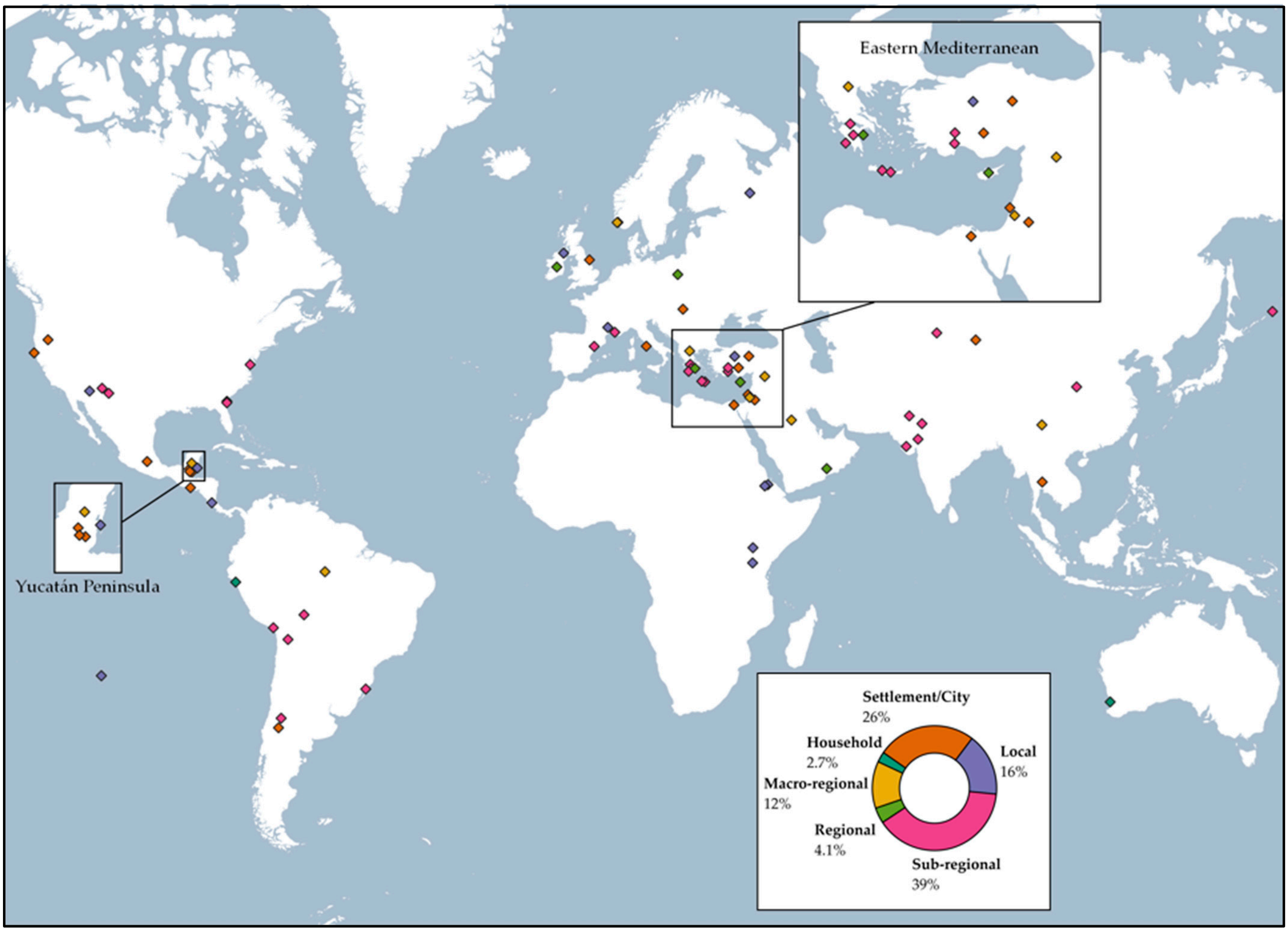

Figure 7. Map showing the location of the 74 case study papers. Cut-outs show two regions with a high density of case studies: the Yucatán Peninsula and the Eastern Mediterranean. The pie chart shows the proportion of case study scales, with colours corresponding to the points on the map.

