



scoping review that met the following criteria, namely: including all persons; considering the heat adaptation concept; and covering the context of the impact of global warming on health and mortality. A total of 23 studies were selected. This review found very few studies targeting adaptation to heat in the human population and a limited number of countries carrying out research in this field, something that highlights the lack of research in this area. It is therefore crucial for political decision-makers to support studies that serve to enhance our comprehension of long-term adaptation to heat and its impact on the health of the human population.

## 1. Introduction

Climate change is the greatest health threat facing humanity (WHO, 2021), due to the increased frequency, intensity and severity of extreme weather phenomena, such as heat waves, cold waves, storms, forest fires, floods and droughts. These phenomena affect human health negatively, in that they increase the mortality and morbidity of the population (Weilhammer et al., 2021).

According to the Intergovernmental Panel on Climate Change (IPCC), there has been a rise in the mean global temperature and an increase in the intensity and frequency of heat waves (IPCC, 2022). That said, however, the effects are felt to differing degrees in different populations, due to individual, demographic, geographical and social factors which determine vulnerability and the capacity to adapt (Adger, 2006; Paavola, 2017a; Satgar and Cherry, 2019; WHO, 2021). These factors are dictated by differences in exposure, sensitivity and adaptability to risk factors (Füssel and Klein, 2006; Marí-Dell'olmo et al., 2022; Paavola, 2017b).

Adaptation in the human system is the process of adjusting and modifying to tackle the current or envisaged climate and its effects, with the aim of minimising harm and maximising the opportunities of obtaining benefits (Allen et al., 2014). Several metrics can be used to measure the effectiveness of adaptation (United Nations Environment Programme, 2022). When it comes to the impact of heat, this can be addressed by reference to its relationship with the adaptation strategies implemented, i.e., health and wellbeing, economic and human security, agriculture and subsistence livelihood, infrastructure and built environment, and socio-cultural impacts (Turek-Hankins et al., 2021). From a health standpoint, the reduction in heat-related mortality is regarded as being the most effective indicator to show the efficacy of adaptation (United Nations Environment Programme, 2022).

Whereas increasingly more tends to be known about the impact of climate change caused by human action, far less is known about global adaptation to such change (Turek-Hankins et al., 2021). In general, virtually nothing is known about how humans have adapted or will adapt to heat stress caused by long-term climate change (Folkerts et al., 2020).

To ascertain the level of a given population's adaptation to heat, this can be analysed via the time trend in the temperature-mortality relationship. To this end, one can use two indicators that link mortality (T<sub>threshold</sub> and MMT) and compare the trend over time to the rate of increase in the maximum daily temperature. If these indicators' rate of change is swifter than the increase in the maximum daily temperature, then the population has adapted: however, if the indicators' rate of change is slower than the rate of increase in the maximum daily temperature, then the population has not succeeded in adapting itself (Follos et al., 2020, 2021; López-Bueno et al., 2021; Navas-Martín et al., 2022a; Navas-Martín et al., 2022b).

*T<sub>threshold</sub>* is the maximum daily temperature above which the effects of heat begin to cause excess heat-related mortality, and above which mortality rises significantly (Linares et al., 2017; López-Bueno et al., 2021). *MMT* is the maximum daily temperature which has the lowest number of deaths (Follos et al., 2020, 2021).

It is thus crucial to understand the factors that influence adaptation (Bakhsh et al., 2018) in order to protect the population from its effects, particularly those related to the rise in temperature and its impact on health (Sánchez Martínez et al., 2011). However, we have no precise

picture of what is known in the scientific literature about the population's adaptation to heat through the temperature-mortality relationship.

In this context, the temperature-mortality relationship, as seen through the time trend in threshold temperatures and minimum mortality temperatures vis-à-vis the maximum daily temperature, makes it possible to ascertain a given population's level of adaptation to heat. Bearing this in mind in order to guide the study, the following research question was posed: What is the available evidence in the literature on population adaptation to heat by reference to the time trend in the temperature-mortality relationship?

This review therefore aimed: firstly, to ascertain existing knowledge about population adaptation to heat by reference to a reduction, if any, in mortality due to the effects of heat on human health; and secondly, to draw up a research network map based on the co-authorships of the papers retrieved.

Reviews of the literature concerning between temperature-related mortality and human adaptation to high temperatures are limited (Arbuthnott et al., 2016; Boeckmann and Rohn, 2014). Consequently, they have highlighted the paucity of substantial evidence. With rising global temperatures and increased frequency and intensity of heat waves, assessing the scope and completeness of existing evidence could help to pinpoint areas where knowledge gaps exist. In addition, this assessment could guide future research.

## 2. Material and methods

A scoping review serves as an initial assessment of the potential breadth and depth of existing research materials, striving to uncover the character and scale of available research findings, which may even encompass ongoing research. This type of review provides policymakers with insights to determine whether a comprehensive systematic review is warranted (Grant and Booth, 2009). Scoping reviews are conducted for a variety of purposes, the main objectives being to examine the breadth or depth of the literature, map and summarise the available evidence, guide future research, and recognise or address areas of knowledge gaps (Peters et al., 2020a).

