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Bioclimatic Change Impacts on Tourist Destinations in the Mediterranean, by Means of the Assessment of Human Thermal Perception †

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Abstract: The aim of this research is to elucidate the projected bioclimatic conditions in the Mediterranean during midday and evening periods for both the near and far future under the representative concentration pathways, RCP4.5 (intermediate) and RCP8.5 (extreme). This analysis focuses on twenty pivotal tourist destinations, including Madrid, Barcelona, Palma de Mallorca, Nice, Tunis, Rome, Malta, Dubrovnik, Corfu, Methoni, Chalkidiki, Athens, Heraklion, Naxos, Rhodes, Istanbul, Alexandria, Antalya, Cairo, and Limassol. To quantify the current and projected bioclimatic conditions, the study employs the physiologically equivalent temperature (PET), which is based on the human energy balance. While the Mediterranean region is recognized as a hot spot for climate change, the distinctive bioclimatic patterns of individual locations are anticipated to exhibit notable variations, with consequential implications on tourism activities.

Keywords: bioclimate; Mediterranean; tourism potential; climate change; physiologically equivalent temperature

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1. Introduction

The majority (70%) of the Mediterranean population lives in urban areas, while one in three people live in the Mediterranean coastal zones [1]. The Mediterranean is considered to be a climate change hot spot with greater increase in heat waves, their intensity, frequency, and length [2,3]. These future climate forecasts are very likely to shape and influence the criteria for choosing a place as a tourist destination. The Mediterranean region attracts millions of tourists each year, drawn by its favorable climate and scenic beauty. However, with the ongoing effects of climate change, the bioclimatic conditions are altering, potentially impacting visitor experiences and the sustainability of tourism. According to the Intergovernmental Panel on Climate Change (IPCC), the Mediterranean region is experiencing increased temperatures and changes in precipitation patterns due to climate change [4]. These changes are resulting in heatwaves, prolonged droughts, and increased frequency of extreme weather events. Understanding how individuals perceive and respond to thermal conditions is essential in assessing their comfort and well-being. Studies have shown that thermal perception is influenced by a combination of meteorological factors and personal characteristics. Temperature is a primary factor affecting human thermal perception, but humidity, wind speed, and solar radiation also play significant roles in determining thermal comfort [5–9].

This research study aims to investigate the impacts of bioclimatic change on twenty touristic destinations situated in the Mediterranean region. Specifically, it focuses on assessing human thermal perception as a key indicator of the changing bioclimatic conditions. The Mediterranean is known for its popularity as a tourist destination due to its pleasant climate, and understanding how bioclimatic change affects the thermal comfort of tourists is crucial for sustainable tourism management. This research will provide valuable insights into the potential challenges and necessary adaptations to ensure the future viability of tourism in the Mediterranean region.

2. Data and Methodology

Bioclimatic analysis was conducted for twenty Mediterranean touristic locations, specifically: Madrid, Barcelona, Palma de Mallorca, Nice, Tunis, Rome, Malta, Dubrovnik, Corfu, Methoni, Chalkidiki, Athens, Heraklion, Naxos, Rhodes, Istanbul, Alexandria, Antalya, Cairo, and Limassol, as depicted in Figure 1. The meteorological data used comprises 3 h intervals of air temperature, humidity, wind speed, and global solar radiation with a spatial resolution of 11 km, sourced from the SMHI RCA4 regional climate model, provided by the Rossby Center of the Swedish Meteorological and Hydrological Institute located in Norrkoping, Sweden. The datasets span the historical timeframe of 1971–2000, serving as the reference period, and extend to future periods of 2021–2050 and 2071–2100. These projections are based on two distinct representative concentration pathways: RCP4.5, which is intermediate, and RCP8.5, which is more extreme.