Characteristics (i.e., how were the community resilient/sustainable?) are presented in Figure 8b. There are 50 different characteristics, with 169 total occurrences, meaning there is an average of 2.3 characteristics in each case study. Subsistence strategies were most frequently-cited, appearing in 37 (50%) of the case studies; more specific details of the utilised strategies are presented in Figure 8d. Additionally, a further 23 (31%) case studies that did not describe subsistence strategies as important did include variables that are subsistence-adjacent (trading food resources, managing wild fauna/flora (food resources), soil or water management for subsistence). Other frequently recurring characteristics are related to water management (n = 23:31%) or moving (settlements, mobility, migration; n = 15:20%). The distinction between these characteristics is that moving settlements and migration are specific responses, whereas mobility is an established pattern of moving around the landscape. There are numerous other characteristics found to promote resilience/sustainability, with many only stated in one (14 characteristics) or two (13 characteristics) case studies.

Evidence types (used to claim resilient/sustainable characteristic) are presented in Figure 8c. There are 26 different evidence types, with 246 total occurrences, meaning there is an average of 3.3 evidence types in each case study. There are five evidence types used in more than twenty case studies: architecture (n = 29:39%), settlement patterns (n = 24:32%), zoo-archaeological remains (n = 24:32%), artefacts (n = 22:30%), and seeds (n = 21:28%).