We conducted a scoping review in accordance with the suggested recommendations of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) extension for scoping reviews and updated methodological guidelines (Peters et al., 2020b; PRISMA, 2021). Scoping reviews begin by establishing a predetermined protocol that describes the planned methodology for each stage (Sargeant and O'Connor, 2020). To do this, we drew up a purpose-designed protocol (Navas-Martín et al., 2023c), which was deposited before extraction of data from the Open Science Framework repository (Center for Open Science, n.d.). The protocol outlines the search strategy, screening process, data-charting process and data-analysis.

### 2.1. Eligibility criteria

In line with the Population, Concept and Context mnemonic (Peters et al., 2020a), this exploratory review included studies that: a) referred to all persons; b) considered the heat-adaptation concept; and c) covered the context of the impact of global warming on health and mortality.

## 2.2. Search strategy and selection criteria

The search strategy was jointly drawn up by a specialist in literature searches and the research team. An initial strategy was designed using the following MeSH controlled vocabulary terms for MEDLINE: “Adaptation Physiological”; “Acclimatization”; “Heat Stress Disorders”; “Hot Temperature”; “Temperature”; “Mortality”; and “Climate Change”. This search strategy was then adapted for use in other databases, such as *Embase*, *Scopus* and *Web of Science Core Collection*. The different search strategies used in the bibliographic databases are shown in Annex 1. We included manuscripts in English published since 2003, the year marking Europe's most lethal heat wave to date and the initiation of heat-prevention plans, and thus collected the most recent studies and reports on the issue until May 2023. Our review covered ecological studies of all geographic regions.

## 2.3. Screening

After using the purpose-designed strategy to conduct the search, we compiled the results and excluded duplicated records with the aid of the JabRef reference management software programme (Kopp, n.d.). A screening process using the liberal accelerated method (Khangura et al., 2012) was then performed, in which one reviewer examined all the documents identified for their possible inclusion, and another reviewer independently screened any documents that had been excluded by the first reviewer. The initial screening process consisted of a perusal of the titles and abstracts of all entries found. The full text of the remaining documents was then evaluated and screened in accordance with the eligibility criteria.

## 2.4. Data-charting process

Information was collected from each paper using a Microsoft Excel data-extraction sheet. One member of the research team extracted the data, which were then verified by a second team member. These data included titles, authors' names, country of corresponding authors' institutional affiliations (in cases where there was more than one the corresponding author, the first author was selected), year, study objectives, and key words.

## 2.5. Data-analysis

We performed quantitative and qualitative analyses of the results of the scoping review. The quantitative analysis focused mainly on the authors, the year of publication, the country of corresponding authors' institutional affiliations, the study objectives, and the key words. A word cloud was generated for analysis of key-word frequencies using the *Wordclouds.com* on-line tool. The qualitative analysis, for its part, consisted of using content analysis to categorise the study objectives, in order to group them by category (Bardin, 2002). For visual depiction of the countries of the institutions where researchers carried out their studies, the *MapChart* on-line tool was used. Lastly, we performed an analysis of social media, using reference data that enable collaborative networks with other authors to be identified. To this end, we used *VOSviewer* version 1.6.19, which is an application for building and visualising bibliometric networks. For analysis of the bibliographic references, all authors' names were manually normalised to unify them, and to prevent duplication as a result of the same name being cited in different ways in the papers.

## 3. Results

A total of 23 studies were selected for review purposes (Table 1) from an initial set of 98 studies that fulfilled the eligibility criteria. Of the 74 studies excluded, 50 did not address adaptation, 13 focused on future projections that did not make it possible to ascertain whether a

population had or had not adapted to heat, and in 11 there was no direct relationship between temperature and mortality (Fig. 1).

Of those selected, eleven approached the issue from the standpoint of axes of inequality, which are factors that contribute to inequality in a society. These axes were identified as territory (Díaz et al., 2018; Navas-Martín et al., 2022b), age (Navas-Martín et al., 2023b), gender (Follos et al., 2020; Navas-Martín et al., 2022a), or the combination between different axes, such as gender and age (Achebak et al., 2019), and age and territory (Bobb et al., 2014; Chung et al., 2018; Navas-Martín et al., 2023a). Furthermore, one study was found which approached the topic using more than two axes, e.g., age, territory and gender (Ordanovich et al., 2023) or ethnicity, age and gender (Roca-Barceló et al., 2022). Eight studies were deemed to be methodological studies (Åström et al., 2016; Follos et al., 2021; Kinney et al., 2008; López-Bueno et al., 2021; Petkova et al., 2017; Thai et al., 2019; Todd and Valleron, 2015). One study was undertaken in multiple cities (Tobías et al., 2021), and one in several countries (Vicedo-Cabrera et al., 2018). Two studies were reviews of literature relating to heat adaptation (Arbuthnott et al., 2016; Boeckmann and Rohn, 2014).