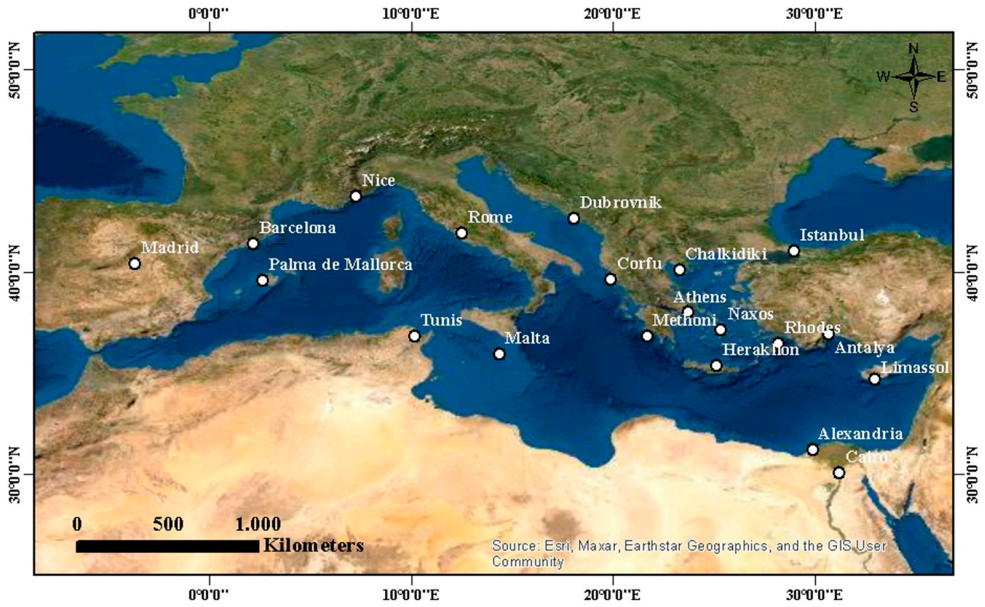


Figure 1. Mediterranean cities (touristic destinations) used in the biometerorological analysis.

The biometeorological conditions across the research area were evaluated using the human thermal index, physiologically equivalent temperature (PET), calculated through the RayMan energy model [10]. PET is a steady-state model characterized by its temperature scale representation in degrees Celsius (°C), which facilitates its interpretation even by individuals with limited meteorological knowledge. This index derives from the Munich energy-balance model for individuals (MEMI) [11] and is defined as the ambient temperature in a standard indoor environment where the human energy balance, comprising skin temperature, core temperature, and sweat rate, remains consistent with the conditions being evaluated [12]. The calculation of PET requires parameters including air temperature, humidity, wind speed, and global solar radiation. Notably, these measurements are made at 1.1 m, which corresponds to the human body's center of gravity and is the reference level for human biometeorological studies.

3. Discussion and Results

Bioclimatic diagrams, illustrating the frequency (%) of PET classes for the twenty touristic destinations with respect to the reference period 1971–2000 along with the near future 2021–2050 and the far future 2071–2100 (RCP4.5 and RCP8.5) have been constructed and analyzed for the hours UTC 12:00 and UTC 21:00.

For the sake of brevity, representative bioclimatic diagrams for Athens (Figure 2) and Cairo (Figure 3) are shown. Furthermore, the box and whiskers plots for thermal comfort (Figure 4), for the reference period and the near and far future have been analyzed for better understanding of human thermal perception in the Mediterranean tourist destinations.