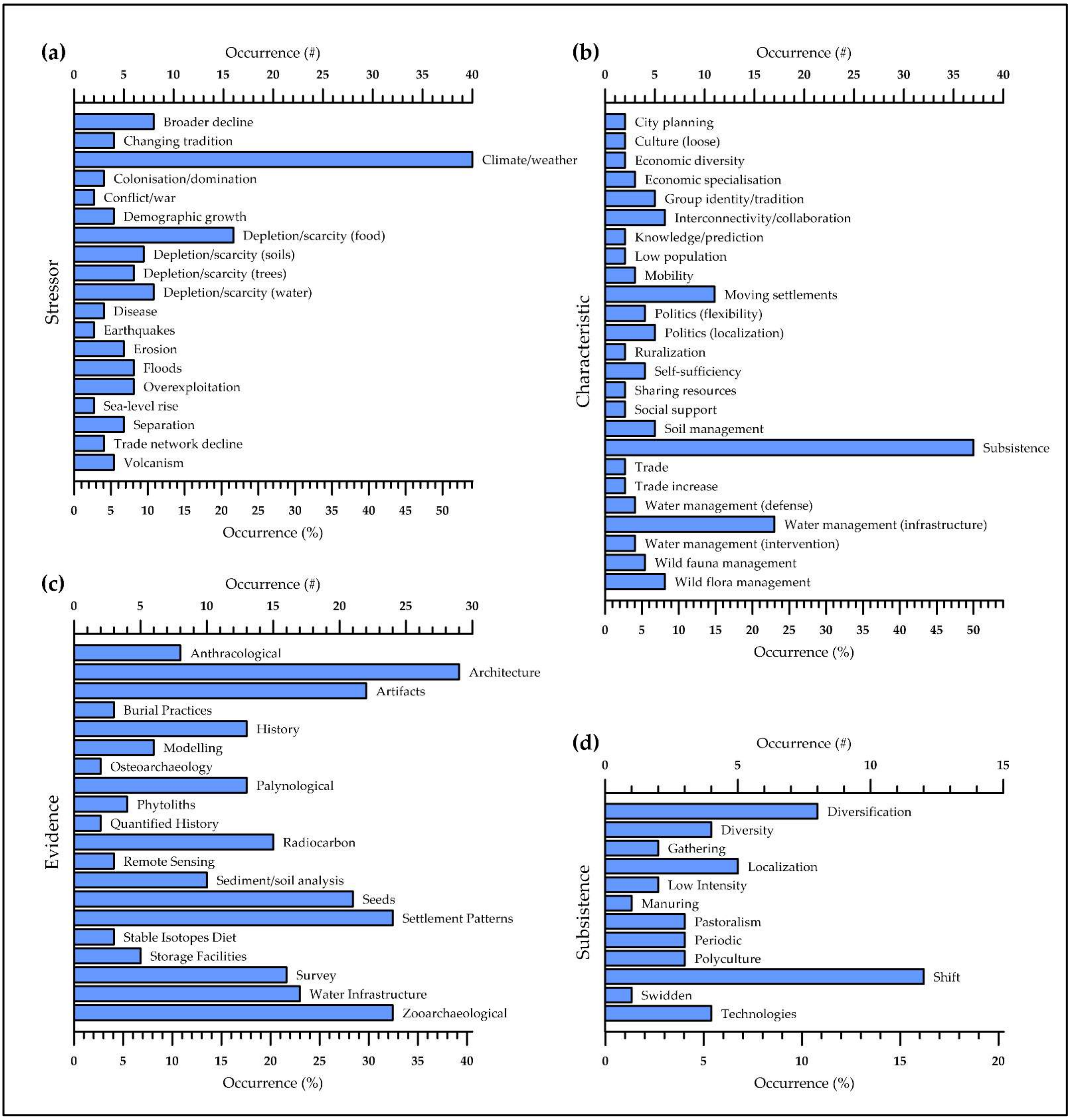

Figure 8. Case study data. (**a**) Stressors, i.e., what they were being resilient to; (**b**) resilient/sustainable characteristics; (**c**) the evidence used to argue resilience; (**d**) subdivisions of the largest category in (**b**): subsistence strategies. Variables that appeared only once were not included, except in (**d**).

4. Discussion

The present bibliometric and quantitative review is based on papers (available from the WoS literature database) that discuss resilience and/or sustainability in archaeological case studies. There are several limitations to the bibliometric analysis, which result in the number of case studies being relatively small (n = 74) and, despite measures to enhance recall (extracting citations and references from the key literature), the list is not exhaustive. Firstly, only articles published in English are included in the dataset. Whilst up to 90% of scientific publications are written in English [126], the proportion is likely lower in archaeology, suggesting at least 10% of relevant papers are missing from this dataset from the outset. Secondly, as with the social sciences and the humanities more broadly, a significant amount of archaeological research is published in books and discipline-specific journals that are not indexed in WoS [127]. Lack of completeness in this dataset is exemplified by the fact that only 5/74 (7%) of the case studies are from books and a key book on archaeological evidence for resilience by Ronald Faulseit [128] was not included. This book contains four chapters with "resilience" in the title and at least five other relevant chapters, which could feasibly have been case studies. Furthermore, a recent article by Tamara Lewit [129] and an additional chapter by Erika Weiberg [116] were not found despite containing "resilience", "theory", and "archaeology" in their titles/abstracts. Regardless of these weaknesses, the bibliometric approach employed here has identified numerous key case studies from which patterns can be observed. The bias of a traditional literature review has also been avoided, whereby experts inadvertently focus on their own research interests at the expense of others.

The bibliometric analysis completed in this paper revealed relationships between papers, authors, and keywords. One important aspect identified in this analysis relates to definitions. Archaeologists in this dataset tend to rely on early definitions of resilience by Holling (in 1973 and 2001/2) and Carpenter (in 2001), or do not cite a definition, see Citation Network: Figure 5. These studies are not from archaeology, they are from ecology, a field in which the definition of "resilience" has both evolved significantly and remained debated since (in many of the other key literature papers and more recently, e.g., [130]). More recent ecological concepts and methods should be better utilised by archaeology. One valuable example of this is found in a case study paper by Riris and de Souza [37], which developed measures of resistance and resilience with radiocarbon datasets; creating replicable formal metrics increases the wider utility of archaeological data (discussed further below). A reconsideration of definitions and terminology is required in archaeology, with the focus needing to shift towards clarity and simplicity. For example, the concept of "persistence" may be more relevant than resilience for archaeological case studies. This term more closely links to the ultimate purported goal of many of the case studies: studying the past so that we can emulate what enabled survival and avoid what led to collapse [131].