With respect to studies categorised as axes of inequality, Díaz et al. (2018) observed a decrease in heat-attributable mortality in the Spanish population in recent years, though there were differences between territories. Furthermore, when it came to evaluating adaptation levels, Navas-Martín et al. (2022a) identified differences in heat adaptation between urban and non-urban populations. Additionally, Bobb et al. (2014) found that the US population had developed greater resistance to heat with time, reflected in a decreased risk of mortality. Differences were, however, observed between cities and age groups, especially in the elderly population. Navas-Martín et al. (2023a, 2023b) and Ordanovich et al. (2023) also found differences in adaptation to heat by territory and gender respectively.

From a gender perspective, Achebak et al. (2019) reported that both men and women showed adaptation across the study period in Spain. For their part, Follos et al. (2020) and Navas-Martín et al. (2022b) found differences in the adaptation of the Spanish population, stressing that while women were more susceptible to heat, they nevertheless showed a greater capacity of adaptation than men. The study conducted by Chung et al. (2018) observed a decrease in the relative risk of heat-related mortality in Japan. In addition, significant differences were found by region and gender: the results indicated that the change in susceptibility was associated with climatic, demographic and socio-economic factors.

Lastly, the study conducted by Roca-Barceló et al. (2022) to evaluate adaptation of the São Paulo population, analysed fluctuations in the MMT and cumulative relative risk, and reported differences by gender, age and ethnicity. With respect to differences by race, whereas non-white men displayed greater difficulties to adapt to heat, white women displayed a greater capacity of adaptation.

With respect to the studies reviewed which addressed methodological aspects, Kinney et al. (2008) indicated the existence of different ways of linking temperature to mortality, though with different limitations. Although the MMT is commonly used, there are different ways of obtaining it. Follos et al. (2021) suggested the use of quadratic or cubic adjustments to find the best relationship between temperature and mortality through the MMT. Moreover, they proposed evaluating a population's adaptation to heat by comparing the rate of increase in the MMT to the maximum daily temperature (TMAX). López-Bueno et al. (2021) indicated that Tthreshold can also be used, though its time trend displays considerable geographical variation.

Todd and Valleron (2015) reported that large urban areas are not uniform and can have important variations, as in the case of their study in Paris, where significant differences were observed between the city and its suburbs. Thai et al. (2019) proposed linking high indoor temperatures to mortality, and stressed that the association between exposure to indoor temperatures and mortality also depends on the geographical situation. Folkerts et al. (2020) used three different methods to ascertain the MMT and sensitivity to heat. The results

**Table 1**  
Summary of reviewed studies on population adaptation to heat through the relationship between temperature and mortality.