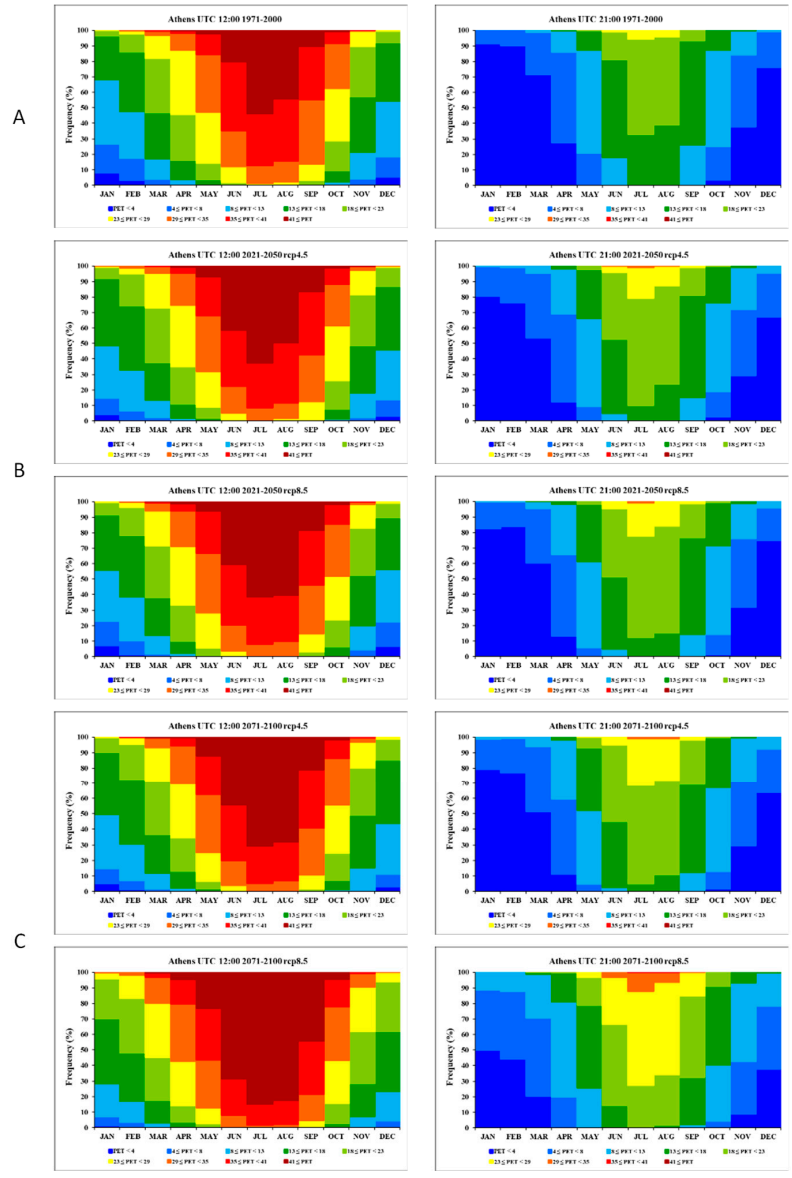


Figure 2. Frequency (%) of PET classes for Athens (Greece). (**A**) Diagrams for the reference period 1971–2000 for UTC 12:00 (left) and UTC 21:00 (right). (**B**) Diagrams for the period 2021–2050 for the RCP4.5 and RCP8.5 for UTC 12:00 (left) and UTC 21:00 (right). (**C**) Diagrams for the period 2071–2100 for the RCP4.5 and RCP8.5 for UTC 12:00 (left) and UTC 21:00 (right).