Resilience and sustainability are buzzwords, as reflected in the shift in their use over time (Figures 3 and 4) and the fact that many authors (367/397: 92.4%) only publish once on the topic in this dataset. Despite this, the number of identified papers discussing them in relation to archaeology is relatively low. Conducting the equivalent search (TS = ((archeo * OR archaeo *) AND (KEYWORDS))) but for collapse narratives reveals a much larger number of papers: 2145 results for "collapse" alone, 22,853 results when synonyms of collapse are included (i.e., breakdown, decline, demise, doom, end, downfall, and fall; from [102]). This contrast is further exaggerated by the fact that only 74 of the 1444 results in the resilience/sustainability "master list" were appropriate case studies. Similarly, a focus on negative narratives has previously been observed in studies of human-environment interactions due to their appeal in public discourse [132,133]. The prominence of resilience and sustainability (and collapse) as buzzwords ultimately harms their study; they are often poorly integrated into funding applications and papers to pique interest or used as a post-hoc explanation for findings without sufficient justification (as described by Michael E Smith, e.g., [109]). The later papers of multi-paper authors in this dataset—notably Carla Lancelotti, Erika Weiberg, and Nicholas Dunning—are generally more sophisticated with their analysis of resilience, suggesting that specialisation in these topics is important to meaningfully progress the field.

Quantification revealed a great variety of scales of analysis, case study locations, stressors (n = 23), resilient/sustainable characteristics (n = 50), and evidence types (n = 26). In stressors, climate/weather was by far the most frequently occurring, appearing in 40 (54%) case studies. Other stressors could be separated into three main categories: resource depletion (37 occurrences), anthropogenic challenges (30 occurrences), and environmental events/problems (24 occurrences). In terms of characteristics, adaptations to subsistence strategies were very important, appearing in 37 (50%) of the case studies. In the case studies that do not have subsistence strategy adaptations as a resilient/sustainable characteristic, another 23 (31%) adopted subsistence-adjacent strategies (e.g., trading food or managing wild food resources). Other commonly recurring characteristics are management of water infrastructure (n = 17), moving settlements (n = 11), and interconnectivity (n = 6). Yet, overall, there was diversity in the characteristics promoting resilience/sustainability, with many only appearing in one (n = 14) or two (n = 13) case studies. Regarding the utilised evidence, occurrences are diverse and more evenly distributed than in stressors and characteristics. The top three are architecture (29:39%), settlement patterns (24:32%), and zoo-archeological remains (24:32%). However, architecture, as well as artifacts (22:30%), are mostly used as secondary types of evidence to support other types. More results from the quantification are discussed below in the context of findings.

A key theme in the dataset is the importance of natural resources, principally related to agriculture and food. Subsistence strategies, primarily agricultural methods, are recurrently stated as characteristics that enable resilience/sustainability, together with subsistence-adjacent strategies, they are in 60 (81%) case studies. When only case studies where climate/weather is a stressor are considered, subsistence is at the forefront of all but two discussions (27:67.5% direct; 11:27.5% subsistence-adjacent). Of direct adaptations, the most frequently occurring successful response was a subsistence shift (n = 12), which is here defined as adopting a new crop or suite of crops. Additionally recurring were diversification (n = 8) and existing diversity (n = 4), as well as localisation (n = 5) of subsistence strategies. The importance of subsistence is also reflected in the evidence types, with paleo-environmental evidence for species presence appearing a total of 70 times across 43 (58%) case studies. Other evidence types are likewise related to agriculture (e.g., soil analysis: n = 10) or food (e.g., storage facilities: n = 5; stable isotopes for diet: n = 3). This may, of course, simply reflect a research preference for subsistence strategies or a greater use of the concepts of resilience/sustainability among those who study subsistence strategies. However, at least for climate, it is consistent with archaeological (e.g., [134]) and modern [135] understanding that agricultural productivity and the environment act as the mediating factor between climate and society. Further support for these links can be seen in Figure 4, where climate (both as a keyword and stressor), subsistence strategies, and subsistence evidence (zoo-archaeology and seeds) follow similar patterns over time. The need to manage other natural resources is also reflected in the results. Climate change, other environmental factors (e.g., erosion or floods) and overexploitation can lead to a depletion of food (n = 16), water (n = 8), soil (n = 7) and tree (n = 6) resources. These stressors are principally adapted to via resource management, for example of water infrastructure (n = 17), soils (n = 5), and wild species (flora = 6; fauna = 4), or by following resource availability, as reflected in the characteristics of moving settlements (n = 11) and mobility (n = 3).