Reference	Country	Aims	Keywords	Category
Kinney et al. (2008)	USA		adaptation, climate change, heat waves, mortality, temperature, weather	Methodological
Bobb et al. (2014)	USA	They investigated the hypothesis that if adaptation is occurring, then heat-related mortality would be decreasing over time		Axes of inequality
Boeckmann and Rohn (2014)	Germany	In this study, the researchers are particularly interested in intentional, planned adaptation	heat, climate change, effectiveness, systematic review, cardiovascular disease, respiratory disease	Review
Todd and Valleron (2015)	France	Their aim was to partition space with a high-resolution grid to assess the temperature-mortality relationship in a territory with wide climate diversity over a period with notable climate warming		Methodological
Arbuthnott et al. (2016)	United Kingdom	The objective of this paper is to review studies that have specifically examined variations in temperature-related mortality risks over the 20th and 21st centuries and determine whether population adaptation to heat and/or cold has occurred.	climate change, adaptation, temperature, heat, cold, heatwave, mortality, health	Review
Åström et al. (2016)	Sweden	They used observations of daily mean temperatures to investigate whether the minimum mortality temperature (MMT) changed in Stockholm, Sweden, from the beginning of the 20th century until 2009		Methodological
Petkova et al. (2017)	USA	The present study derived projections of temperature-related mortality in New York City, considering future patterns of adaptation or demographic change, both of which can have profound influences on future health burdens.		Methodological
Chung et al. (2018)	South Korea	The objective of study was to investigate the changing population susceptibility to non-optimum temperatures in 47 prefectures of Japan over a span of four decades, specifically from 1972 to 2012. We aimed to address three aspects: minimum mortality temperature (MMT) and the risks of heat- and cold-related mortality. Additionally, we aimed to examine the associations between these aspects of susceptibility and climate, demographic, and socioeconomic variables.		Axes of inequality
Vicedo-Cabrera et al. (2018)	United Kingdom	This study aims to address the issue of potential adaptive mechanisms to non-optimal ambient temperatures by providing a comprehensive assessment. The assessment will cover recent decades and different locations characterised by diverse climates.	climate change, heat, cold, adaptation, mortality	Multiple locations
Dfáz et al. (2018)	Spain	The objective of this study is to analyze whether there has been a temporal change in the maximum daily temperatures that constitute a heat wave (T <sub>threshold</sub> ) in Spain during the period of 1983–2013. Additionally, the study aims to investigate whether there has been variation in the attributable risk (AR) associated with mortality due to high temperatures during this period.	heat waves, daily mortality, time trend, impact assessment, prevention plans	Axes of inequality
Achebak et al. (2019)	Spain	The aim of this study was to assess trends in temperature-related cardiovascular disease mortality in Spain, considering both sex and age. Additionally, the study investigated the association between climate warming and changes in the risk of mortality.		Axes of inequality
Thai et al. (2019)	Australia	This study aimed to address the challenge by employing an indirect approach to evaluate the impact of elevated indoor temperature on mortality in different climate zones. The objective was to investigate whether humans adapt or acclimatize to different ranges of indoor temperatures.	minimum mortality temperature, indoor temperature, human health, adaptive thermal approach, adaptability	Methodological
Folkerts et al. (2020)	Netherlands	The aim of the current study was twofold: they investigated changes in minimum mortality temperature (MMT) in the Netherlands over a period of 23 years, from 1995 to 2017, specifically focusing on older adults (≥65 years). Additionally, they compared the three previously mentioned models (SEG, CSDL, and DLNM).	mortality, temperature, climate change, human adaptation, older adults, minimum mortality temperature	Methodological
Follos et al. (2020)	Spain	The objective of this study is to determine the temporal evolution of minimum mortality temperature (MMT) in two Spanish provinces (Seville and Madrid), during the period of 1983–2018. Additionally, the study aims to evaluate whether the rate of adaptation to heat is appropriate.	minimum mortality temperature, adaptation, daily mortality, prevention plans	Axes of inequality
Follos et al. (2021)	Spain	The objective of this study was twofold. Firstly, it aimed to analyze the temporal evolution (time trend) of minimum mortality temperature (MMT) registered in Spain's 52 provinces during the period of 1983–2018. Secondly, the study aimed to investigate whether there was an increase in MMT sufficient to compensate for the increase in environmental temperatures detected in Spain during the same period.	minimum mortality temperature, adaptation, temporal trend, mortality, heat	Methodological
López-Bueno et al. (2021)	Spain	The objective of this study was to analyze the temporal evolution of threshold temperatures (T <sub>threshold</sub> ) in different Spanish regions during the period of 1983–2018. Additionally, the study aimed to compare this evolution with the evolution of mean monthly temperature (MMT).	temperature threshold, minimum mortality temperature, adaptation, mortality attributable	Methodological
Tobías et al. (2021)	Spain	The researchers aimed to estimate mean monthly temperatures (MMTs) using data from hundreds of communities across various countries under different climates. Additionally, they sought to	adaptation; time-series; distributed lag nonlinear models; multi-city; multi-country	Multiple locations

(continued on next page)

Table 1 (continued)

Reference	Country	Aims	Keywords	Category
Navas-Martín et al. (2022a)	Spain	study the geographical, climatic, and socioeconomic determinants of the MMT. The aim of this study was to provide knowledge related to the social, climate, and economic factors that are associated with the evolution of minimum mortality temperatures (MMT) in Spain, considering both rural and urban contexts, during the time period of 1983–2018. The aim of this study was to analyze the values of minimum mortality temperatures (MMT) in men and women and examine their temporal evolution during the period of 1983–2018 in the provinces of Spain.	adaptation, minimum mortality temperature, urban, rural, prevention plans, local factors	Axes of inequality
Navas-Martín et al. (2022b)	Spain	The aim of this study was twofold. Firstly, to ascertain adaptation to heat among individuals aged 65 years and older across the period from 1983 to 2018 by analyzing the minimum mortality temperature (MMT). Secondly, to examine the trend in adaptation to heat over time in relation to the total population.	adaptation, vulnerability, minimum mortality temperature, gender, sex	Axes of inequality
Roca-Barceló et al. (2022)	United Kingdom		urban health, health inequalities, climate change, temperature, mortality	Axes of inequality
Navas-Martín et al. (2023a)	Spain	The aim of this study is to ascertain the differences in vulnerability and the heat-adaptation process among the Spanish population aged 65 years and older, specifically through the analysis of the minimum mortality temperature (MMT), using territorial classification.	adaptation; MMT; age; prevention plan; mortality; health	Axes of inequality
Navas-Martín et al. (2023b)	Spain	This study aims to explore the temporal variations of the minimum mortality temperature and the mortality burden from both heat and cold between the years 1979 and 2018.	adaptation; MMT; age; elderly; rural; nonurban; urban; mortality; health	Axes of inequality
Ordanovich et al. (2023)	Spain		adaptation, temperature, climate change, time-series regression, distributed lag non-linear models	Axes of inequality

indicated that susceptibility to heat decreased in the elderly population of The Netherlands, regardless of the method used. Åström et al. (2016) proposed using extended time series to examine demographic trends. To this end, they analysed data on the Stockholm population covering more than a century and suggested that the population had adapted by virtue of increase in the MMT. Lastly, Petkova et al. (2017) suggested that adaptation to heat can be evaluated by observation of changes in the relative risks of heat-related mortality across time.