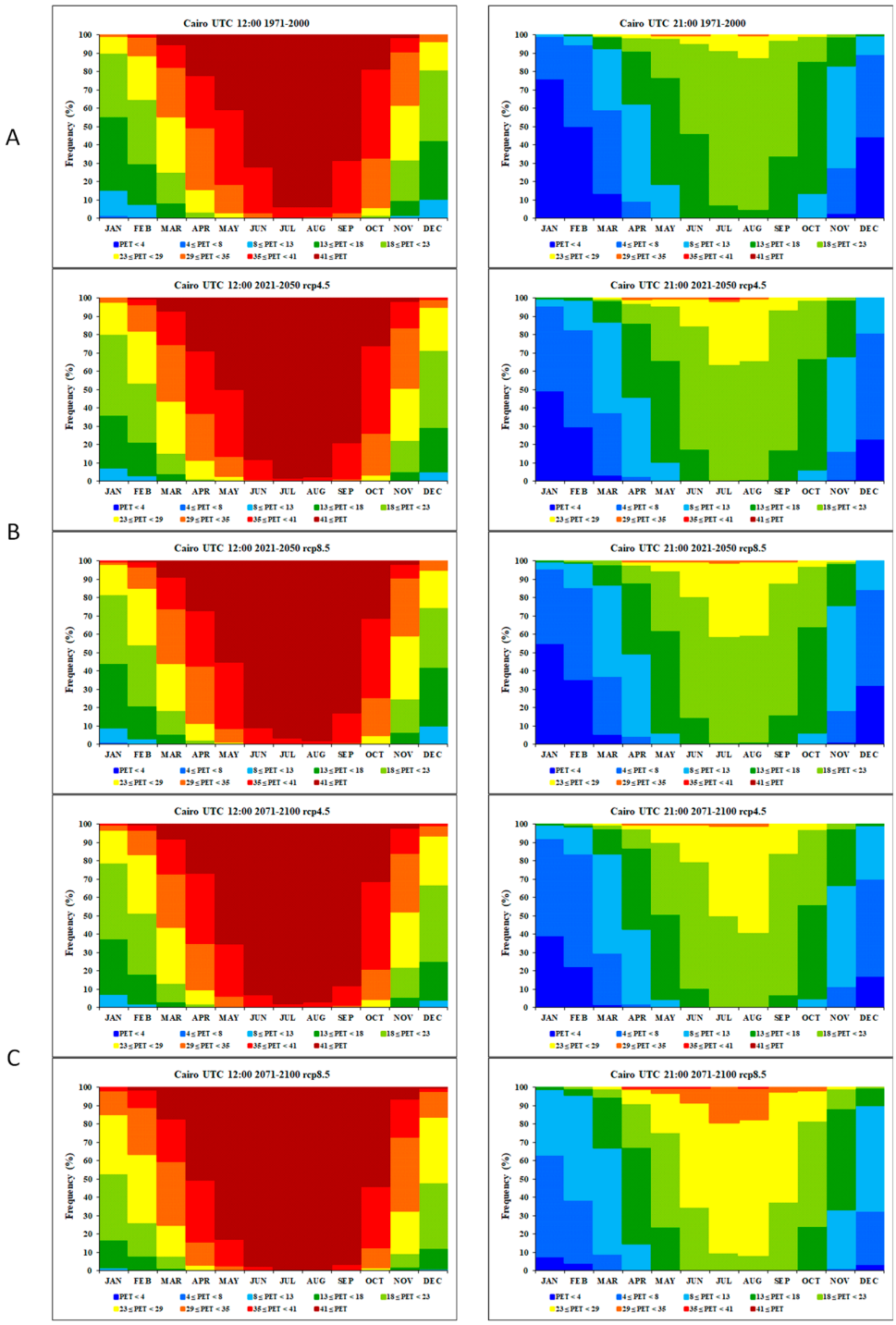
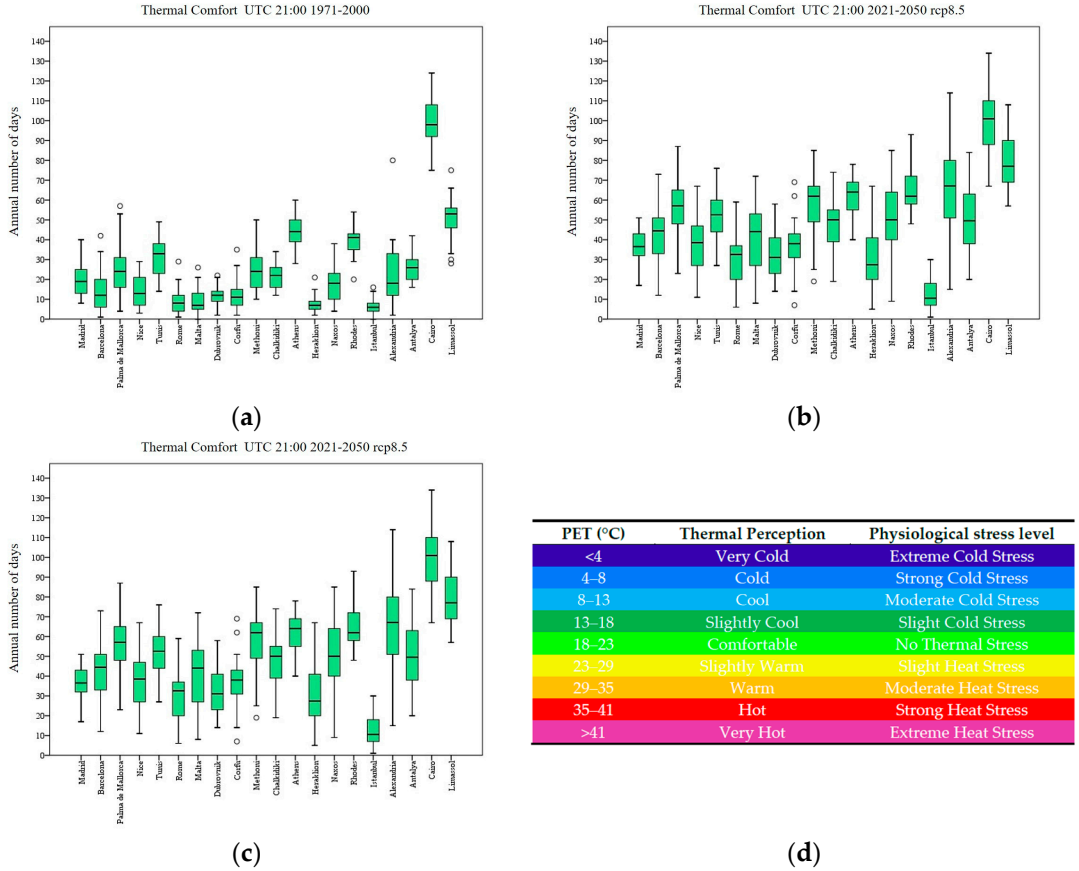