There are several conflicting findings between the identified resilient/sustainable characteristics, which themselves provide significant insights. The first is between existing characteristics (e.g., economic or subsistence diversity, location, mobility, trade) and responses (e.g., subsistence diversification and other adaptations, moving settlements, increasing or reducing trade). For example, the geography of the Yucatán Peninsula made coastal communities more resilient than others, because of their location they had more dependable access to drinking water, increased agricultural productivity, and the rivers/coastline provided easier access to trade, all of which increased their ability to withstand droughts [88]. Existing characteristics are not always natural, however. At Çadır Höyük, the low amount of intervention by the Hittite Empire preceding the broader regional decline made adjusting to it easier as the community was already relatively self-sufficient and autonomous [52]. On the other hand, in different circumstances similar stressors required adaptations by the afflicted communities to survive. For example in Tell el-Dabʿa, Egypt, broader regional decline was adapted to by establishing new trading relationships and collaborating with neighbouring settlements [33]. The success of both existing characteristics and responses might be explained by varied definitions of resilience and sustainability. Resilience is generally defined as the capacity of a system to retain essential functioning under changing conditions, whereas sustainability is meeting the needs of the present without compromising future needs. Resilience is therefore more related to adaptation and can be interpreted both in the short- and long-term, whereas sustainability is focused on long-term outcomes [16,98,99].

Another chronological conflict is between characteristics which promote resilience on shorter timescales but are ultimately un-sustainable. In Mexico City, management of water through construction of defences and direct interventions temporarily solved issues of flooding. However, the same management ultimately led to more severe flooding once the defences were overcome, or moved the floodwaters to other areas without defences [56]. A second example of this is observed in Amazonia, where investment in and management of raised fields was found to improve resilience to climatic shocks by retaining moisture, thus improving agricultural productivity. Yet, on longer timescales, the raised fields lowered the quality of the soil, which led to their abandonment [46]. Significant infrastructure projects, such as Amazonian raised fields, require specific knowledge and organized maintenance that can be difficult to maintain in periods of strife. Other examples of failed large-scale water infrastructure resulting from a lack of expertise or management capacity are found globally. In Crete, after the Minoan Period, dry periods were found to result in water scarcity, followed by social unrest and economic decline, as communities did not have the knowledge required to maintain and innovate upon the existing Minoan water infrastructure [76]. Alternatively, in the Arabian Peninsula, water infrastructure was abandoned when the large work forces required for maintenance and repair could not be mobilised following the dissolution of states [60,136]. These examples emphasise the unique value of archaeology in providing long-term perspectives on issues of resilience and sustainability, which can be used to guide modern and future policy. This has been noted many times previously (e.g., [14,19,121]), and in this special issue [107], but this potential has not yet been fully actualised.