With reference to the multiple-location category, this was characterised by featuring comparative studies undertaken in different places, whether different cities or countries. Tobías et al. (2021) carried out a study in 43 different countries, in which they suggested that populations showed adaptation to high temperatures, especially in areas with greater variations in temperature and seasonal changes. Vicedo-Cabrera et al. (2018) conducted a study in 10 different countries to estimate trends in attributable mortality fractions, which decreased in most countries. The authors suggested that there had been a reduction in heat-related mortality in more recent decades.

Lastly, two literature reviews were found. Boeckmann and Rohn (2014) conducted a systematic review of effective measures to reduce heat-related mortality. They located a total of 30 papers but found no conclusive evidence of which measures were effective for adaptation to heat. Arbutnott et al. (2016), on the other hand, carried out a study to explore the relationship between temperature, health outcomes, and changes in vulnerability or adaptation. They found only 11 studies that quantified absolute risk of heat-related mortality across time, as well as 6 studies that compared the effects of heat waves on mortality. Their findings indicated a decrease in susceptibility to heat and heat waves in the population.

When it came to analyzing the place of origin of corresponding authors' institutions, the continents represented were North America (USA), Asia (South Korea), Europe (Spain, France, The Netherlands, United Kingdom and Sweden) and Oceania (Australia) (Fig. 2).

In terms of key-word analysis, a total of 52 key words with 101 repetitions were analysed. The terms that registered the highest frequency were “adaptation” (12 times), “minimum mortality temperature” (8 times), “climate change” (7 times), “mortality” (6 times), “temperature” (4 times), “health” (3 times), “heat” (3 times) and “prevention plans” (3 times). In contrast, the terms “age”, “cold”, “heat waves”, “MMT”, “rural” and “urban” appeared twice, while the majority of key words analysed (74.1 %) appeared only once (Fig. 3).

In the analysis of the research network map identified in the scoping review (Fig. 4), the presence of 12 groups or clusters was observed: of these, 7 were isolated, and 5 were interconnected. One cluster in particular was noteworthy (shown in red), which was the main component and the largest of all. This cluster was in turn made up of 4 additional clusters, though the ties of the central cluster were weak, since they depended on a single node (the researcher, Roosli). According to Granovetter's theory about the strength of weak ties (Granovetter, 1973), if this researcher were to disappear, the component would split and the network would become more tenuous.

Finally, as a summary of the evidence on the main findings of the reviewed publications on the process of human adaptation to heat, in general it can be stated that the population is undergoing heat adaptation. However, it is important to note that the availability of studies on this subject is limited and differences have been identified both in methodological approaches and in the populations analysed. On the one hand, few reviews have been found in this area. In the systematic review conducted by Boeckmann and Rohn (2014), >56.6 % of the studies reviewed reported a decrease in negative effects related to extreme heat conditions. However, the reviewed studies did not provide definitive evidence on the effectiveness of adaptation measures, as it is difficult to quantify the health impacts of adaptation.

In contrast, the review by Arbutnott et al. (2016) mostly (91 %) identified a decrease in population vulnerability to heat over time.

On the other hand, the few studies obtained in both reviews may be attributed, in part, to the complexity of obtaining accurate measurements of MMT. In addition, it is important to consider that the relationship between temperature and mortality may vary between different cities or communities, suggesting the usefulness of using time series spanning long time periods, as proposed by Kinney et al. (2008).

With regard to the results, in the United States, during the period from 1987 to 2005, most of the cities analysed (70 %) proved to have adapted to heat. Although the population has become increasingly resistant to heat, this does not rule out the persistence of heat-related risks, as noted by Bobb et al. (2014). In the context of New York City, a study spanning from the 19th to the 20th century revealed limited heat adaptation during the first half of the 20th century. However, a change in this trend was observed in the last four decades, indicating increased adaptation, especially from the year 2000 onwards. These findings suggest that the main factor driving this change was the widespread use of domestic air conditioning, as noted by Petkova et al. (2017).