Figure 3. Frequency (%) of PET classes for Cairo (Egypt). (**A**) Diagrams for the reference period 1971–2000 for UTC 12:00 (left) and UTC 21:00 (right). (**B**) Diagrams for the period 2021–2050 for the RCP4.5 and RCP8.5 for UTC 12:00 (left) and UTC 21:00 (right). (**C**) Diagrams for the period 2071–2100 for the RCP4.5 and RCP8.5 for UTC 12:00 (left) and UTC 21:00 (right).



PET (°C)	Thermal Perception	Physiological stress level
<4	Very Cold	Extreme Cold Stress
4–8	Cold	Strong Cold Stress
8–13	Cool	Moderate Cold Stress
13–18	Slightly Cool	Slight Cold Stress
18–23	Comfortable	No Thermal Stress
23–29	Slightly Warm	Slight Heat Stress
29–35	Warm	Moderate Heat Stress
35–41	Hot	Strong Heat Stress
>41	Very Hot	Extreme Heat Stress

Figure 4. Box and whiskers plots illustrating the thermal comfort in the twenty Mediterranean tourist destinations for the reference period, (**a**) the near future (**b**) and the far future, (**c**) for the extreme scenario RCP8.5, during the evening (21:00 UTC). Threshold values of PET (**d**) for different grades of thermal sensation and physiological stress on human beings [13].

The biometeorological analysis reveals the PET classes (%) at the twenty tourist destinations for midday and the evening for the historical period (1971–2000), the near future (2021–2050), and the far future (2071–2100) under RCP4.5 and RCP8.5. Regarding the historical data, the analysis indicates that Nice, Dubrovnik, Methoni, Heraklion, Crete, and Naxos experience the most comfortable bioclimatic conditions at noon (UTC 12:00). Conversely, cities like Cairo, Athens, Rome, Rhodes, Limassol, Tunis, Palma de Mallorca, Chalkidiki, and Antalya often endure prolonged and intense heat stress throughout the year. In the evenings (UTC 21:00), the eastern Mediterranean tends to have more favorable thermal conditions compared to the central and western Mediterranean regions. Looking at climate model projections for 2021–2050 and 2071–2100 under RCP8.5, the eastern Mediterranean is predicted to face harsher bioclimatic conditions with intense heat stress around noon (UTC 12:00), in contrast to the central and western Mediterranean. An exception to this pattern can be observed in the Aegean islands. The increasing prevalence and intensity of etesian winds during summer may play a role in reducing this strong/extreme heat stress. The frequency and duration of comfortable evening temperatures (UTC 21:00) are forecast to rise in the eastern Mediterranean, presenting a consistent trend for both near and far future scenarios under both RCP models. Interestingly, cities like Istanbul, Dubrovnik, and Madrid are projected to experience strong to extreme cold stress around midday. Additionally, when comparing evening bioclimatic conditions, there seems to be a decrease in these extreme conditions as one moves from the western to the eastern Mediterranean, with this pattern more pronounced under RCP8.5.

4. Conclusions

Countries within the Mediterranean region witnessed approximately 360 million international tourist arrivals annually, accounting for about 27% of global tourism in 2017 [14]. These visits are primarily clustered in coastal areas during summer. Given this context, the outcomes of the bioclimatic evaluation serve as a vital tool for managing and disseminating climatic information relevant to tourism. The physiologically equivalent temperature is particularly appropriate for evaluating outdoor thermal comfort because of its physiological relevance and its straightforward interpretation. Moreover, the approach employed, which revolves around bioclimatic diagrams, offers comprehensive insights to quantify the effects of climate change on Mediterranean tourism potential.

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