Comparison of the case studies reveals opposite characteristics which can promote resilience/sustainability, dependent on the circumstances. For example, both collaborative (interconnectivity (n = 6)/trade or trade increase (n = 4)/sharing resources (n = 2)) and isolationist (self-sufficiency (n = 4)/trade embargo (n = 1)/isolation (n = 1)) strategies are found to have enhanced resilience/sustainability in the case studies. This contrast is exemplified in a network analysis of 24 communities/regions in the late pre-Hispanic North American Southwest; this paper is also a prime example of quantification for better comparison (discussed below). Having an external orientation in social relationships was found to predict persistence through a prolonged drought; however, the Zuni region was an exception, persisting despite isolation from the regional network. The study suggests the Zuni persisted by having a high population and mobility that enabled them to follow niches of productivity [81]. This indicates two important points: (1) there are multiple possible methods for persisting through stressors, and (2) it is the combination of factors that is ultimately more important for determining resilience/sustainability.

The significance of the interaction of factors has been stressed before and is best explained by Carla Lancelotti [115]. In this paper, a framework for studying the resilience of small-scale societies is provided with three resource domains (environmental, economic, and social) and it is argued that the interactions between these domains may be more important than the specifics of each individual factor. This ties into another problem in studies of resilience to environmental changes. Whilst environmental determinism was too extreme of a position, both baseline environmental conditions and the magnitude of change can still be relevant for human impacts and perhaps the characteristics/strategies that are most effective. This is illustrated in a paper focusing on community resilience to volcanic eruptions in Costa Rica. Here, the frequency of eruptions in the region of the Arenal volcano is suggested to have enhanced resilience by enabling the survival of local knowledge between events [86]. The inverse is suggested in a recent study of climate change impacts in southwest Anatolia, where the extended duration of drier conditions resulted in a reduction of settlement and agricultural intensity. In this example, the local population initially adapted following a shift to drier conditions but were eventually overwhelmed by them. It may be that the endurance of the drier period, which had been persisting for over a century, was more impactful. On the other hand, it may also have been the result of a "perfect storm" of factors as threat of invasion, earthquakes and disease later impacted the region simultaneously [91]. Likewise, a coalescence of factors was deemed significant for the Barrilles chiefdoms in Costa Rica, where ongoing warfare undermined their ability to adapt to a relatively low-magnitude volcanic eruption [86].

The paragraphs above all reflect the complexity of resilience and sustainability. To unlock the full potential of case studies, coding of variables is required, as is a model or framework that integrates these variables and their interactions. As has been highlighted elsewhere, consistency in the coding of variables is crucial to enable quantitative cross-comparisons of case studies; see examples discussing the value of this for sustainability science by Michael E Smith [109,131]. The benefit of coding variables has been demonstrated by statistical analyses of the SESHAT database to gain new insights, for example assessment of climate change impacts on past societies by Peter Peregrine [137,138]. However, establishing methods for measuring different aspects of resilience/sustainability is a significant challenge [19,122] and it is unclear what archaeological evidence can be used to reflect core processes of societies [17]. This would necessitate archaeological projects designed specifically around this outcome. Coding of variables would be particularly valuable to enable modelling of socio-environmental systems at varied scales, especially the longer timescales which archaeology is in a unique position to explore [107]. By doing this, we can gain greater insights for modern and future resilience/sustainability.

Overall, whilst this initial quantification has identified some interesting patterns, a more formally-produced catalogue of case studies should be produced. This would be a collaborative effort between multiple parties, with different decisions made in selecting relevant papers/case studies. For instance, refining definitions of categories—in this example scale is only roughly defined and there is significant overlap due to the varying size of countries. It may also be advantageous to develop separate frameworks for resilience and sustainability, or to reframe them under the category of persistence. There may also be a need to separate the frameworks by the external shock and/or the type of community, due to the differing effects. For example, a framework examining the persistence of communities under climate change might look rather different for a small-scale agricultural society when compared to a group of hunter-gatherers, or a pre-industrial city and its hinterlands.

5. Summary and Conclusions

A total of 74 archaeological case studies of a community exhibiting resilience and/or sustainability were identified using bibliometric searching methods. The number of case studies was limited by a lack of books, discipline-specific journals, and non-English papers in WoS, as well as a disproportionate focus on negative narratives (i.e., collapse) in archaeology. Additionally, many papers from the initial results were not suitable as they merely identify a community that survived a particular shock, and then use resilience as a post-hoc explanation, without establishing the evidence/characteristics behind this supposed resilience.