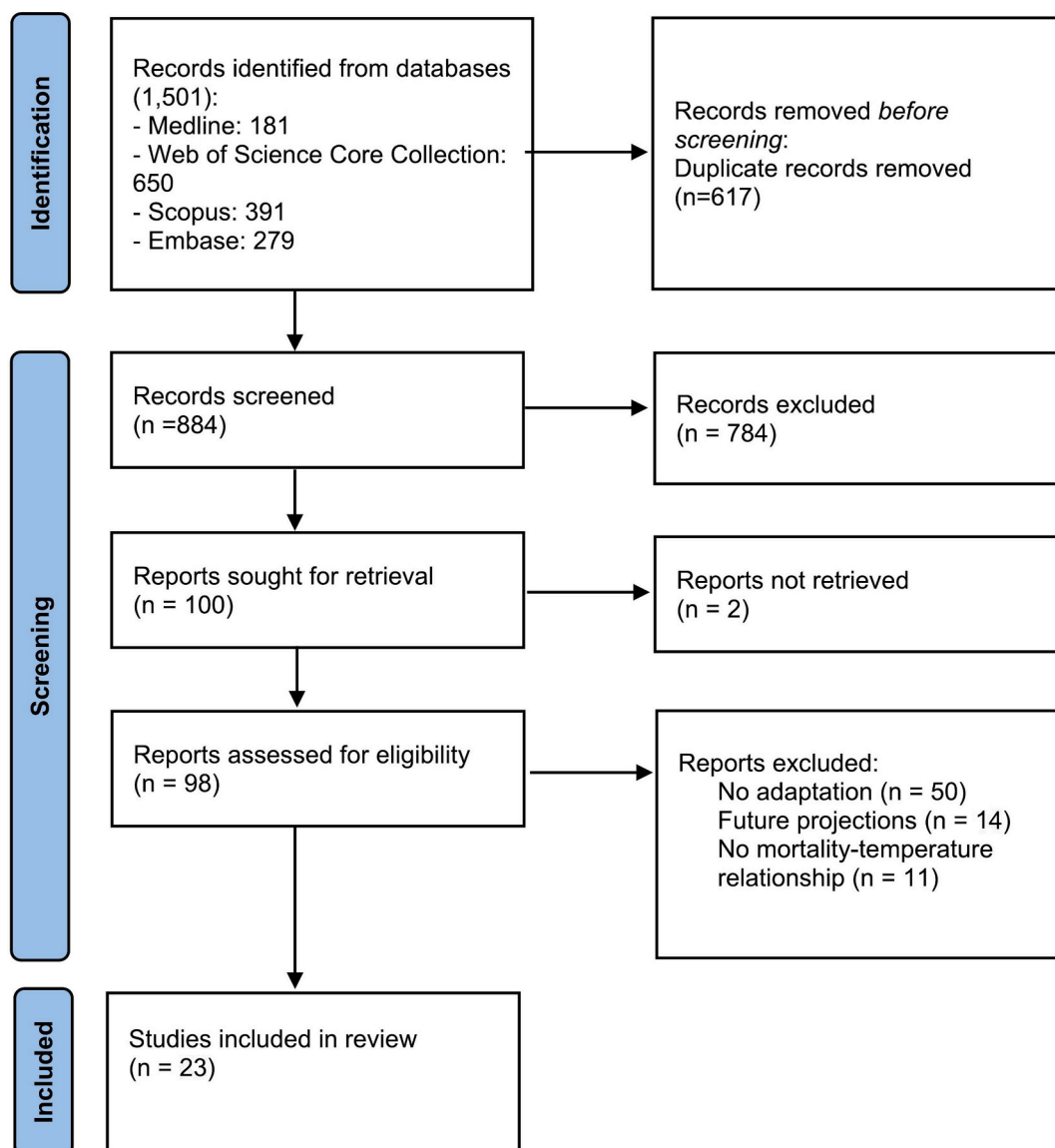


Fig. 1. Flow chart of study selection for scoping review process.

In France, a study in an elderly population during the period from 1968 to 2009 showed indications of heat adaptation in their results, according to [Todd and Valleron \(2015\)](#). In Sweden, an analysis conducted in the Stockholm population during the period 1901 to 2009 suggests that the gradual increase in MMT over time could indicate heat adaptation, as indicated by [Åström et al. \(2016\)](#). On the other hand, in Japan, a study covering all 47 prefectures during the period 1972 to 2012 found a decrease in population susceptibility to heat over time, as mentioned by [Chung et al. \(2018\)](#). In the Netherlands, a study conducted in an elderly population during the period 1995 to 2017 suggests the presence of adaptation, indicated by a decrease in human susceptibility to heat [Folkerts et al. \(2020\)](#). In Brazil, a study conducted in the city of São Paulo during the period 2000 to 2018 suggests that white women adapted more than women of other races, while non-white men showed less favourable adaptation [Roca-Barceló et al. \(2022\)](#).

An analysis conducted in 10 countries over the period 1985 to 2012 indicated that most of these countries (70 %) experienced adaptation, evidenced by decreases in heat-related mortality impacts, as reported by [Vicedo-Cabrera et al. \(2018\)](#). In addition, a study covering 43 countries over the period 1984 to 2016 suggests that populations have shown adaptation, as indicated by [Tobías et al. \(2021\)](#). In a more specific

approach, a study that took place in 8 cities and focused on the relationship between indoor and outdoor temperatures and mortality revealed that populations may be in the process of adapting to higher indoor temperatures, as evidenced by [Thai et al. \(2019\)](#).

In the context of Spain, several studies have addressed human adaptation at various scales and time periods. Studies conducted between 1983 and 2018 include research carried out in different numbers of provinces, such as two specific provinces (Madrid and Seville) analysed by [Follos et al. \(2020\)](#), 10 provinces studied by [López-Bueno et al. \(2021\)](#), and a 50-province level analysis by [Follos et al. \(2021\)](#) that all showed adaptation in general. Also, in the same period, in relation to urban and non-urban populations, a study by [Navas-Martín et al. \(2022a\)](#) suggests that the urban population has experienced greater adaptation, while [Navas-Martín et al. \(2022b\)](#) suggest that women have shown greater adaptation than men. In the context of the elderly population, it found that the majority (62 %) had adapted to the heat, according to [Navas-Martín et al. \(2023a\)](#), while other research focused on the elderly population in urban and non-urban provinces during the same period suggests adaptation in non-urban provinces ([Navas-Martín et al., 2023b](#)). During another study period, spanning from 1983 to 2013, the research conducted by [Díaz et al. \(2018\)](#) also indicates



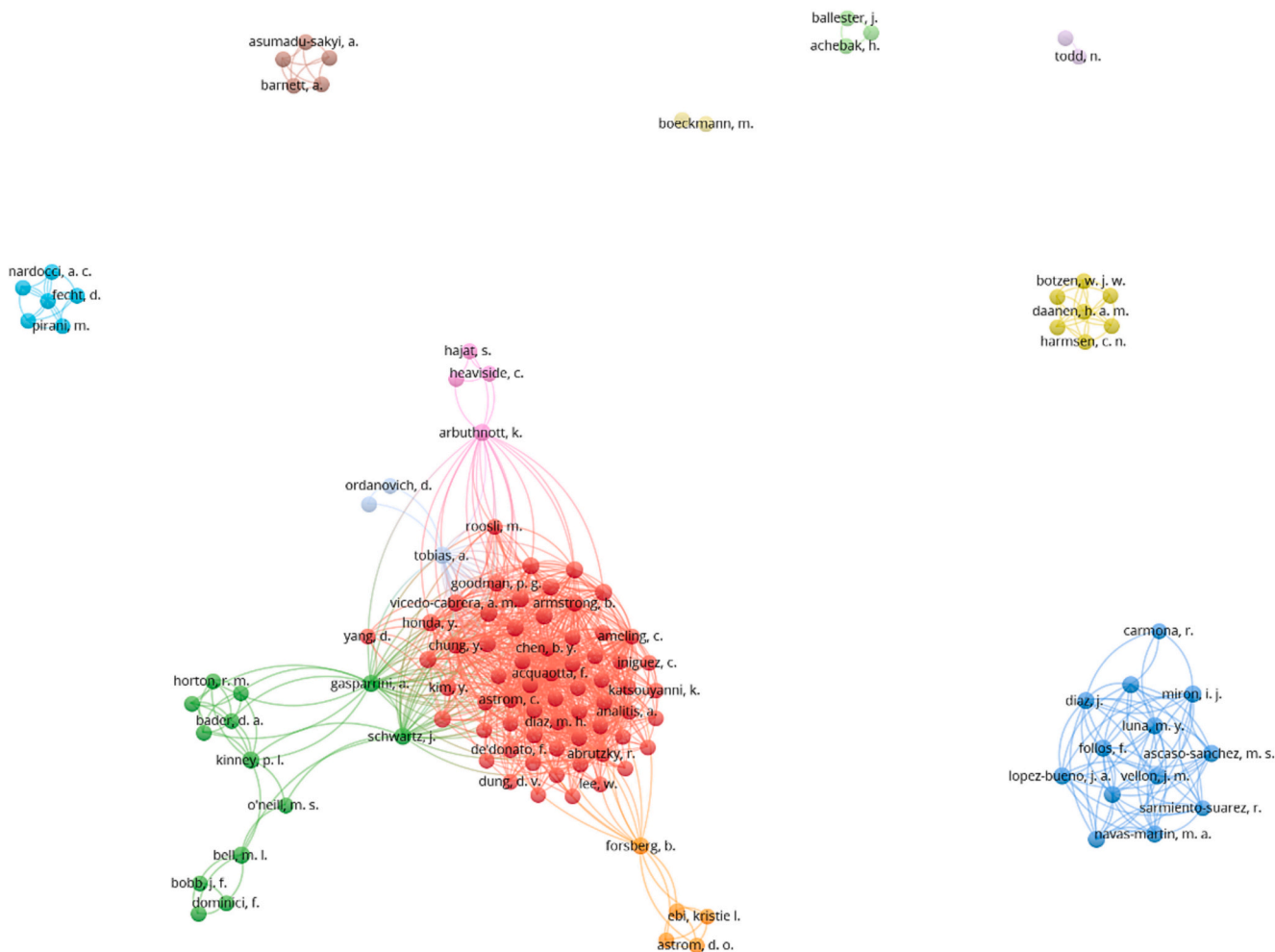


Fig. 4. Visualization of the researcher network grouped by clusters.

this crucial issue. Furthermore, the results of the limited evidence are in line with those of another two literature reviews using similar approaches, one conducted in 2014 which included 30 selected studies (Boeckmann and Rohn, 2014), and another in 2016 which covered 17 studies (Arbuthnott et al., 2016).