Bibliometric analysis of the 74 case studies, as well as the key resilience/sustainability theory (13 papers) and archaeological theory/summary (10 papers) datasets, revealed an increase in publications per year over time. This is a highly collaborative discipline (average of 4.2 authors per paper) but balkanised, with isolated groups researching one region and/or methodology. Resilience and sustainability, as buzzwords, were topics that 92.4% of authors only published on once; furthermore, 60% of papers did not have any multi-paper authors. This is an overall negative for the concepts in archaeology, as evidenced by a reliance on outdated ecological definitions and poor integration of the concepts. The higher quality of later work by multi-paper authors suggests that to improve research, more specialists in ancient resilience/sustainability are required.

Several aspects of the 74 case study papers were then quantified—scale, location, period, stressor (i.e., why was resilience/sustainability required?), characteristic (i.e., how were the community resilient/sustainable?) and evidence (used to claim resilient/sustainable characteristic), to summarise and gain additional insight from previous research. The full dataset can be found in Supplementary Table S1. There were many diverse stressors, characteristics, and evidence types, but several occurred with high frequency. Climate was by far the most prominent stressor (n = 40), as also reflected in the keyword analysis. Other natural stressors included depletion/scarcity of various natural resources and extreme events (e.g., floods and volcanic eruptions). Anthropogenic challenges were also present, such as broader regional decline, separation from networks and demographic changes. The high prevalence of both climate and natural resource deficiency were impactful on the characteristics and evidence types. Subsistence adaptation was the most common resilient/sustainable characteristic (n = 35) and in many other case studies different solutions were found to address subsistence deficiencies (n = 23). Other common characteristics dealt with different resource deficiencies, such as water and wild resource management, as well as moving to follow resource abundance. Evidence for agriculture, such as zooarchaeological and archaeobotanical (seeds, phytoliths) remains, was thus frequent, as were water infrastructure and settlement patterns. Evidence types were overall more diverse and often combined to reach conclusions. For instance, architecture and artefacts were commonly used as supplementary evidence.

Perhaps more insightful than the characteristics themselves were the conflicts between them. Firstly, some actions were found to be resilient in the short term but ultimately unsustainable. Archaeology is unique in its ability to provide this longue durée perspective, which enables understanding of slower processes unobservable in a single human's lifetime [107], to policymakers so that these pitfalls can be avoided in the future. Secondly, directly opposing characteristics were found to promote resilience/sustainability under different circumstances. This stresses that there is no simple, universally successful policy; there may be multiple strategies for overcoming the challenges of the future.

A more rigorous scientific methodology is required to access the as-yet untapped potential of archaeological case studies of resilience/sustainability (as argued for previously in [109]). Formal comparative analysis between varied regions with high-quality datasets is essential but will first require uniform methods for coding community variables using archaeological evidence. Subsequently, a framework or model should be produced that integrates these variables and, more importantly, their interactions with one-another, building upon previous work [115]. This work is of the utmost importance because it would enable the development of long-term policy tailored to the specific (environmental, economic, and social) characteristics of individual communities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142416591/s1, Table S1: Case Study Quantification.

Funding: This research was funded by the German Archaeological Institute (DAI) as part of the "Global Archaeology, Sustainable Archaeology and the Archaeology of Sustainability" scholarship program.

Data Availability Statement: The data presented in this study are available in the Supplementary Materials.

Acknowledgments: Thank you to Lisa Backhouse for providing vital feedback and guidance on multiple drafts of this manuscript. There are many other researchers with whom discussions have contributed greatly to my understanding of resilience/sustainability. For this, I would particularly like to thank Nicki Whitehouse, Marco Madella, Martin Finné, Tamara Lewit, Felix Riede, Phil Riris, and Michael E Smith. Finally, I would like to thank the three reviewers for their invaluable feedback.

Conflicts of Interest: The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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