Similarly, most of the studies identified were characterised by being ecological studies that use different axes of inequality, such as gender, ethnicity, age or territory, to determine a given population's capacity of adaptation. These axes are those which determine the possibilities that individuals have to preserve their health and adapt to the effects of climate change and their impact on health. The results also highlight the fact that there is no single methodology to ascertain a population's long-term heat-adaptation process. Despite the fact that two of the studies located were undertaken in many cities spread across different countries, and even in different countries, most of the studies were undertaken at a smaller scale of analysis, something that highlights the fact that adaptation policies should be approached from a local rather than a global perspective (Füssel and Klein, 2006), taking into account the fact that the geographical, climatic and socio-economic characteristics of each particular area determine its adaptation (Navas-Martín et al., 2023b).

In terms of the origin of the institutions at which the studies were carried out, Spain heads the number of studies on heat adaptation and its impact on health, followed by the United Kingdom and the USA. The lack of studies in Africa and South America is notable, which underscores the fact that, despite the impact of global warming on all countries, there are few countries which are currently undertaking

research in this field.

Although the key-word analysis showed a wide diversity in the terms used, the most noteworthy elements were adaptation, the implications of climate change on health, and the use of the MMT as the most usual indicator for measuring the temperature-mortality relationship.

Insofar as the research network map is concerned, there are a significant number of groups that are not interconnected as compared to groups that do collaborate. This could account, on the one hand, for the methodological differences found in the studies. On the other hand, the characteristics of the studies require that they be conducted on a smaller scale, which means that collaborations to replicate studies between countries or cities could be determined by the problem of these studies being comparable, due to the fact that the adaptation process is influenced by the climatic, geographical and socio-economic characteristics of each particular area (Navas-Martín et al., 2023b).

In general, it can be said that, while some populations have partially succeeded in adapting to heat, many others still have to overcome difficulties to achieve this. A number of studies have indicated that in some countries, both in Europe and in other parts of the world, there has been a lessening in the effects of heat, though this reduction is neither uniform nor found everywhere (WHO Regional Office for Europe, 2021).

Lastly, while studies on heat and mortality have increased in the last two decades (Mayrhuber et al., 2018), it is not known to what degree a given population has adapted to heat spontaneously (i.e., without external intervention), or whether it has succeeded in adapting through direct or indirect interventions in the adaptive processes. It is therefore crucial to understand two important aspects: firstly, the need to

ascertain whether the rate of temperature-related mortality across time is greater or constant as compared to the rate of increase in the recorded temperature, since this may be an indicator of adaptation; and secondly, it is fundamental to identify the factors that intervene in the heat-adaptation process over time, with the aim of minimising the effects of global warming on human health.

Scoping reviews inherently come with limitations because their primary aim is to provide a wide-ranging overview rather than a detailed exploration of a specific topic ((Tricco et al., 2016). It is because of them that some relevant studies may be excluded (Pham et al., 2014).

This scoping review has some limitation. First, the searches were limited to English content published after 2003. This limitation may introduce linguistic and temporal bias that may exclude other studies published in other languages and before the indicated date. Furthermore, our search was limited to four databases: MEDLINE, Embase, Scopus and Web of Science (WOS), which may not cover all relevant literature in other databases, in addition to gray literature being excluded. Second, despite using a methodical approach, it is conceivable that not all studies were included in this review during the screening stage. Furthermore, since only articles with the search terms in the abstract or title were considered, those that mentioned the concept of considered the heat-adaptation within the content but did not explicitly name it in the title or abstract might have been left out.

Finally, regarding the various approaches that this study could encompass, it is important to highlight that adaptation is a complex phenomenon that could manifest itself in different ways, such as shifting or changing the shape of the temperature-mortality curve. In particular, adaptation could be evident as a less steep curve for warmer temperatures—an approach that has not been included in this review.

## 5. Conclusions

Climate change is the greatest health threat currently facing humanity, and among the measures to combat the effects of change, are mitigation and adaptation measures. With respect to the human population's capacity to adapt to heat, few studies have been carried out and there are few countries that are undertaking research in this area. This scoping review highlights a gap in research, and it is therefore crucial for those responsible for decision-making to support studies which will enable us to better understand long-term adaptation to heat and its implications for human health.

## CRedit authorship contribution statement

Miguel Ángel Navas-Martín. Original idea of the study. Study design; Providing and Analysis of data; Elaboration and revision of the manuscript.

María-Antonia Ovalle-Perandones. Providing and Analysis of data; Elaboration and revision of the manuscript.

José Antonio López-Bueno. Analysis of data; Elaboration and revision of the manuscript.

Julio Díaz. Original idea of the study. Study design; Elaboration and revision of the manuscript.

Cristina Linares. Original idea of the study. Study design; Elaboration and revision of the manuscript.

Gerardo Sánchez-Martínez. Original idea of the study. Study design; Elaboration and revision of the manuscript.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

No data was used for the research described in the article.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2023.168441>.

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